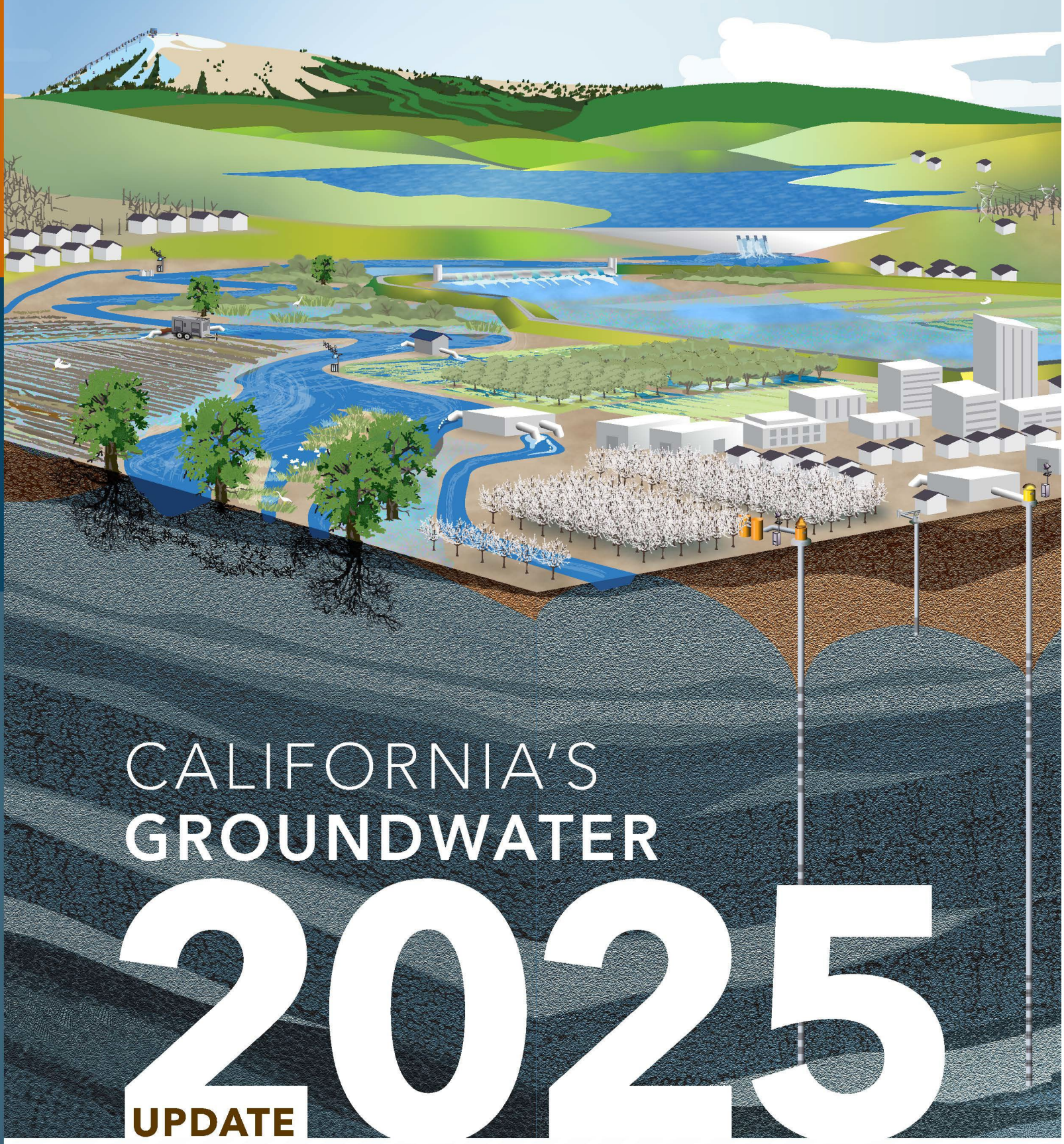


CALIFORNIA'S GROUNDWATER 2025 UPDATE

GROUNDWATER: THE FOUNDATION OF CALIFORNIA'S RESILIENCE

PUBLIC DRAFT

This publication,

California's Groundwater: Bulletin 118 — Update 2025,

has a companion summary document

available in English and Spanish.

Both the statewide report and the companion summary can be accessed on the Department of Water Resources' California's Groundwater webpage.

PUBLIC DRAFT

A publication of
the California Department of Water Resources

California's Groundwater:
Bulletin 118 — Update 2025

PUBLIC DRAFT

October 2025

State of California

The Natural Resources Agency

Department of Water Resources

Gavin Newsom
Governor, State of California
Wade Crowfoot
Secretary for Natural Resources, Natural Resources Agency
Karla Nemeth
Director, Department of Water Resources

PUBLIC DRAFT

Using CalGW Update 2025

California's Groundwater: Bulletin 118 — Update 2025 (CalGW Update 2025) is the most up-to-date compendium of statewide data and information on the occurrence, nature, use, and conditions of California's groundwater resources and management. CalGW Update 2025 continues the series of earlier DWR publications, building on past progress and knowledge. It synthesizes the latest data to address knowledge gaps and focuses on statewide groundwater management and planning efforts, including drought planning and response.

CalGW Update 2025 consists of a summary highlights document, a detailed statewide report (this document), and a series of appendices, and is supported by CalGW Live and *California's Groundwater: Semi-Annual Updates,* as described below.

Highlights (English and Spanish): A stand-alone summary document describing the value, current state, and challenges of groundwater conditions and management in California, including findings and recommendations to advance sustainable groundwater management.

Statewide Report (Chapters 1 to 7): A detailed report on the current state of knowledge of groundwater resources including information on the location, basin characteristics, water use, management, climate change vulnerability, monitoring, and conditions of the state's groundwater. It includes "Groundwater at a Glance," a hydrologic region-based summary of key groundwater-related topics.

Appendices A to K: A series of appendices that provide additional details supporting the content of the various chapters of the statewide report, including methods and assumptions, selected data, citations, and references.

CalGW Live: A user-friendly interactive website that allows users to explore, analyze, and visualize the latest groundwater data and information for California.

PUBLIC DRAFT

Message from the Director



Although much work remains to fully protect and manage California's groundwater, our efforts to understand this vital resource have finally begun to reflect its immeasurable value to the state. The report that follows, *California's Groundwater: Bulletin 118 — Update 2025 (CalGW Update 2025)*, represents the most comprehensive collection of information yet assembled about a resource that meets 30% to 60% of the water needs of the people, businesses, and farms of California every year and helps sustain vital ecosystems.

California's underground aquifers are as formative to the state's natural infrastructure as Mount Shasta or Yosemite Valley. Though hidden from view, these geologic formations function as ably as any human-designed infrastructure and are capable of holding far more water than all of California's surface reservoirs combined. No resource helps the state cope with drought better than groundwater. In a changing climate, its value only grows. The most extreme atmospheric rivers will become more so, and dry spells will be longer and more severe. Groundwater basins offer massive capacity to buffer water supplies against weather whiplash, but they are more than a safety net. When sustainably managed, these basins are a cornerstone of climate resilience, enabling the capture of excess stormwater during floods, supporting biodiversity, and helping stabilize water supplies across hydrologic extremes.

One of our biggest challenges is to halt the billions of dollars of damage that comes from groundwater overdraft, such as failed wells; deteriorated water quality; environmental harm; and irreversible land subsidence that impacts bridges, levees, roads, and canals. Bringing groundwater basins into sustainable conditions will require substantial economic adjustments and changes in historical groundwater use and considerations in regions where users have pumped too much groundwater for too long. But to avoid or delay this reckoning would inflict even greater pain on future generations. The time to act is now.

Ten years into the implementation of the Sustainable Groundwater Management Act (SGMA), local groundwater agencies are shifting gears from project planning to project implementation. They must work together to capture and store water when it is available, expand conjunctive use programs, transition to less water intensive land use, and fallow farmland to reduce demand where necessary. State

PUBLIC DRAFT

agencies will continue to support local efforts toward sustainable groundwater management. The California Department of Water Resources stands ready to help local water districts establish water-sharing arrangements and water bank accounting methods and to assist in the development of locally managed canals, pipes, and wells necessary to convey water to prime recharge locations. The California Department of Conservation, through its Multi-Benefit Land Repurposing Program, stands ready to help communities chart an economic future in which irrigated agriculture plays a smaller but more sustainable role. As part of SGMA implementation and the State's broader commitment to sustainable groundwater stewardship, State agencies will continue to support local agencies in improving groundwater science, making data more accessible and timely, and building the capacity needed to enable informed decisions that strengthen water supply reliability and drought resilience, and protect communities over the long term.

CalGW Update 2025 captures a decade of SGMA implementation progress, describes the challenges of the next 10 years, sets forth a more complete set of facts about groundwater conditions than ever assembled, and connects groundwater to all aspects of water resources. This report marks a five-year milestone since the previous *Bulletin 118*, and the next one is planned for 2035. In the meantime, DWR's compendium of groundwater data will continue to deepen and expand, and all of it is available to everyone at any time through the interactive website California's Groundwater Live and the California's Groundwater: Semi-Annual Updates. I invite you to explore this wealth of information and learn more about the incredible natural infrastructure that makes California's prosperity possible.



Director, California Department of Water Resources

PUBLIC DRAFT

State of California
Gavin Newsom, Governor

California Natural Resources Agency
Wade Crowfoot, Secretary for Natural Resources

Department of Water Resources
Karla A. Nemeth, Director
Cindy Messer, Lead Deputy Director
Thomas Gibson, Lead Deputy Director

Office of the
General Counsel
Ann Carroll

Senior Water Policy Advisor
to the Director
Nancy Vogel

State Climatologist
Michael Anderson

Internal Audit Office
Mabel Lun

Tribal Affairs
Anecita Agustinez

Lead Scientist
Louise Conrad

Deputy Directors

Stephanie Varrelman	Business Operations
Laura Hollender	Flood Management and Dam Safety
James Newcomb	Natural Infrastructure and Ecosystem Resilience
John Paasch	Security and Emergency Management Program
John Yarbrough	State Water Project
Kasey Schimke	Legislative Affairs Office
Ryan Endean	Public Affairs Office
Paul Gosselin	Sustainable Water Management
Delphine Hou	Statewide Energy
Joel Metzger	Statewide Water Resources Planning and Enterprise Project Management

This report was prepared under the direction of:
Steven Springhorn, Sustainable Groundwater Management Office

PUBLIC DRAFT

CalGW Update 2025 Preparers

Core Team:

Department of Water Resources
Steven Springhorn (Program Manager)
Amanda Ott (Co-Project Manager)
Emilia Wisniewski (Co-Project Manager)
Erin Crandall (Outreach and Engagement Manager)
Brett Wyckoff

Woodard & Curran
Saquib Najmus (Project Manager)
Josh Uecker
Frank Qian

Executive Review:

Department of Water Resources

Paul Gosselin
Nancy Vogel
Keith Wallace
Scott Morgan
Eric Tsai
Timothy Godwin
Hanspeter Walter

Chapter and Cross-Cutting Content Leads:

Department of Water Resources

Bill Brewster
Andres Guillen
Barrett Kaasa
Kyle Hardage
Katherine Dlubac
Erica Haight
Mark Nordberg
Romain Maendly
Michelle Dooley
M. Katy Janes
Wyatt Arnold

Technical Reviewers:

Department of Water Resources

Roy Hull
Chris Bonds
Dane Mathis
Bryce Russell
Jennifer Marr
Jack Tung
Shane Edmunds

Woodard & Curran

Jim Blanke
Reza Namvar
Rich Juricich

PUBLIC DRAFT

Additional Content Developers and Reviewers:

Department of Water Resources

Yaman Al Ahmed
Alexander Arita
Christopher Baker
Kimberly Bowman
Nathan Burley
Jackson Cook
Behrooz Etebari
Eric Garcia
Francisco Guzman
Abdul Khan
Quinn Little
Bryce Matsumura
Anthony Navasero
George Peraza
Giancarlo Restreppo
Andrew Schwarz
K. Sunny Singh
Scarlett Tovar
Craig Altare
Dee Ayres
Victor Bautista
Benjamin Brezing
Zhiming Chen
Jamie Dubay
David Fairman
Benjamin Gooding
Edween Hernandez
Salma Kibrya
Christopher Lyles
Caitlin McHugh
Michael Parker
Anita Regmi
Alicia Ruplinger
Heather Shannon
Deborah Spangler
Michelle Zhang
Nicholas Anchor
Jorge Baca
Tad Bedegrew
Alyse Briody
James Common
Julie Ekstrom
Monique Gaido
Vivian Guillen
Zoe Kanavas
Kelley List
Evan MacKinnon
Andrew Morgan
Constance Pawell
Andrew Renshaw
Monica Salais
Paul Shipman
Jennifer Stricklin

State and Regional Water Boards

Mike Conway Emily Haugen Emily Houlihan Sarah Sugar

California Department of Fish and Wildlife

Adam Weinberg

NASA Jet Propulsion Laboratory

John Reager

Woodard & Curran

Nicole Jacobsen Art Machado

Earth Knowledge, Inc.

Lorraine E. Flint

Graphics and Document Production Services Provided by:

Department of Water Resources

Asif Ali Frank Keeley Scott Olling

Woodard & Curran

Sandy Bailey Leah Makler

Public Affairs Support Provided by:

Department of Water Resources

Allison Armstrong

PUBLIC DRAFT

Contents

CHAPTER 1. VISION AND CONTEXT FOR SUSTAINABLE GROUNDWATER MANAGEMENT 1-1

Chapter Summary 1-1

1.1 Introduction 1-2
1.1.1 Groundwater: The Foundation of California's Resilience 1-4
1.1.2 Groundwater Management Priorities 1-5
1.1.3 Rising Groundwater Reliance Amid Climatic Extremes 1-7
1.1.4 A Reservoir Beneath Our Feet 1-9

1.2 A Decade of Progress Under SGMA 1-12
1.2.1 The SGMA Accomplishments 1-12
1.2.2 Charting the Future of Groundwater Stewardship 1-14

1.3 CalGW Update 2025 Builds on Administrative, Legislative, and Local Water Initiatives 1-17
1.3.1 Themes of CalGW Update 2025 1-17
1.3.2 Prioritizing Equity and Partnerships 1-20
1.3.3 Local Agencies; Key to Success of Sustainable Groundwater Management Program 1-25

1.4 California's Groundwater — A Compendium of Information 1-28
1.4.1 CalGW Update 2025 1-29
1.4.2 CalGW Update 2035 1-30
1.4.3 California's Groundwater Information Products 1-30
1.4.4 Future Basin Reports 1-31
1.4.5 California's Groundwater Data Availability 1-31

1.5 Climate Change Adaptation and Sustainable Groundwater Management 1-32
1.5.1 Climate Change Trends with Major Implications to California's Groundwater Resource 1-35
1.5.2 Preparing for Climatic Extremes and Planning Toward Sustainable Water Management in a Changing Climate 1-44
1.5.3 State Efforts at Building Resilience and Sustainability 1-57

1.6 The Future of Sustainable Groundwater Management 1-71

1.7 Organization of CalGW Update 2025 1-73

CHAPTER 2. PROGRESS TOWARD SUSTAINABLE GROUNDWATER MANAGEMENT 2-1

Chapter Summary 2-1

2.1 Introduction 2-2

2.2 Ten Years of the Sustainable Groundwater Management Act 2-3

PUBLIC DRAFT

2.3 Evolution of Groundwater Management in California 2-7
2.3.1 Water Rights 2-8
2.3.2 Pre-SGMA Groundwater Adjudications 2-13
2.3.3 Groundwater Management Special Act Districts 2-19
2.3.4 County Groundwater Ordinances 2-22
2.3.5 Groundwater Management Legislation 2-26
2.3.6 Coordination Between Water Agencies and Land Use Agencies 2-30
2.3.7 Other Related Local and Regional Groundwater Management Plans and Programs 2-33

2.4 DWR's Sustainable Groundwater Management Program 2-33
2.4.1 Statutory Responsibilities 2-34
2.4.2 Regulatory Oversight 2-46
2.4.3 Planning Assistance 2-62
2.4.4 Technical Assistance 2-64
2.4.5 Financial Assistance 2-75
2.4.6 Groundwater Recharge Assistance 2-83
2.4.7 Land Subsidence Guidance 2-88
2.4.8 Water Shortage Vulnerability 2-89

2.5 Groundwater Management by Other State and Local Agencies 2-90

2.6 Local Implementation of SGMA 2-91
2.6.1 Role of Sustainable Management Criteria and Corrective Actions in SGMA 2-92
2.6.2 Projects and Management Actions 2-113
2.6.3 PMA Spotlight: Groundwater Markets 2-118

2.7 State-Supported Groundwater Accounting Platform 2-133

2.8 State Water Board Intervention 2-134
2.8.1 Consultation with DWR 2-134
2.8.2 Potential Probationary Basin Designation 2-135
2.8.3 Interim Plans 2-136

CHAPTER 3. CALIFORNIA'S NATURAL AND BUILT GROUNDWATER INFRASTRUCTURE 3-1

Chapter Summary 3-1

3.1 Introduction 3-2

3.2 Natural Groundwater Infrastructure 3-5
3.2.1 Watersheds 3-6
3.2.2 Rivers and Floodplains 3-8
3.2.3 Forests and Meadows 3-10
3.2.4 Groundwater Aquifers 3-14
3.2.5 Other Natural Groundwater Infrastructure 3-20

3.3 Impacts of Climate Change on Natural Groundwater Infrastructure 3-21
3.3.1 Temperature Increases 3-22

PUBLIC DRAFT

3.3.2 Snowpack Shifts 3-23
3.3.3 Precipitation Shifts 3-25
3.3.4 Evapotranspiration Increases 3-26
3.3.5 Impacts on Watersheds 3-26
3.3.6 Impacts on Non-Basin Areas 3-27

3.4 Groundwater Basin Characterization 3-32
3.4.1 Hydrogeologic Conceptual Models and Basin Characteristics 3-33
3.4.2 DWR's Basin Characterization Program 3-55
3.4.3 Other Basin Characterization Efforts in California 3-83

3.5 Non-Basin Areas 3-86
3.5.1 Population in Non-Basin Areas 3-87
3.5.2 Hydrogeologic Provinces of Non-Basin Areas 3-89
3.5.3 Recharge Areas in Non-Basin Areas 3-139
3.5.4 Non-Basin Area Characterization Efforts 3-143

3.6 Built Groundwater Infrastructure 3-145
3.6.1 Groundwater Extraction Infrastructure 3-147
3.6.2 Groundwater Recharge Infrastructure 3-166
3.6.3 Conveyance Infrastructure 3-183
3.6.4 Groundwater Infrastructure Utilization 3-186
3.6.5 Groundwater Recharge Infrastructure Expansion 3-201

CHAPTER 4. GROUNDWATER USE, EXTRACTION, AND WATER BUDGETS 4-1

Chapter Summary 4-1

4.1 Introduction 4-2

4.2 Groundwater Use 4-6
4.2.1 Groundwater Use Across California 4-6
4.2.2 Recent Trends in Groundwater Use (Water Years 2017–2021) 4-9
4.2.3 Long Term Trends in Groundwater Use (Water Years 2002–2021) 4-12
4.2.4 Groundwater Use by Sector 4-18
4.2.5 Comparison Between Basin and Non-Basin Groundwater Use 4-33
4.2.6 Water Use in SGMA Reporting Basins 4-46

4.3 Groundwater Recharge 4-64
4.3.1 Baseline Recharge 4-64
4.3.2 Managed Aquifer Recharge 4-70

4.4 Water Accounting in California's Groundwater Management 4-92
4.4.1 Groundwater Accounting Applications in California 4-94
4.4.2 Water Accounting Resources 4-107

PUBLIC DRAFT

CHAPTER 5. GROUNDWATER MONITORING **5-1**

Chapter Summary **5-1**

5.1 Introduction **5-2**

5.2 Groundwater Level Monitoring **5-5**
5.2.1 Groundwater Level Monitoring Well Summary 5-8
5.2.2 Frequency of Groundwater Level Measurements 5-8
5.2.3 Groundwater Level Data Submission 5-11
5.2.4 Groundwater Level Monitoring Wells by Program 5-14
5.2.5 Groundwater Level Monitoring Wells by Collecting Agency 5-18
5.2.6 Groundwater Level Monitoring Wells by Well-Use Type 5-21
5.2.7 Groundwater Level Monitoring Wells by Well Depth 5-24

5.3 Change in Groundwater Storage Monitoring **5-28**

5.4 Groundwater Quality Monitoring **5-29**
5.4.1 Groundwater Quality Monitoring Under SGMA 5-35

5.5 Land Subsidence Monitoring **5-39**
5.5.1 Monitoring by Borehole Extensometer 5-42
5.5.2 Monitoring by Leveling 5-42
5.5.3 Monitoring by Continuous Global Positioning System 5-46
5.5.4 Monitoring by Interferometric Synthetic Aperture Radar 5-48
5.5.5 Regional Monitoring Networks 5-49

5.6 Interconnected Surface Water Monitoring **5-51**
5.6.1 Interconnected Surface Water 5-51
5.6.2 Identifying ISW via Monitoring Nearby Groundwater Elevations 5-53
5.6.3 Depletion of Interconnected Surface Water by Groundwater Use (Pumping) 5-56
5.6.4 Statewide Stream Gaging 5-58

5.7 Seawater Intrusion Monitoring **5-61**
5.7.1 Monitoring Methods 5-61
5.7.2 Data Collection 5-66
5.7.3 Data Analysis 5-69

CHAPTER 6. GROUNDWATER CONDITIONS **6-1**

Chapter Summary **6-1**

6.1 Introduction **6-2**

6.2 Groundwater Levels **6-3**
6.2.1 Depth to Groundwater 6-3
6.2.2 Groundwater Surface Elevation 6-7
6.2.3 Groundwater Level Percentiles 6-10
6.2.4 Groundwater Level Changes 6-14

PUBLIC DRAFT

6.2.5 Groundwater Level Trends 6-19

6.3 Change in Groundwater Storage 6-23
6.3.1 Change in Groundwater Storage — 2006 to 2024 6-28
6.3.2 Change in Groundwater Storage — Water Years 2019–2024 6-31

6.4 Groundwater Quality 6-42
6.4.1 Overall Groundwater Quality Conditions 6-43
6.4.2 Concentrations for Constituents of Concern 6-44
6.4.3 Groundwater Quality Reported Under SGMA 6-74

6.5 Land Subsidence 6-74
6.5.1 Recent Subsidence Conditions 6-75
6.5.2 Recent Subsidence Conditions and Long-Term Groundwater Level Trends 6-80
6.5.3 Future Subsidence 6-85

6.6 Depletion of Interconnected Surface Water 6-86

6.7 Seawater Intrusion 6-87
6.7.1 Regions of California Subject to Seawater Intrusion 6-89
6.7.2 Impacts of Seawater Intrusion 6-103
6.7.3 Groundwater Quality Data Related to Seawater Intrusion Conditions 6-104

CHAPTER 7. GROUNDWATER AT A GLANCE: HYDROLOGIC REGION SUMMARIES
(available as a separate download)..... 7-1
Chapter Summary.....7-3
7.1 North Coast.....7-4
7.2 San Francisco Bay.....7-16
7.3 Central Coast.....7-28
7.4 South Coast.....7-40
7.5 Sacramento River.....7-52
7.6 San Joaquin River.....7-64
7.7 Tulare Lake.....7-76
7.8 North Lahontan.....7-88
7.9 South Lahontan..... 7-100
7.10 Colorado River.....7-112

APPENDICES (Draft appendices A, B, D and I available as part of the public draft, as a separate download)
Appendix A. Findings and Recommendations
Appendix B. Glossary
Appendix C. Methods and Assumptions
Appendix D. Citations, Reference Materials, and Links
Appendix E. Hydrologic Region Basin Maps with Basin Tables
Appendix F. Water Use Data
Appendix G. Hydrologic Region, Basin, and County Data
Appendix H. California's Groundwater: Semi-Annual Updates
Appendix I. Update on Land Subsidence in California
Appendix J. Projects and Management Actions

PUBLIC DRAFT

Figures

Figure 1-1 Percentage of Water Use by Source: Historical Statewide Data (2002–2021) and Annual Reports Data (2021–2023) 1-9

Figure 1-2 California's Groundwater Basins 1-11

Figure 1-3 Number of Groundwater Basins Identified in California's Groundwater Updates 1-29

Figure 1-4 Multi-Faceted Nature of Climate Change Impacts 1-32

Figure 1-5 Climate Change Impacts on Groundwater Recharge 1-40

Figure 1-6 Future Scenarios of Groundwater Dependency, Water Scarcity, and Flood Risk (Water Plan Update 2023) 1-46

Figure 1-7 Areas of Physical Water Shortage Vulnerabilities with Small Water Systems and Domestic Wells 1-48

Figure 1-8 Areas of Social Water Shortage Vulnerabilities with Small Water Systems and Domestic Wells 1-49

Figure 1-9 (a-e) Climate-Driven Flood and Drought Risk Mitigation with Flood-MAR in the Merced River Watershed 1-52

Figure 1-10 Survey and Examples of Climate Change Data Use in Groundwater Sustainability Planning, by Number of GSPs 1-56

Figure 2-1 Accomplishments in the First Ten Years of SGMA 2-6

Figure 2-2 Areas with Pre-SGMA Groundwater Adjudications 2-18

Figure 2-3 Number of GSAs in Each Groundwater Basin (December 2024) 2-37

Figure 2-4 Groundwater Basins Subject to Critical Conditions of Overdraft 2-45

Figure 2-5 Number of GSPs and Alternatives in Each Groundwater Basin (April 2025) 2-52

Figure 2-6 Groundwater Management Under SGMA as of August 2025 2-55

Figure 2-7 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Chronic Lowering of Groundwater Levels[3] 2-101

Figure 2-8 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Change in Groundwater Storage 2-102

Figure 2-9 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Seawater Intrusion 2-104

PUBLIC DRAFT

Figure 2-10 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Degraded Groundwater Quality 2-105

Figure 2-11 Number of GSPs Employing Approaches for Setting Sustainable Management Criteria for Land Subsidence 2-107

Figure 2-12 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Depletions of Interconnected Surface Water 2-109

Figure 2-13 Corrective Actions Associated with Each Sustainability Indicator 2-112

Figure 2-14 PMA Types Reported in the SGMA Portal PMA Module 2-118

Figure 2-15 Location of Water Market Case Studies 2-120

Figure 3-1 The Hydrologic Cycle 3-3

Figure 3-2 Major California Watersheds (Hydrologic Unit Code 8 of the USGS National Watershed Boundary Dataset) 3-7

Figure 3-3 Major California Rivers 3-9

Figure 3-4 Meadow Areas of California 3-12

Figure 3-5 Healthy Meadow 3-13

Figure 3-6 Unhealthy or Degraded Meadow 3-13

Figure 3-7 Spatial Relationships Among Aquifers, Basins, Subbasins, and Non-basin Areas 3-15

Figure 3-8 California's 515 Groundwater Basin and Subbasin Boundaries and Hydrologic Regions 3-17

Figure 3-9 Statewide Map of Non-Basin Areas and River Systems 3-19

Figure 3-10 California Snowpack Measurement Sites 3-24

Figure 3-11 Changes in Annual Groundwater Infiltration by Watershed: Historic (1981–2010), Near Future (2026–2055), and Late Future (2056–2085) 3-27

Figure 3-12 Trends in Location, Size, and Number of Fires in California (1990–2023) 3-30

Figure 3-13 Hydrogeologic Conceptual Model of an Aquifer System 3-36

Figure 3-14 Schematic Showing Basin Storage Capacity Terms (on the left side of the column) and Groundwater Storage Terms (on the right side of the column) 3-42

PUBLIC DRAFT

Figure 3-15 Schematic of Alluvial Fans and Incised Valley Fills Can Serve as a Recharge Pathway to Get Water into Deeper Sections of an Aquifer 3-45

Figure 3-16 Illustration of Subsidence Mechanics 3-49

Figure 3-17 Schematic of Seawater Wedge and a Seawater Intrusion Front 3-52

Figure 3-18 Statewide AEM Survey Project Flight Lines 3-59

Figure 3-19 Schematic of the SkyTEM AEM System 3-61

Figure 3-20 Example of (a) AEM Electrical Resistivity Cross Section, (b) AEM Coarse Fraction Cross Section, and (c) the Resistivity, lithology, and salinity relationship (modified from Palacky 1987; Behroozmand et al. 2022) 3-62

Figure 3-21 Supporting Data Digitized as a Part of the Statewide AEM Survey Project 3-65

Figure 3-22 Texture Models of the Central Valley for (a) All Textures, (b) 50-100% Coarse-grained Materials, and (c) 0-20% Coarse-grained Materials 3-68

Figure 3-23 Average percent Coarse Grained Materials from AEM Data Relative to Mapped Alluvial Fans (modified from Weissmann et al. 2005 and Faunt et al. 2024) 3-69

Figure 3-24 Surficial Groundwater Recharge Map (from AEM data) 3-71

Figure 3-25 AEM Data Interpretation for the Monterey Bay Area 3-73

Figure 3-26 Hydrogeologic Conceptual Model of the Subsurface, Aquifer Recharge Potential Types, and Associated ARP Maps 3-78

Figure 3-27 Integrated percent coarse values from the surface down to 50 feet deep derived from (a) Statewide AEM Survey Project data and (b) Local Investigation infill AEM data (c) Vertical coarse-fraction sections identifying potential incised valley fill units 3-81

Figure 3-28 Aquifer Recharge Potential Maps for the Upper San Joaquin River Local Investigation Area for Shallow (Natural), Deep Preferential Pathways (Natural), and Deep Preferential Pathways (Built) Map Types 3-83

Figure 3-29 Hydrogeologic Province Non-Basin Areas 3-90

Figure 3-30 Geysers Power Plant in the Geothermal Field, Near Clear Lake, California 3-95

Figure 3-31 North Coast Ranges Hydrogeologic Province Non-Basin Area — Faults and Springs 3-96

PUBLIC DRAFT

Figure 3-32 Klamath Mountains Hydrogeologic Province Non-Basin Area — Faults and Springs....3-98

Figure 3-33 Groundwater Seeps in Fractured Rock – Klamath Mountains Province, State Highway 299 near Big French Creek, California....3-99

Figure 3-34 Cascades and Modoc Plateau Hydrogeologic Province Non-Basin Area — Faults and Springs....3-103

Figure 3-35 Diagram of Volcanic Flood Basalt Columns Showing Potential Groundwater Recharge and Flow Pathways....3-105

Figure 3-36 Diagram Showing Potential Groundwater Pathways in Interflow Zones Between Basalt Flow Units....3-106

Figure 3-37 Diagram Showing Faults as Potential Groundwater Barriers and Flow Pathways Across Basalt Flow Units....3-107

Figure 3-38 Ahjumawi Lava Springs, Part of the Fall River Springs System, Cascades and Modoc Plateau Hydrogeologic Province....3-109

Figure 3-39 Ahjumawi Lava Springs' Crystal Spring Fish Trap, Part of the Fall River Springs System, Cascades and Modoc Plateau Hydrogeologic Province....3-110

Figure 3-40 Burney Falls, Where Groundwater Emerges from Volcanic Deposits, Cascades and Modoc Plateau Hydrogeologic Province....3-111

Figure 3-41 View West Across the Medicine Lake Caldera Toward Mount Shasta, Cascades and Modoc Plateau Hydrogeologic Province....3-113

Figure 3-42 Sierra Nevada Hydrogeologic Province Non-Basin Area - Faults and Springs....3-116

Figure 3-43 Basin and Range Hydrogeologic Province Non-Basin Area — Faults and Springs....3-121

Figure 3-44 Southern Coast Ranges Hydrogeologic Province Non-Basin Area — Faults and Springs....3-124

Figure 3-45 Conceptual Model Illustrating Interactions Between Fracturing, Chemical Weathering, and Hydrologic Processes Based on Field Measurements (after Callahan et al. 2024)....3-125

Figure 3-46 Transverse and selected Peninsular Ranges Hydrogeologic Province Non-Basin Area — Faults and Springs....3-128

Figure 3-47 Groundwater Monitoring Well in the Fractured Rock Non-Basin Area Near the San Pasqual Valley Alluvial Groundwater Basin, San Diego Drainages Hydrogeologic Province....3-132

PUBLIC DRAFT

Figure 3-48 San Diego Drainages Hydrogeologic Province Non-Basin Area — Faults and Springs 3-134

Figure 3-49 Desert Hydrogeologic Province Non-Basin Area — Faults and Springs 3-137

Figure 3-50 California Highland Areas Adjacent to Groundwater Basins and Province-Based Highland Areas (from Johnson and Belitz 2014) 3-142

Figure 3-51 Schematic of Built Groundwater Infrastructure Components Used to Extract, Convey, and Replenish Groundwater 3-146

Figure 3-52 Statewide Production Well Completion Reports by Well Use Type (1977–2023) 3-149

Figure 3-53 Statewide Production Well Completion Reports by Well Use Type (2019–2023) 3-152

Figure 3-54 Production Well Completion Reports in Groundwater Basins by Well Use Type (1977–2023) 3-154

Figure 3-55 Production Well Completion Reports in Non-basin Areas by Well Use Type (1977–2023) 3-155

Figure 3-56 Density and Spatial Distribution of Domestic Wells Estimated from Well Completion Reports (1977–2023) 3-158

Figure 3-57 Density and Spatial Distribution of Irrigation Wells Estimated from Well Completion Reports (1977–2023) 3-159

Figure 3-58 Total Domestic Wells by Well Depth (in ft) with a Cumulative Curve Based on Well Completion Reports (1977–2023) 3-161

Figure 3-59 Total Irrigation Wells by Well Depth (in ft) with a Cumulative Curve Based on Well Completion Reports (1977–2023) 3-162

Figure 3-60 Domestic Well Installations by Year with Cumulative Curve (1977–2023) 3-164

Figure 3-61 Irrigation Well Installations by Year with Cumulative Curve (1977–2023) 3-165

Figure 3-62 Major State, Federal, and Local Water Projects in California 3-185

Figure 3-63 Direct Aquifer Recharge Projects Identified in GSPs by Basin 3-208

Figure 4-1 Statewide Annual Precipitation 4-3

Figure 4-2 Communities Dependent on Groundwater 4-8

Figure 4-3 Groundwater Use and Total Water Use by Hydrologic Region (Water Years 2017–2021) 4-11

PUBLIC DRAFT

Figure 4-4 Statewide Water Use by Source of Water (Water Years 2002–2021) 4-13

Figure 4-5 Statewide Water Use by Source as a Percentage of Total Water Use (Water Years 2002–2021) 4-15

Figure 4-6 Hydrologic Region Average, Minimum, and Maximum Groundwater Use (Water Years 2002–2021) 4-17

Figure 4-7 Statewide Groundwater Use by Sector (Water Years 2002–2021) 4-20

Figure 4-8 Statewide Percentage of Total Groundwater Use by Sector (Water Years 2002-2021) 4-23

Figure 4-9 Statewide Agricultural Groundwater Use (Water Years 2002–2021) 4-25

Figure 4-10 Statewide Irrigated Crop Acres by Type vs. Agricultural Groundwater Use (Water Years 2002–2021) 4-26

Figure 4-11 Fallow Acres by Hydrologic Region vs. Groundwater Use (Water Years 2016, 2018–2021) 4-28

Figure 4-12 Statewide Annual Urban Water Use and Population 4-30

Figure 4-13 Statewide Annual Pumped Groundwater Use for Managed Wetlands 4-33

Figure 4-14 2021 Basin and Non-Basin Agricultural Land 4-35

Figure 4-15 Agricultural Acres in Basin Area by Hydrologic Region (2019–2021) 4-37

Figure 4-16 Agriculture Acres in Non-Basin Area by Hydrologic Region (2019–2021) 4-37

Figure 4-17 Agriculture Groundwater Use in Basins by Hydrologic Region (Water Years 2019–2021) 4-39

Figure 4-18 Agriculture Groundwater Use in Non-Basin Areas by Hydrologic Region (Water Years 2019–2021) 4-39

Figure 4-19 2021 Statewide Urban Area, Basin vs. Non-Basin 4-41

Figure 4-20 Urban Acres in Basin by Hydrologic Region (2019–2021) 4-43

Figure 4-21 Urban Acres in Non-Basin Areas by Hydrologic Region (2019–2021) 4-43

Figure 4-22 Urban Groundwater Use in Basins by Hydrologic Region (Water Years 2019–2021) 4-45

Figure 4-23 Urban Groundwater Use in Non-Basin Areas by Hydrologic Region (Water Years 2019–2021) 4-45

PUBLIC DRAFT

Figure 4-24 Water Use by Source Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-49

Figure 4-25 Percent Water Use by Source Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-50

Figure 4-26 Hydrologic Region Percent Water Use by Source Reported in GSP and Alternative Annual Reports (Water Years 2021–2023) 4-52

Figure 4-27 Groundwater Extraction Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-54

Figure 4-28 Water Use by Sector Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-56

Figure 4-29 Percent Water Use by Sector Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-57

Figure 4-30 Annual Change in Storage Rates by Basin Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-61

Figure 4-31 DWR Estimate of Average Annual Surface Water Available for Recharge, by Hydrologic Region 4-73

Figure 4-32 Managed Aquifer Recharge per Acre by Basin Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-79

Figure 4-33 Managed Aquifer Recharge Volumes by Hydrologic Region Reported in GSP and Alternative Annual Reports (Water Years 2019–2023) 4-80

Figure 4-34 Points of Diversion and Groundwater Recharge Parcel Locations Reported under Executive Orders N-7-23 and N-4-23, between March 22 and September 19, 2023 4-84

Figure 4-35 Participating Local Agencies in the 2023 Temporary Flood Diversion Equipment and Recharge Enhancement and follow-on Flood Diversion and Recharge Enhancement Initiative 4-86

Figure 4-36 Methods used to Develop Water Budgets in GSPs and Alternatives 4-100

Figure 4-37 DWR Tools Used to Develop Water Budgets in GSPs and Alternatives 4-101

Figure 4-38 USGS Tools Used to Develop Water Budgets in GSPs and Alternatives 4-102

Figure 4-39 Total Water Budget 4-108

Figure 4-40 Simulation Geometry for C2VSimCG 4-117

Figure 4-41 Simulation Geometry for C2VSimFG 4-118

PUBLIC DRAFT

Figure 4-42 Simulation Geometry for SVSim 4-119

Figure 5-1 Climate Change Impacts and Statewide Monitoring Efforts 5-4

Figure 5-2 Groundwater Level Measurement Collection Frequency (Water Years 2019–2023) 5-10

Figure 5-3 Groundwater Level Data Submission Latency (Water Years 2019–2023) 5-10

Figure 5-4 Statewide Groundwater Level Data Reported for WY 2024 5-13

Figure 5-5 Statewide Groundwater Level Data Statistics Based on Data Collection and Submission (Water Years 2019–2024) 5-14

Figure 5-6 Groundwater Level Monitoring Wells by Monitoring Program (Water Years 2019–2024) 5-17

Figure 5-7 Groundwater Monitoring Wells by Collecting Agency (Water Years 2019–2024) 5-20

Figure 5-8 Groundwater Level Monitoring Wells by Well-Use Type (Water Years 2019–2024) 5-23

Figure 5-9 Groundwater Level Monitoring Wells by Well Depth, in Feet (Water Years 2019–2024) 5-27

Figure 5-10 Groundwater Quality Monitoring Wells in GAMA Database that Monitor at Least One of the Eight COCs (Water Years 2014–2023) 5-32

Figure 5-11 Cumulative Count of Groundwater Quality Monitoring Wells in the GAMA Database Sampled for the First Time for at Least One of Eight COCs (WY 2014–WY 2023) 5-34

Figure 5-12 Groundwater Quality Monitoring Wells Available in the Monitoring Network Module for GSPs and Alternatives 5-38

Figure 5-13 Distribution of Continuous GPS Stations, Borehole Extensometers, InSAR Data Coverage, and Selected Regional Subsidence Networks 5-41

Figure 5-14 Distribution of Leveling Lines Throughout California from 1901 through 2004 5-44

Figure 5-15 Distribution of Historical Leveling Lines in the Westside Subbasin 5-45

Figure 5-16 Location of borehole extensometers and Global Positioning System stations in the Central Valley 5-47

Figure 5-17 Interconnected Surface Water Body — Gaining and Losing 5-52

Figure 5-18 Disconnected Surface Water Body — Unsaturated Zone is Below the Surface Water Body 5-52

PUBLIC DRAFT

Figure 5-19 Considerations and Interpretation of Interconnected Surface Water Based on Five Example Cases of Nearby Groundwater Elevation Data 5-54

Figure 5-20 Groundwater Elevations Tracking Stream Stage Elevation are a Potential Condition of ISW 5-55

Figure 5-21 Statewide Stream Gaging Network 5-60

Figure 5-22 Conceptual Diagram Showing the Estimated Depth of the Seawater Intrusion Front using the Ghyben-Herzberg Equation 5-63

Figure 5-23 Groundwater Basins with Seawater Intrusion Monitoring 5-65

Figure 6-1 Depth to Groundwater by Hydrologic Region (Spring 2024) 6-5

Figure 6-2 Depth to Groundwater Contour Map for the Central Valley (Spring 2024) 6-6

Figure 6-3 Groundwater Surface Elevation Contour Map for the Central Valley (Spring 2024) 6-9

Figure 6-4 Groundwater Level Conditions as of Fall 2022 (August, September, October) 6-12

Figure 6-5 Groundwater Level Conditions as of Spring 2024 (March, April, May) 6-13

Figure 6-6 One-Year Changes in Groundwater Levels (Spring 2023–Spring 2024) 6-16

Figure 6-7 Five-Year Changes in Groundwater Levels (Spring 2019–Spring 2024) 6-17

Figure 6-8 Ten-Year Changes in Groundwater Levels (Spring 2014–Spring 2024) 6-18

Figure 6-9 Groundwater Level Trend Analysis Results (2004–2024) 6-22

Figure 6-10 Mix of Change in Groundwater Storage Estimation Methods and Timeframes used in Annual Reports for Basins within the Central Valley 6-25

Figure 6-11 Reporting Areas for Various Methods Used to Estimate Change in Groundwater Storage 6-27

Figure 6-12 Estimated Cumulative Change in Groundwater Storage using DWR Groundwater Level Method, DWR C2VSim-FG Model, and NASA GRACE Program Data (in Thousand Acre-Feet) 6-29

Figure 6-13 Estimated Annual Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet)** 6-32

Figure 6-14 Cumulative Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet)** 6-34

Figure 6-15 Estimated Annual Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-36

PUBLIC DRAFT

Figure 6-16 Cumulative Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet)** 6-38

Figure 6-17 Estimated Annual Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-40

Figure 6-18 Cumulative Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-42

Figure 6-19 Geographic Distribution of 1,2,3-TCP Concentrations Detected in Groundwater (Water Years 2014–2023) 6-51

Figure 6-20 Geographic Distribution of Nitrate as Nitrogen Concentrations Detected in Groundwater (Water Years 2014–2023) 6-54

Figure 6-21 Geographic Distribution of Arsenic Concentrations Detected in Groundwater (Water Years 2014–2023) 6-57

Figure 6-22 Geographic Distribution of Uranium Concentrations Detected in Groundwater (Water Years 2014–2023) 6-60

Figure 6-23 Geographic Distribution of Hexavalent Chromium Concentrations Detected in Groundwater (Water Years 2014–2023) 6-63

Figure 6-24 Geographic Distribution of Total Dissolved Solids Concentrations Detected in Groundwater (Water Years 2014–2023) 6-66

Figure 6-25 Geographic Distribution of Perfluorooctanoic Acid (PFOA) Concentrations Detected in Groundwater (Water Years 2014–2023) 6-69

Figure 6-26 Geographic Distribution of Perfluorooctane Sulfonate Concentrations Detected in Groundwater (Water Years 2014–2023) 6-72

Figure 6-27 U.S Drought Monitor Data for California (Percent Area in Drought Monitor Categories) 6-77

Figure 6-28 Annual InSAR Land Subsidence Data (Water Years 2016–2023) 6-78

Figure 6-29 Cumulative Land Subsidence over 5 Years (Water Years 2019–2023) 6-79

Figure 6-30 Long-term Subsidence and Groundwater Levels: Site A at State Hwy 99 / Ave 120 6-83

Figure 6-31 Long-term Subsidence and Groundwater Levels: Site B at the California Aqueduct / Panoche Rd 6-84

Figure 6-32 Long-term Subsidence and Groundwater Levels: Site C at Woodland 6-85

Figure 6-33 Schematic Showing the Seawater Intrusion Front in a Coastal Aquifer 6-88

PUBLIC DRAFT

Figure 6-34 Status of Seawater Intrusion in Groundwater Basins 6-91

Figure 6-35 Status of Seawater Intrusion in Groundwater Basins (Detailed Inset) 6-92

Tables

Table 2-1 Groundwater Basins with Adjudicated Areas Prior to SGMA 2-15

Table 2-2 Groundwater Management Special Act Districts in SGMA 2-20

Table 2-3 County Ordinances Addressing Seawater Intrusion, Land Subsidence, and Depletion of Interconnect Surface Water 2-23

Table 2-4 County Ordinances Updated or Adopted Post-SGMA 2-25

Table 2-5 Basin Boundary Modification Requests 2-39

Table 2-6 Groundwater Basins Subject to Critical Conditions of Overdraft 2-44

Table 2-7 Groundwater Basins Managed Under an Alternative to GSP 2-48

Table 2-8 Summary of GSP and Alternative Status as of August 2025 2-54

Table 2-9 Groundwater Basins with GSPs as of August 2025 2-56

Table 2-10 Funding Awarded under the SGM Grant Program by Round 2-77

Table 2-11 PMAs Reported in the SGMA Portal PMA Module 2-117

Table 2-12 Summary of Water Market Case Studies 2-119

Table 2-13 Pathways to Designate a Basin Probationary 2-135

Table 3-1 Regulatory Limits for TDS Concentration That Define “Drinking Water” and “Freshwater” (Modified from Gillespie et al. 2017) 3-39

Table 3-2 Aquifer Recharge Potential Map Types 3-77

Table 3-3 Summary of Sub-indices Description, Data Source, and Binning Criteria for Each ARP Map Type 3-79

Table 3-4 Non-Basin Population by County and Decade (2000 to 2020) 3-88

Table 3-5 Statewide Production Well Completion Reports by Well Use Type and Hydrologic Region (1977–2023) 3-150

Table 3-6 Statewide Production Well Completion Reports by Well Use Type and Hydrologic Region (2019–2023) 3-152

PUBLIC DRAFT

Table 3-7 Production Well Completion Reports in Groundwater Basins by Well Use Type and Hydrologic Region (1977–2023) 3-154

Table 3-8 Production Well Completion Reports in Non-basin Areas by Well Use Type and Hydrologic Region (1977–2023) 3-156

Table 3-9 Direct Aquifer Recharge PMAs with Estimated Benefits Data 3-203

Table 3-10 Direct Aquifer Recharge PMAs with Estimated Costs Data 3-205

Table 3-11 Direct Aquifer Recharge PMAs with Estimated Costs and Benefits Data 3-206

Table 4-1 CDEC Water Year Indices 4-4

Table 4-2 Statewide Water Use by Source of Water in Million Acre-Feet (Water Years 2017–2021) 4-9

Table 4-3 Average Annual Groundwater Use by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021) 4-12

Table 4-4 Statewide Water Use by Source of Water in Million Acre-Feet (Water Years 2002–2021) 4-14

Table 4-5 Percent of Average Annual Groundwater Use by Use Type and Hydrologic Region (Water Years 2017–2021) 4-18

Table 4-6 Statewide Groundwater Use by Sector in Million Acre-Feet (Water Years 2002–2021) 4-21

Table 4-7 Statewide Percentage of Total Groundwater Use by Sector (Water Years 2002–2021) 4-22

Table 4-8 Average Annual Agricultural Use Met by Groundwater by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021) 4-24

Table 4-9 Average Annual Urban Use Met by Groundwater by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021) 4-31

Table 4-10 Average Annual Managed Wetlands Use Met by Pumped Groundwater by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021) 4-32

Table 4-11 Annual Statewide Agricultural Acreage, Basin vs. Non-Basin Areas (2019–2021) 4-34

Table 4-12 Percent Agricultural Area in Basin and Non-Basin Areas by Hydrologic Region (2019–2021) 4-36

Table 4-13 Agricultural Groundwater Use, Basin vs. Non-Basin Areas by Hydrologic Region in Thousand Acre-Feet (Water Years 2019–2021) 4-38

Table 4-14 Annual Statewide Urban Area, Basin vs. Non-Basin Areas (2019–2021) 4-40

Table 4-15 Percent Urban Area in Basin and Non-Basin Areas, Hydrologic Region (2019, 2020, 2021) 4-42

Table 4-16 Urban Groundwater Use, Basin vs. Non-Basin Areas, Hydrologic Region in Thousand Acre-Feet (Water Years 2019–2021) 4-44

PUBLIC DRAFT

Table 4-17 GSP and Alternative Annual Report Summary in Thousand Acre-Feet (Water Years 2019–2023) 4-47

Table 4-18 Water Use by Source Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 2019–2023).....4-48

Table 4-19 Hydrologic Region Average Annual Water Use by Source Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 2021–2023) 4-53

Table 4-20 Sector Water Use Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 201-2023) 4-55

Table 4-21 Hydrologic Region Average Annual Water Use by Sector Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 2021–2023) 4-58

Table 4-22 Change in Groundwater Storage Calculation Methods from Annual Reports.....4-59

Table 4-23 Total Change in Storage by Hydrologic Region Reported in GSP and Alternative Annual Reports (Water Years 2021–2023).....4-60

Table 4-24 Average Annual Recharge Volumes into the Central Valley Modeled by CVHM2 (Faunt et al. 2024) .4-66

Table 4-25 Average Annual Recharge Volumes into the Central Valley Modeled by C2VSimFG for Water Years 1974-2021 4-67

Table 4-26 Differences in recharge estimates between C2VSimFG and CVHM2 for Water Years 1974-2021 4-68

Table 4-27 Managed Aquifer Recharge Volumes Reported in GSP and Alternative Annual Reports (Water Years 2019–2023).....4-77

Table 4-28 Managed Aquifer Recharge Volumes by Hydrologic Region Reported in GSP and Alternative Annual Reports in Acre-Feet (Water Years 2019–2023) 4-81

Table 4-29 2023 Temporary Flood Diversion Equipment and Recharge Enhancement Effort 4-87

Table 4-30 Flood Diversion and Recharge Enhancement Initiative Projects, 2024 to 2026 4-87

Table 4-31 Water Year 2023 State-Enhanced Diversions for Flood Risk Reduction and Recharge 4-89

Table 4-32 Sustainable Yield Reported in GSPs and Alternatives by Hydrologic Region 4-104

Table 5-1 Actively Monitored Groundwater Level Monitoring Wells by Monitoring Program and Hydrologic Region (Water Years 2019–2024).....5-16

Table 5-2 Actively Monitored Groundwater Level Monitoring Wells by Collecting Agency and Hydrologic Region (Water Years 2019–2024).....5-19

Table 5-3 Number of Groundwater Level Monitoring Wells by Well-Use Type and Hydrologic Region (Water Years 2019–2024).....5-22

PUBLIC DRAFT

Table 5-4 Number of Groundwater Monitoring Wells by Well Depth in each Hydrologic Region (Water Years 2019–2024) 5-26

Table 5-5 Number of Groundwater Quality Monitoring Wells in GAMA Database that Monitor at Least One of the Eight COCs by Hydrologic Region and Basin and Non-Basin Area (Water Years 2014–2023) ... 5-31

Table 5-6 Three Most Commonly Monitored Constituents by GSPs by Hydrologic Region 5-36

Table 5-7 Total Dissolved Solids Concentrations Based on Water Type 5-62

Table 5-8 Groundwater Basins with Seawater Intrusion Monitoring Data Since 2011 5-67

Table 6-1 Summary of Groundwater Level Percentiles[1] (Fall 2022 and Spring 2024) 6-11

Table 6-2 Summary of Groundwater Level Changes (2023–2024, 2019–2024, and 2014–2024) 6-15

Table 6-3 Summary of Groundwater Level Trends (2004–2024) 6-21

Table 6-4 Estimated Cumulative Change in Groundwater Storage using DWR Groundwater Level Method, DWR C2VSim-FG Model, and NASA GRACE Program Data (in Thousand Acre-Feet)[1] 6-30

Table 6-5 Estimated Annual Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-31

Table 6-6 Cumulative Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-33

Table 6-7 Estimated Annual Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-35

Table 6-8 Cumulative Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-37

Table 6-9 Estimated Annual Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-39

Table 6-10 Cumulative Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet) 6-41

Table 6-11 Number of Water Quality Monitoring Wells Tested by Constituent in Each Hydrologic Region and Statewide (Water Years 2014–2023) 6-47

Table 6-12 Percentage of Water Quality Monitoring Wells Exceeding Reference Concentration in Each Hydrologic Region and Statewide (Water Years 2014–2023) 6-48

Table 6-13 Three Most Frequently Measured Constituent in Each Hydrologic Region by Basin and Non-basin Area (Water Years 2014–2023) 6-49

Table 6-14 Statistics of 1,2,3-TCP Concentrations in Groundwater (Water Years 2014–2023) 6-52

PUBLIC DRAFT

Table 6-15 Statistics of Nitrate as Nitrogen Concentrations (Water Years 2014–2023) 6-55
Table 6-16 Statistics of Arsenic Concentrations in Groundwater (Water Years 2014–2023) 6-58
Table 6-17 Statistics of Uranium Concentrations in Groundwater (Water Years 2014–2023) 6-61
Table 6-18 Statistics of Hexavalent Chromium Detected in Groundwater (Water Years 2014–2023) 6-64
Table 6-19 Statistics of Total Dissolved Solids in Groundwater (Water Years 2014–2023) 6-67
Table 6-20 Statistics of Perfluorooctanoic Acid in Groundwater (Water Years 2014–2023) 6-70
Table 6-21 Statistics of Perfluorooctane Sulfonate in Groundwater (Water Years 2014–2023) 6-73
Table 6-22 Total Area (in square miles) of Cumulative Subsidence and Uplift over 5 Years (Water Years 2019–2023) 6-80
Table 6-23 Status of Seawater Intrusion in Coastal Groundwater Basins 6-93
Table 6-24 Drinking Water Standards of Total Dissolved Solids and Chloride Relative to Seawater 6-103
Table 6-25 Total Dissolved Solids Concentrations Based on Water Type 6-104
Table 6-26 Groundwater Quality Data Related to Seawater Intrusion 6-105

PUBLIC DRAFT

Acronyms and Abbreviations

1,2,3-TCP	1,2,3-trichloropropane
AB	Assembly Bill
AEM	airborne electromagnetic
af	acre-feet
alternative	alternative to groundwater sustainability plan
Alpha	gross alpha radionuclides
AR	atmospheric river
ARP	Aquifer Recharge Potential
AS	arsenic
ASR	aquifer storage and recovery
AWMP	agricultural water management plan
BBMRS	Basin Boundary Modification Request System
BC Program	Basin Characterization Program
BCX	Basin Characterization Exchange
BCM	Basin Characterization Model
bgs	below ground surface
BMP	best management practice
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
C2VSim-FG	C2VSIM-Fine Grid
C2VSim-CG	C2VSIM-Coarse Grid
CDS	coastal distribution system
CalGW 1975	California's Ground Water (1975)
CalGW Update 1980	Ground Water Basins in California: A Report to the Legislature in Response to Water Code Section 12924
CalGW Update 2003	California's Groundwater Update 2003
CalGW Update 2016	Bulletin 118 – California's Groundwater Interim Update 2016
CalGW Update 2020	California's Groundwater Update 2020
CalGW Update 2025	California's Groundwater: Bulletin 118 – Update 2025

PUBLIC DRAFT

CalGW webpage	California's Groundwater webpage
Caltrans	California Department of Transportation
CASGEM	California Statewide Groundwater Elevation Monitoring
CCR	California Code of Regulations
CCTAG	Climate Change Technical Advisory Group
CDAA	California Disaster Assistance Act
CDFA	California Department of Food and Agriculture
CDFW	California Department of Fish and Wildlife
CEQA	California Environmental Quality Act
CGPS	continuous global positioning system
CNRA	California Natural Resources Agency
CVHM	Central Valley Hydrologic Model
CVP	Central Valley Project
CVFPP	Central Valley Flood Protection Plan
CWD	climatic water deficit
CWAP	California Water Action Plan
CWP	California Water Plan
DAC	disadvantaged communities
Delta	Sacramento-San Joaquin Delta
DBCP	1,2-Dibromo, 3-chloropropane
DDW	Division of Drinking Water
DPR	California Department of Pesticide Regulation
DRIP	Drought Resilience Interagency Partners
DTSC	California Department of Toxic Substances Control
DWR	California Department of Water Resources
EcoFIP	Ecological Floodplain Inundation Potential
EDB	ethylene dibromide
ETaw	evapotranspiration of applied water
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act

PUBLIC DRAFT

FDRE	Flood Diversion and Recharge Enhancement
FEMA	Federal Emergency Management Agency
FIRO	Forecast-Informed Reservoir Operations
FloaTEM	floating transient electromagnetic methods
Flood-MAR	flood-managed aquifer recharge
FSS	Facilitation Support Services
GAMA	Groundwater Ambient Monitoring Assessment
GCM	global climate model
GIS	geographic information system
GPS	global positioning system
GRACE	Gravity Recovery and Climate Experiment
GRAT	Groundwater Recharge Assessment Tool
GRS	groundwater replenishment system
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
GWL	groundwater level
GWMP	Groundwater Management Plan
HCM	hydrogeologic conceptual model
HR	hydrologic region
InSAR	interferometric synthetic aperture radar
IRWM	integrated regional water management
ISW	interconnected surface water
IWFM	Integrated Water Flow Model
LID	low impact development
LiDAR	light detection and ranging
maf	million acre-feet
MAR	managed aquifer recharge
MCL	maximum contaminant level
MNM	Monitoring Network Module
MODFLOW-OWHM	MODFLOW-One Water Hydrologic Model

PUBLIC DRAFT

MRP	Monitoring and Reporting Program
NAVD88	National Vertical Datum 1988
NGOs	non-governmental organizations
NO_3N	nitrate as nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPS	nonpoint source pollution
NSF	National Science Foundation
NWIS	National Water Information System
OSWCR	Online Statewide Well Completion Report database
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate
PCE	tetrachloroethylene
PMAs	projects and management actions
POC	point of contact
Reclamation	U.S. Bureau of Reclamation
RMS	Representative Monitoring Site
RWQCB	regional water quality control board
SAGBI	Soil Agricultural Groundwater Banking Index
SB	Senate Bill
SB X7-7	Water Conservation Act of 2009
SGMA	Sustainable Groundwater Management Act
SGMA TAG	Sustainable Groundwater Management Act Tribal Advisory Group
SGMO	Sustainable Groundwater Management Office
SGMP	sustainable groundwater management plan
SMC	sustainable management criteria
SMCL	secondary maximum contaminant level
State Water Board	State Water Resources Control Board
SVSim	Sacramento Valley Groundwater-Surface Water Simulation Model
SWP	State Water Project
taf	thousand acre-feet

PUBLIC DRAFT

TCE	trichloroethylene
TDS	total dissolved solids
TSS	Technical Support Service
tTEM	towed electromagnetic methods
U	uranium
URTAC	Underrepresented Communities, California Tribes, and Small Farmers Groundwater Technical Assistance Program
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UWMP	urban water management plan
WAFR	Water Available for Replenishment
Water Code	California Water Code
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WCR	well completion report
WGEN	Stochastic Weather Generator
WQ Conditions Dataset	Statewide Groundwater Quality Data
WRP	Water Resilience Portfolio
WTIMS	Water Transfer Information Management System
WY	Water Year

PUBLIC DRAFT

1 . Vision and Context for Sustainable Groundwater Management

Chapter Summary

Chapter 1, "Vision and Context for Sustainable Groundwater Management," of *California's Groundwater: Bulletin 118 — Update 2025* (CalGW Update 2025), establishes the foundational rationale, vision, and strategic context for advancing groundwater sustainability in California. It frames the growing importance of groundwater as a cornerstone of the state's water resilience — particularly as climate extremes intensify — and highlights key legislative, administrative, and community-driven initiatives and actions.

The chapter begins with a broad overview of groundwater's central role in California's water portfolio and its increasing importance amid more frequent and severe droughts. It discusses critical groundwater management priorities, the unseen reservoir beneath our feet, and the need to proactively manage this resource in the face of uncertainty. These discussions emphasize that groundwater is not merely a backup but a primary pillar of water security.

The chapter then summarizes the first decade of implementation under the Sustainable Groundwater Management Act (SGMA), highlighting its achievements and identifying forward-looking strategies for continued stewardship. It underscores the growing alignment between SGMA's vision and statewide water resilience goals, particularly through data integration, local planning, and governance innovation.

Building on this foundation, Chapter 1 outlines how CalGW Update 2025 builds upon concurrent State initiatives — both legislative and administrative — while aligning with local and regional actions. It introduces the four core themes of CalGW Update 2025 and reinforces the importance of equity, transparency, and partnership, particularly with local agencies that remain at the heart of SGMA's success. A special focus is placed on advancing groundwater equity through inclusive engagement and targeted investments in underserved communities. The chapter provides a high-level overview of the suite of California's Groundwater information products, including basin reports, data tools, and future projections.

PUBLIC DRAFT

In its final section, the chapter turns to climate change — highlighting emerging trends such as snowpack loss, temperature shifts, and precipitation volatility — and explores how these shifts impact groundwater sustainability. It summarizes the State's efforts to prepare for climatic extremes and increase resilience through integrated water management, groundwater recharge strategies, and robust planning tools.

Collectively, Chapter 1, "Vision and Context for Sustainable Groundwater Management" offers a clear and compelling vision for sustainable groundwater management in California. It positions groundwater as an essential component of climate adaptation and water resilience, while laying out the strategic, collaborative, and data-informed approach needed to achieve long-term sustainability. By offering a vision rooted in integrated governance, climate resilience, and shared stewardship, the chapter sets the stage for the technical, policy, and infrastructure-focused discussions that follow in subsequent chapters.

1.1 Introduction

California is facing an era where extreme weather, prolonged and extreme droughts, and intense storms are no longer anomalies but the new normal — placing unprecedented strain on the state's water systems amid increasing uncertainty. Beyond these extreme events, long-term projections indicate that California's surface water supply may decline by up to 10% by 2040 (California Natural Resources Agency 2022). The State Water Project (SWP) recently updated its projections of climate change impacts showing that delivery capability declines of 13% were likely within 20 years and reductions of 23% were possible under more rapid climate change scenarios (Department of Water Resources 2024a). Amid these challenges, groundwater, the invisible backbone of the state's water system, has become more and more indispensable to California's water resilience and long-term sustainability.

The indispensable role of groundwater is not new — it reflects California's long-standing commitment to stewarding its water resources wisely and equitably. That commitment is embedded in the mission of the California Department of Water Resources (DWR): "to sustainably manage the water resources of California, in cooperation with other agencies, to benefit the state's people and protect, restore, and enhance the natural and human environments." (California Department of Water Resources 2023). Groundwater lies at the heart of this mission — serving as a vital source of resilience for both people and ecosystems.

PUBLIC DRAFT

DWR also acknowledges the essential role of equity in achieving groundwater sustainability. In alignment with California's Human Right to Water and Senate Bill 552 — which prioritizes small systems and vulnerable communities — DWR is committed to building inclusive connections with historically underserved populations. This includes amplifying the voices of disadvantaged communities, Tribal governments, and rural water users who are often on the front lines of water insecurity.

Grounded in these principles, the State's vision for groundwater management aspires to be inclusive, science-driven, and future-focused. It supports locally led, equitably executed, and State-supported actions to ensure that every basin reaches sustainability — securing safe, reliable groundwater for large and small communities, irrigated agriculture, rural groundwater users, Tribal cultural and religious practices, and the environment and natural ecosystems.

With this strategic vision and institutional foundation in place, Chapter 1, "Vision and Context for Sustainable Groundwater Management," of CalGW Update 2025, begins by examining the essential role of groundwater in supporting statewide climate resilience. It explains the unique characteristics that make groundwater indispensable: its reliability during times of scarcity, its hidden but vast storage potential, and its ability to serve multiple benefits — including flood mitigation and biodiversity support. By describing groundwater's physical behavior and hydrologic role, the section sets the stage for understanding the urgency and complexity of managing it sustainably.

The chapter then summarizes a decade of progress under the SGMA, highlighting how local Groundwater Sustainability Agencies (GSAs), Tribal governments, and frontline communities are working in partnership with the DWR to implement sustainable solutions. It describes the scale and impact of these collective efforts — including projects, data tools, planning frameworks, and governance structures — designed to bring groundwater basins into long-term balance. The report is organized around four overarching themes that frame California's approach to sustainable groundwater management — highlighting key stressors on natural and built groundwater systems and the strategies, investments, and partnerships needed to address them. These themes are closely aligned with the state's broader goals for climate resilience, water security, and equity.

Following this conceptual overview, the chapter turns to the evolving pressures on groundwater systems. It outlines how urban growth, agricultural demands, and climate-driven extremes have altered groundwater use across the state. These

PUBLIC DRAFT

pressures are reshaping when, where, and how groundwater is extracted, and are intensifying the need for effective planning and local stewardship. The discussion introduces broader themes of groundwater dependency, historical overuse, and the critical inflection point California now faces. This chapter concludes with a look into the future, bringing together technical insights, updated data, and policy priorities to guide decision-makers and communities in advancing groundwater sustainability across diverse regions and conditions. It closes with a description of the report's organization, which provides a roadmap for navigating the key themes and findings presented.

Together, these sections provide the foundation for understanding why groundwater is at the heart of California's climate adaptation strategy. They frame the technical, ecological, and policy contexts that shape groundwater's role today and preview the deeper analysis that follows in the subsequent chapters.

1.1.1 Groundwater: The Foundation of California's Resilience

Groundwater is the foundation of California's water resilience, meeting a wide range of water demands. Groundwater provides roughly 41% of California's total water supply in average years and rises to nearly 60% during dry years. It serves as a primary source of drinking and household water for approximately 32 million Californians — about 82% of the state's population — including 8.5 million residents in small and mid-sized communities that are entirely dependent on groundwater for their drinking water needs. In agriculture, groundwater supports around 40% of the water used to irrigate the state's $59 billion farming sector, with this proportion climbing to 60% during drought conditions (California Department of Food and Agriculture 2024). Agriculture also plays a critical role in the state's economy, providing jobs for more than 880,000 people (Hooker et al. 2024). Beyond meeting human and agricultural needs, groundwater is vital for sustaining groundwater-dependent ecosystems. It contributes to the baseflow of rivers and streams, which not only provides important water supply benefits, but also helps maintain the water levels of wetlands and supports critical habitat for many aquatic and riparian species. Groundwater also plays a vital role in protecting water quality. As it moves through soil and geologic layers, it undergoes natural filtration that can reduce contaminants and improve overall water quality. In coastal areas, maintaining healthy groundwater levels can help prevent seawater intrusion and protect the quality of drinking and irrigation supplies.

Unlike surface reservoirs that fluctuate with seasonal weather and runoff, groundwater aquifers offer a more stable and consistent supply — even during

PUBLIC DRAFT

prolonged droughts and extreme water scarcity. Beyond acting as a buffer in dry times and sustaining biodiversity, groundwater enables Californians to bridge flood management and long-term water security through innovative approaches like using floodwater for managed aquifer recharge (Flood-MAR), reducing flood risks while increasing groundwater storage. Additionally, interconnected infrastructure presents a powerful opportunity to enhance resilience. As a versatile and largely invisible resource, groundwater is uniquely positioned to help Californians respond effectively to both shortages and surpluses — quietly meeting demand during dry periods and offering abundant storage during wet periods.

Groundwater's significant versatility and reliability make it the foundation of California's water security, and fully harnessing its potential is key to the state's resilience against escalating climate uncertainties. Its role in supporting communities, powering the economy, sustaining agriculture, and protecting ecosystems underscores why safeguarding groundwater is central to the state's water security and climate adaptation strategy. As climate change intensifies, characterized by more frequent and dramatic swings in extreme weather — from severe, prolonged droughts to devastating deluges — the role of groundwater in California's water management has never been greater. This out-of-sight yet vast resource has become the cornerstone of California's climate adaptation strategy and a linchpin for ensuring long-term water resilience and security. Sustainable groundwater management is not merely a legal mandate or a policy obligation, it is a shared commitment and the bedrock of California's strategy to address future water challenges. Without effective stewardship of this critical resource, the state's ability to adapt to the impacts of climate change would be gravely compromised, threatening the vitality of its communities, the health of ecosystems, and the foundation of California's resiliency.

The following sections examine California's evolving approach to groundwater management in greater depth — highlighting the state's strategic priorities under SGMA, the rising dependence on groundwater in response to climate extremes, and the immense storage potential of California's aquifers as a natural infrastructure asset.

1.1.2 Groundwater Management Priorities

Since the passage of the Sustainable Groundwater Management Act (SGMA) in 2014, California has made notable strides in transforming how groundwater is managed across the state. Over the past decade, SGMA has established a durable framework for long-term sustainability, catalyzing a fundamental shift from

PUBLIC DRAFT

reactive crisis management to proactive, locally driven stewardship. Groundwater Sustainability Agencies (GSAs), in partnership with local agencies, have taken the lead in developing and implementing Groundwater Sustainability Plans (GSPs) that address the unique conditions of each basin. Their efforts have been strengthened by nearly $1 billion in State funding for planning, implementation, and oversight, as well as by critical technical assistance, data tools, and policy guidance from DWR and partner organizations. As a result, the groundwork has been laid for measurable progress: hundreds of GSPs have been submitted and reviewed; new monitoring networks and data systems are operational; innovative projects like managed aquifer recharge and land repurposing are being piloted; and conversations around water budgets, demand reduction, and multi-benefit solutions have moved from theory to practice in many regions.

While major challenges remain — including addressing chronic overdraft, land subsidence, and water equity — the first 10 years of SGMA represent a foundational decade of institution-building, learning, and action. The coming years must build on this momentum with deeper integration, stronger coordination, and continued investment to ensure that all basins can achieve groundwater sustainability and water resilience for future generations. Accelerating SGMA implementation with greater speed, alignment, and resolve is more critical now than ever. The following priorities are central to this coordinated approach:

- **Building climate resilience** by holistically managing interconnected groundwater and surface water, natural and built infrastructures, basin and non-basin areas, and ecosystems.
- **Managing groundwater demand and land use** including through strategies such as land repurposing, groundwater accounting, and water markets, to achieve sustainable extraction levels and improve overall water efficiency.
- **Aligning land use planning with water supply availability** to ensure that future development is multi-benefit and land use does not exhaust available water resources.
- **Minimizing or avoiding subsidence** through targeted recharge and sustainable pumping practices, before further, irreversible damage to aquifer capacity and infrastructure limits resource availability and increases infrastructure failure risk.
- **Maximizing groundwater recharge**, especially during high-flow periods, to replenish groundwater storage and strengthen drought resilience.

PUBLIC DRAFT

- **Understanding and managing natural and built infrastructures** to support integrated, basin-wide and regional solutions.

1.1.3 Rising Groundwater Reliance Amid Climatic Extremes

Over the last 20 years, California has undergone major transformations in land use, water demand, the operation of State and federal water projects, and allocation strategies — all increasingly shaped by the effects of a changing climate, prolonged droughts, and more frequent extreme weather events. Together, these factors have significantly altered how, when, and where groundwater is utilized across the state. Rapid urban expansion, fueled by a population expected to reach 42 million by 2050 (California Department of Finance 2024), has heightened water demand in cities. Simultaneously, agricultural shifts toward higher-value but more water-intensive crops — driven largely by market forces — have placed additional stress on water supplies, despite widespread adoption of efficiency measures.

Climate change has further intensified these pressures by increasing crop water needs through higher evaporative demand and is projected to reduce California's surface water availability by up to 10% by 2040 (California Natural Resources Agency 2022). As surface water becomes more variable and uncertain, groundwater has emerged as a vital source for meeting the needs of urban centers, agriculture, and rural communities — particularly during droughts and extended dry spells.

California's inherently variable climate exerts strong influence over groundwater use from year to year, as illustrated by statewide water use trends depicted in Figure 1-1. The figure shows total annual statewide groundwater use as a percentage of total annual water use (which includes surface water, groundwater, and reuse) for Water Years (WY) 2002 to 2021. Over this 20-year period, statewide groundwater use averaged approximately 17.2 million acre-feet (maf) annually. In wetter years like 2011, 2017, and 2019, groundwater comprised about 31% of total statewide water use. In contrast, during critically dry years such as 2014, 2015, and 2021, groundwater usage rose sharply to approximately 53%, 58%, and 51%, respectively. These trends underscore a growing reliance on groundwater in response to climatic extremes and surface water shortages. This increased dependence during drought periods — particularly in 2012–2016 and again in 2020–2021 — has intensified adverse outcomes such as chronic overdraft, land subsidence, well failures, groundwater quality degradation, and environmental stress.

PUBLIC DRAFT

While comprehensive statewide water use data beyond 2021 is still being compiled, more recent data from 2021 to 2023 is available for SGMA-managed basins, including those operating under approved Alternatives, and adjudicated areas. This information, submitted annually to DWR by Groundwater Sustainability Agencies (GSAs) and local agencies, marks a significant step forward in data availability under SGMA. As seen on the right side of Figure 1-1, groundwater accounted for as much as 64% of total water use in these basins during the dry years of 2021 and 2022 — highlighting both the critical role of groundwater and the importance of ongoing monitoring and sustainable management.

These emerging patterns are part of a larger statewide shift that is expected to accelerate in the decades ahead as climate change intensifies. The *California Water Plan Update 2023* evaluated the long-term risks to water supply through 2070 and highlighted an increasing dependence on groundwater across all major hydrologic regions. Projections under the most likely scenarios show a 2–9% rise in groundwater reliance statewide, with the San Joaquin region experiencing the highest projected increase at 9%. When climate uncertainty is taken into account, reliance on groundwater could grow even more sharply — by as much as 11% in the Sacramento River region, 32% in the San Joaquin region, and 6% in the Tulare Lake Region — raising the risk of substantial storage losses unless bold demand reduction strategies or new water supplies are introduced.

Both historical trends and future projections reveal that growing reliance on groundwater in the face of climate extremes represents a critical turning point for California. The evidence is compelling: unchecked reliance without sustainable management has already resulted in serious consequences for communities, ecosystem and aquifer health, water quality, and key infrastructure. Meeting this challenge will require a transition toward forward-looking stewardship, integrated planning, and coordinated implementation of projects and actions at every level of governance. Whether this increasing dependence becomes a long-term vulnerability or a pathway to resilience will depend on how quickly and decisively we act.

PUBLIC DRAFT

Figure 1-1 Percentage of Water Use by Source: Historical Statewide Data (2002–2021) and Annual Reports Data (2021–2023)

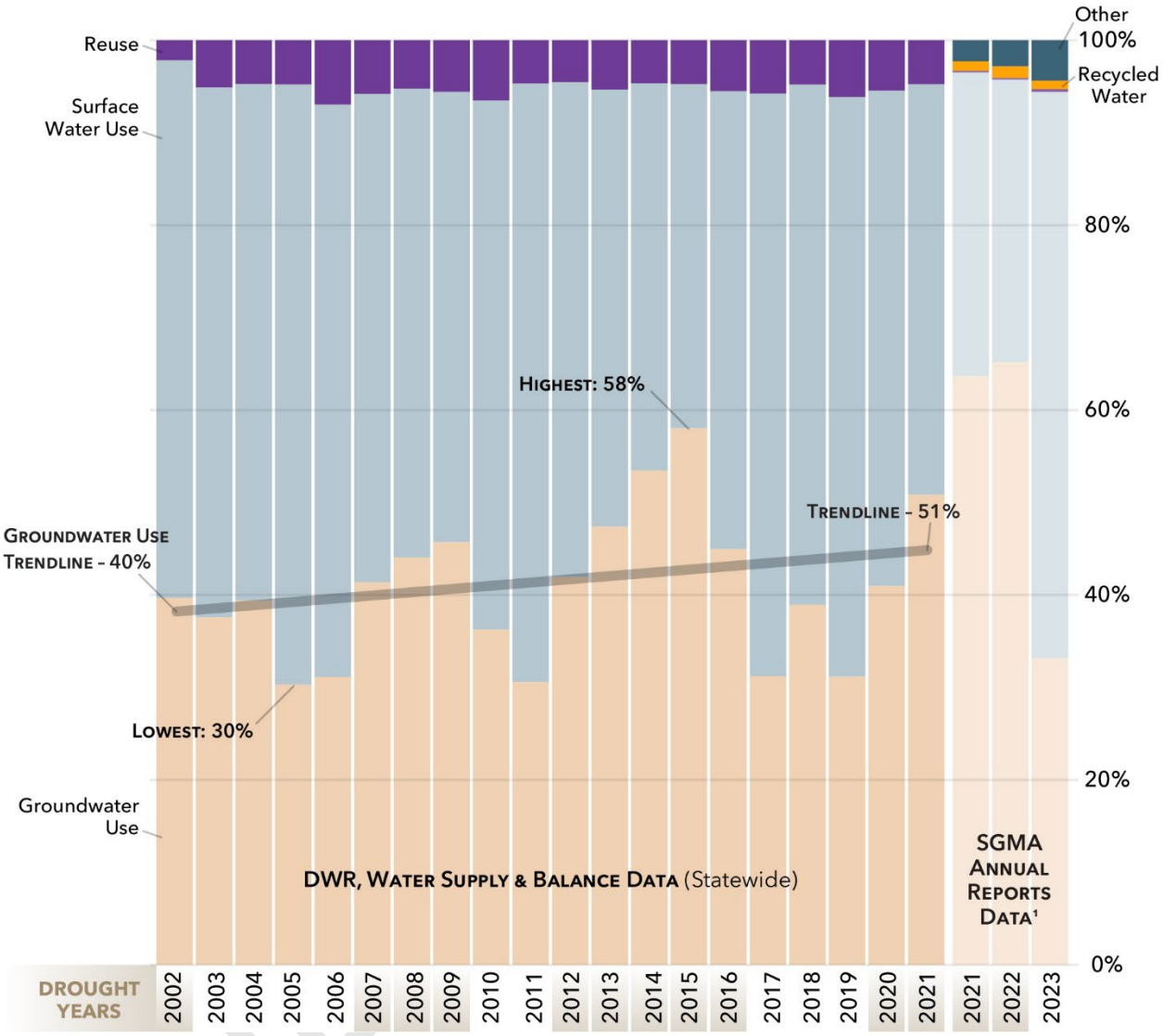


Figure 1-1 Note:

1. *SGMA Annual Reports Data (2021–2023) represents the percentage of total water use by source within in-basin areas of the state, based on data submitted in GSPs, Alternatives, and for adjudicated areas; non-basin areas are excluded. The number of basins submitting annual reports varies by year: 2021 data is based on 94 basins, 2022 is based on 98 basins, and 2023 is based on 100 basins.*

1.1.4 A Reservoir Beneath Our Feet

While surface water reservoirs visibly reflect signs of abundance or scarcity, the true measure of California's water health lies underground in the 515 groundwater basins. The state's vast groundwater storage capacity, estimated at more than

1,000 maf, far surpasses the combined capacity of all surface reservoirs, which is only about 40 maf (Figure 1-2). While physical limitations, poor water quality, and economic constraints reduce the usability of this vast groundwater storage, its sheer size underscores its importance and potential for long-term water security.

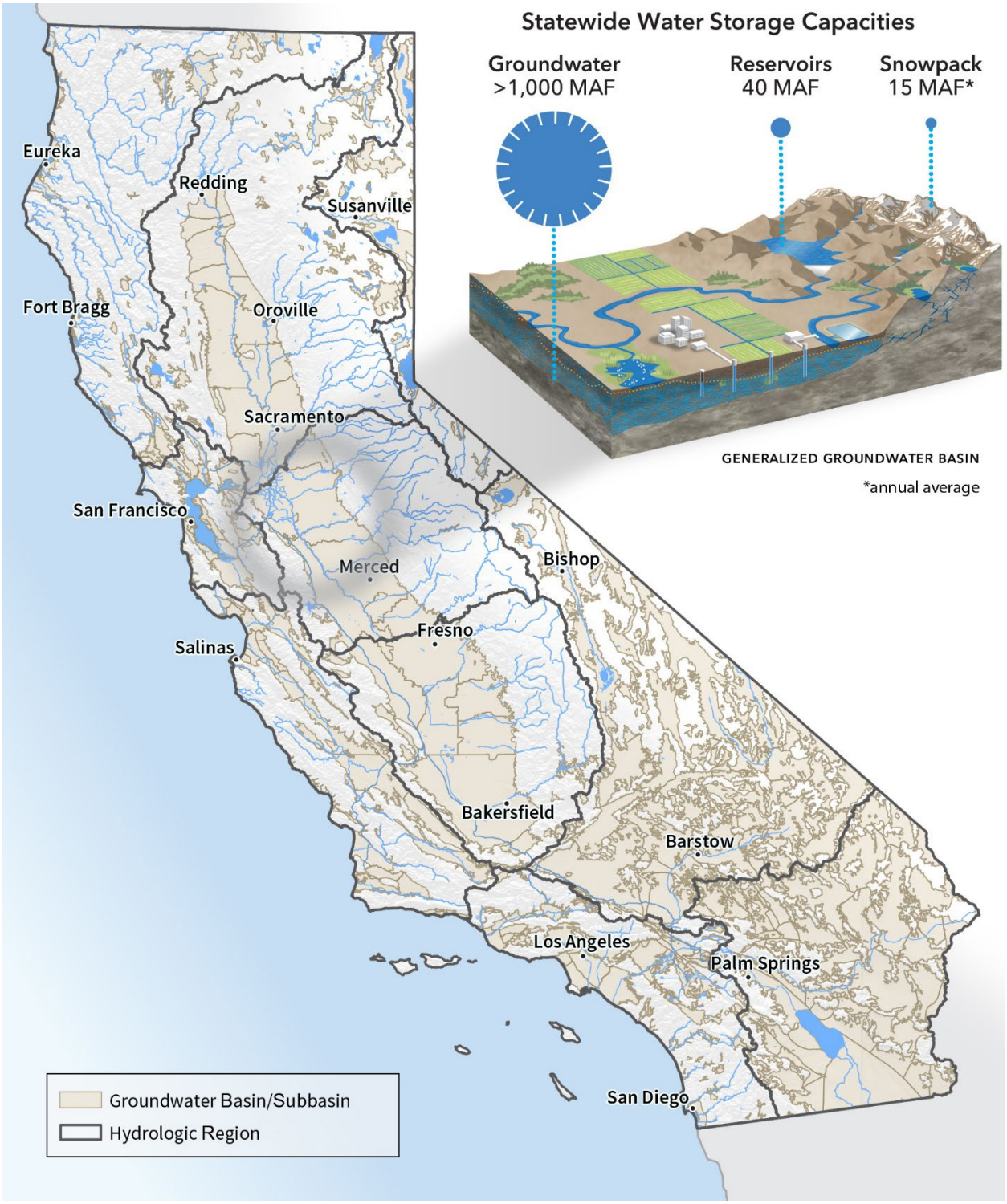
Decades of over-extraction, however, have severely depleted aquifers, with some regions facing groundwater levels that will take decades of careful management to recover. This historical chronic groundwater depletion becomes more concerning because climate change has fundamentally disrupted California's water cycle. The 2001–2022 period marked the driest 22-year span in at least 1,200 years, surpassing even the megadrought of the late 1500s. This new reality of hotter, drier conditions threatens to reduce the state's overall water supply by up to 10% by 2040.

The unpredictability of extreme weather and swings between wet periods and dry periods — known as "weather whiplash" — has further complicated water management. A significant multi-year drought from 2020–2022 was followed by one of the wettest years on record. In early 2023, California experienced a record-breaking sequence of 19 atmospheric rivers, delivering 192%, 237%, and 300% of normal snowpack respectively in northern Sierra Nevada, central Sierra Nevada, and southern Sierra Nevada. Although the resulting floods only scratched the surface of what is needed to replenish deeply stressed aquifers, they also provided opportunities. In WY 2023, for example, regulatory streamlining, State support, and significant local action enabled approximately 4.1 maf of managed aquifer recharge, with 93% occurring in the water-stressed San Joaquin Valley. These recharge efforts demonstrate the potential to turn extreme weather and climatic events, like floods, into opportunities for drought preparedness and long-term water resilience.

To further harness this potential, California has redefined aquifers as "natural infrastructure" through legislation (Senate Bill 122), passed in 2023. This designation opens the door to increased public funding available for projects that replenish groundwater. By providing opportunities for additional funding to maximize aquifer recharge and expand infrastructure to capture high flows, this legislation could significantly strengthen the state's capacity to adapt to climate change.

PUBLIC DRAFT

Figure 1-2 California's Groundwater Basins



1.2 A Decade of Progress Under SGMA

In 2014, in response to the worsening effects of drought and the growing pressures of climate change, California enacted the Sustainable Groundwater Management Act (SGMA). This landmark legislation is the cornerstone of the State's efforts to ensure the long-term sustainability of California's groundwater resources. SGMA mandates that all high- and medium-priority groundwater basins achieve sustainability by the early 2040's, providing a framework for consideration of beneficial uses of groundwater and informing local agencies' management of extraction and recharge to avoid locally defined impacts. The California Department of Water Resources (DWR) plays a pivotal role in implementing SGMA by providing technical, planning, and financial assistance, and general guidance to local Groundwater Sustainability Agencies (GSAs) as they develop, update, and implement Groundwater Sustainability Plans (GSPs). DWR evaluates these plans and updates to ensure they meet SGMA's requirements and also offers critical resources such as data tools, modeling support, facilitation support services, and grant funding to aid sustainable groundwater management efforts. The State Water Resources Control Board (State Water Board) complements this work by serving as a regulatory backstop, stepping in to manage groundwater basins if local agencies are unable or unwilling to meet SGMA requirements. The State Water Board, through separate non-SGMA regulatory programs, also ensures that beneficial uses and users of groundwater are protected by enforcing water quality standards and monitoring compliance through its Basin Plans, which designate specific beneficial uses for groundwater.

Together, these efforts have laid institutional groundwork for a decade of progress under SGMA. The following sections highlight the accomplishments achieved so far and chart the path forward — demonstrating how SGMA is evolving into a powerful tool for resilience, innovation, and long-term groundwater stewardship across California.

1.2.1 The SGMA Accomplishments

In its first decade, the Sustainable Groundwater Management Act (SGMA) has driven major progress in reshaping groundwater management across California. More than 250 Groundwater Sustainability Agencies (GSAs) have been formed to develop and implement Groundwater Sustainability Plans (GSPs). All high- and medium-priority basins have submitted GSPs or approved Alternatives, and nine low-priority basins have voluntarily done the same. DWR has approved nearly all submissions, with only seven high-priority basins deemed non-compliant.

PUBLIC DRAFT

SGMA has spurred over 1,500 local projects and management actions (PMA), the development of robust hydrologic models and accounting platforms, and monitoring of nearly 9,000 wells — many now delivering real-time data. About 50% of PMAs quantify water supply benefits, totaling 2.9 million acre-feet (maf) per year — including 1.3 maf from supply augmentation and 1.1 maf from recharge and conjunctive use. However, sustaining this progress will require ongoing funding. DWR has provided $500 million in grants over the last 10 years ($140 million for planning and $360 million for projects), but the State cannot cover the full cost of SGMA implementation. GSAs must find ways to self-fund their ongoing efforts, including project implementation, administration, community engagement, and monitoring. SGMA has also catalyzed cross-disciplinary innovations such as watershed-scale assessments linking land use, water availability, and long-term resilience. It has generated valuable data and advanced basin characterization and water budget studies, improving understanding of groundwater as "natural infrastructure" and its connections to surface water. These insights now inform infrastructure investments, recharge expansion, and demand-side strategies, reinforcing the need for land and water planning integration. SGMA has further mandated coordination between land use planners and water agencies to ensure new development supports sustainability.

Despite two severe drought periods, SGMA has established a more equitable and forward-looking approach to groundwater governance. GSAs have begun implementing demand management and local recharge efforts aimed at reducing overdraft. While difficult, these actions help stabilize groundwater conditions and promote balanced outcomes for all beneficial uses. Some areas have also seen reduced subsidence due to new recharge basins and infrastructure improvements. SGMA is emerging as a core climate adaptation tool, helping make water systems more resilient to variability. Groundwater level trends from fall 2014 to fall 2024 show net improvement: 41% of wells rose by five feet or more with reference to 2014 fall levels, 39% stayed within five feet of reference levels, and 20% declined by five feet or more. This marks the first time more wells have recovered than declined in a 10-year fall water-level comparison — likely reflecting the impacts of both wet years and SGMA-driven management.

Public understanding of groundwater has also deepened. Communities, GSAs, and agencies are now planning for long-term drought resilience, ensuring agricultural, environmental, and community water needs are met. The passage of Proposition 4 in November 2024 — a $10 billion natural resources bond for climate resilience and environmental protection projects — will extend support for GSP implementation and build on the progress of SGMA's first decade. SGMA has also

PUBLIC DRAFT

elevated equity in groundwater planning, especially for historically underserved communities. Disadvantaged communities (DACs) now have greater representation and access to resources. DWR has amplified the voices of those affected by dry wells, water quality concerns, and limited access to drinking water by using tools like the Human Right to Water Framework and DAC Engagement Pilots. Senate Bill 552 has strengthened this focus by requiring the State to track and prioritize vulnerable small systems and domestic wells through the Water Shortage Vulnerability Score and Tool.

A more detailed description of SGMA accomplishments is provided in Chapter 2, "Progress Toward Sustainable Groundwater Management."

Looking ahead, SGMA's success will depend on deeper collaboration, faster implementation, and a shared ethic of stewardship — treating groundwater not just as a resource to extract, but as a legacy to protect future generations.

1.2.2 Charting the Future of Groundwater Stewardship

Despite these advances, the challenges ahead are formidable, underscoring the need for continued investment and innovation. As California experiences increasing variability in precipitation and temperature due to climate change, the importance of groundwater cannot be overstated. It is a lifeline in times of drought, a buffer that reduces impacts during floods, and a critical element of the state's climate resilience. To fully harness its potential, the State must accelerate recharge efforts by expanding infrastructure to capture high flows and maximize opportunities for aquifer replenishment during wet years; enhance monitoring and transparency by leveraging cutting-edge technologies to collect and share groundwater data in real time; promote conservation and collaboration by fostering partnerships among State agencies, local governments, and communities to reduce demand and implement sustainable practices; and address regional disparities by tailoring strategies to the unique challenges of each hydrologic region, particularly those experiencing severe subsidence and overdraft.

> "To fulfill the promise of SGMA, we must integrate groundwater with surface water — dam safety, reservoir operations, flood management, and ecosystem restoration — thereby expanding the solution space available to facilitate climate resilience and equity."
>
> — California DWR Strategic Plan, 2023

PUBLIC DRAFT

Building on the recognition of groundwater as the foundation of California's resilience, advancing groundwater management further requires innovative tools and technologies to enhance decision-making and sustainability. One such advancement is groundwater forecasting, which will enhance the state's ability to effectively and efficiently steward sustainable groundwater management into the future.

Groundwater forecasting, much like surface water forecasting, involves predicting future groundwater availability, recharge rates, and aquifer conditions over short- and long-term periods. This process relies on integrating hydrological models, historical data, and real-time monitoring to anticipate changes in groundwater storage, flow, and quality. Groundwater forecasting would enable water managers to prepare for fluctuations in demand and supply caused by extreme weather and climatic events, seasonal variability, and long-term climate change. Key components could include monitoring aquifer levels, analyzing recharge rates from precipitation and managed aquifer recharge projects, and assessing land-use changes that both affect and are influenced by groundwater availability. Forecasting these conditions and providing timely information to water managers would help them better manage groundwater extraction, avoid over-pumping, ensure sustainable use while protecting ecosystems and meeting urban and agricultural water needs, and be better prepared to respond to extreme and climatic weather events.

California is making progress and becoming better positioned to forecast groundwater conditions and impacts by enhancing statewide monitoring network coverage and data collection frequency, and making this information easily accessible through online platforms such as California's Groundwater Live (CalGW Live). These systems can integrate data from over 9,000 monitored wells across the state, including telemetered, real-time wells providing hourly updates on groundwater levels. To move toward robust forecasting, the State is expanding its monitoring network, investing in advanced modeling tools, and enhancing data-sharing platforms. As those investments continue, groundwater forecasting can become more impactful to water managers. For example, expanding the tracking and monitoring of initiatives like Flood-MAR can offer valuable insights on recharge potential, while advances in satellite data and remote sensing technologies such as Interferometric Synthetic Aperture Radar (InSAR) can enable tracking of subsidence and aquifer depletion in real time. By combining these tools with machine learning and predictive analytics, California can develop dynamic groundwater forecasts akin to surface water forecasting systems such as DWR's Bulletin 120, which provides seasonal surface water supply forecasts, and the

PUBLIC DRAFT

California-Nevada River Forecast Center which provides hydrologic, river, and flood forecast data. This approach would enable proactive decision-making, improve drought and flood preparedness, and enhance the long-term sustainability of groundwater resources.

Groundwater basins and the aquifers contained within them are more than a resource; they are some of California's most precious natural assets. By treating aquifers as essential natural infrastructure, embracing innovation, and maintaining a steadfast commitment to sustainable management, California can secure a resilient water future for generations to come. The State's efforts today will determine whether groundwater continues to serve as a foundation for resiliency in the face of a changing climate.

As California navigates this era of unprecedented climate challenges, the transition from foundational groundwater principles to actionable strategies becomes paramount. Building on this recognition, CalGW Update 2025 serves as a critical resource, leveraging administrative and legislative initiatives to transform the State's commitment to sustainable groundwater management into tangible outcomes.

PUBLIC DRAFT

1.3 CalGW Update 2025 Builds on Administrative, Legislative, and Local Water Initiatives

CalGW Update 2025 and its accompanying documents and tools represent a pivotal step toward achieving the State's mission to secure a sustainable water future. Groundwater, a critical resource supporting communities, agriculture, ecosystems, and drought resilience, lies at the heart of California's water management strategies. This update builds on the State's robust administrative and legislative framework (discussed under the Climate Change Adaptation and Sustainable Groundwater Management section of this Chapter), including SGMA, the Human Right to Water Act, the Newsom administration's California's Water Supply Strategy, the Water Resilience Portfolio, and the DWR *Strategic Plan* as well as decades of planning and collaborative efforts to combat climate-induced water challenges. More importantly, the State's initiatives built upon decades of foundational work carried out by local agencies, whose expertise, projects, and management actions in relation to groundwater management have set the stage for broader State-level strategies. With extreme weather conditions becoming the norm, marked by persistent droughts and intensified flood events, the urgency to enhance statewide groundwater management has never been greater.

To help guide statewide action, CalGW Update 2025 builds on decades of local and State efforts and introduces a strategic framework that reflects the most pressing groundwater challenges and opportunities across California. The next section presents key thematic priorities developed through this update, while the section that follows emphasizes the importance of equity and partnership — especially with Tribes, frontline communities, and local agencies — as central to achieving long-term groundwater sustainability.

1.3.1 Themes of CalGW Update 2025

The CalGW Update 2025 introduces four themes for advancing sustainable groundwater management, grounded in the findings of this report, which highlight the most significant pressures on California's natural and built groundwater infrastructure and the strategies and tools needed to address them. The themes align with California's vision, policies, and priorities for climate resilience, equity, and water security.

The first theme, "Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency," emphasizes the vision to maximize the potential of groundwater infrastructure to mitigate the impacts of a changing climate and extreme weather

PUBLIC DRAFT

by understanding and investing in it. The second theme, "Accelerating Momentum for Sustainability," calls for a continued commitment to SGMA implementation to secure long-term sustainability. The third theme, "Strengthening Connections for Equity," highlights the necessity of incorporating diverse voices, especially those from frontline and underrepresented communities, into water management decisions. Finally, the fourth theme, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support," underscores the need for cutting-edge data and technologies, and long-term systematic water level measurements that will enable accurate evaluation of resource changes, trend forecasting, real-time science-based decision-making, and monitoring of the effectiveness of groundwater management.

These four themes, discussed below in detail, reflect the depth of California's commitment to sustainable water management and serve as the foundation for the State's success in addressing water scarcity and hydrologic variability. As climate challenges intensify, CalGW Update 2025 builds on the groundwork laid by other efforts included in the California Water Plan Update 2023*, the* 2022 Central Valley Flood Protection Plan Update, the Newsom administration's California's Water Supply Strategy, the Water Resilience Portfolio, and other policy roadmaps. Together, these efforts provide a forward-thinking blueprint for addressing water management challenges and highlighting sustainable groundwater management as a cornerstone of California's water resilience and equity efforts.

Theme 1: Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency

Over the next two decades, fully harnessing California's groundwater basins, aquifers, and recharge infrastructure will be essential for advancing climate adaptation, strengthening long-term resilience, and enhancing preparedness for extreme weather and climatic events. Foundational components of California's natural and built infrastructure, groundwater basins play a crucial role in supporting communities, ecosystems, and the economy while providing a vital buffer against droughts and reducing dependence on surface water. Understanding and optimizing California's groundwater systems, together with sustainable watershed and land management practices and strategic investments in conveyance infrastructure, will help the State enhance groundwater recharge efforts and water supply reliability, capture high flows during heavy rainfall to reduce flood risks, and support biodiversity.

PUBLIC DRAFT

Strategic investments, both financial and non-financial, aimed at stabilizing, preserving, and maximizing groundwater resources are necessary to sustain these benefits. Policy incentives and regulatory flexibility to foster innovation and implement nature-based solutions will be indispensable for safeguarding groundwater supplies, improving water quality, and expanding the adaptive capacity of California's water systems. By prioritizing groundwater natural infrastructure in climate resiliency strategies, California can achieve a more robust and sustainable water management system that meets the needs of both current and future generations.

Theme 2: Accelerating Momentum for Sustainability

With just over 15 years remaining to achieve sustainability, accelerating progress toward sustainable groundwater management is crucial for California's water future. While the State provides the regulatory framework, guidance, and technical, planning, and financial assistance, local agencies are at the forefront of funding and implementing SGMA.

Local agencies need to persist in their efforts in the SGMA implementation phase, intensifying actions to carry out their GSPs, projects, and management actions. By expanding its support, the State can enable local agencies to implement more effective groundwater management strategies, address current challenges, enhance recharge efforts, and reduce over-extraction. This partnership between the State and local agencies is essential for accelerating momentum and achieving SGMA's sustainability goals, ultimately securing California's groundwater resources for future generations.

Theme 3: Strengthening Connections for Equity

People and communities across the state depend on safe, clean groundwater for their daily needs, but many are underserved and among the first to experience the impacts of declining groundwater levels and degraded water quality. Through the enactment of California Water Code Section 106.3 in 2013, California was the first state in the nation to legislatively recognize that "every human being has the right to safe, clean, affordable, and accessible water." Building on this foundational commitment, the State must continue to strengthen engagement, communication, and outreach efforts to work toward equity in groundwater management and outcomes for communities. Ensuring that various communities — including frontline and vulnerable communities and Tribes — are involved in all aspects of groundwater management decisions allows valuable input from these water users to be leveraged. By fostering collaborative and inclusive connections, the State

PUBLIC DRAFT

empowers local agencies, community leaders, and decision-makers to work together not only to protect groundwater, a critical resource, but also ensure its long-term resilience for all who depend on it.

Essential resources like CalGW, along with companion and complementary platforms such as DWR's Dry Well Susceptibility and Water Shortage Vulnerability Tools, provide critical insights and help bridge the information gaps faced by historically underrepresented communities. Identifying and addressing these data gaps promotes equity in information access, ultimately leading to more equitable groundwater management practices and solutions. By utilizing these resources, the State can leverage local knowledge and data to better inform agency partners and engage communities. These actions affirm that all voices should be valued and considered in the pursuit of sustainable groundwater management and water equity.

Theme 4: Enhancing Groundwater Data, Tools, and Analysis for Decision Support

Effective groundwater management requires both high-frequency and long-term groundwater data, as well as advanced analytical forecasting capabilities, similar to those used in the surface water arena, to support real-time, informed decision-making. The State is committed to strengthening these capabilities by improving data collection, reporting, tool development, and analysis in partnership with local and federal agencies. Reports such as CalGW Updates and CalGW Semi-Annual Updates, along with data-driven platforms like the SGMA Data Viewer and California's Groundwater Live, will serve as central repositories for comprehensive, statewide groundwater data, facilitating real-time operational insights.

By making this information accessible through the California Natural Resources Agency (CNRA) Open Data webpage, the State aims to empower water managers and decision-makers with the tools necessary for data-driven solutions in sustainable groundwater management and extreme weather preparedness. Enhanced data availability, frequency, and quality will ensure effective groundwater management addressing current challenges and advancing sustainable practices statewide.

1.3.2 Prioritizing Equity and Partnerships

As California moves toward sustainable groundwater management, it is essential for the State to prioritize equity, inclusion, and meaningful engagement. Giving historically marginalized groups, such as Tribal and frontline communities, a voice

PUBLIC DRAFT

in water management helps address past neglect. Strengthening partnerships with local agencies responsible for managing resources at a local level is also crucial. By fully integrating these communities and partnerships into the CalGW themes and vision for sustainable groundwater management, California can build a more inclusive and resilient water future.

Tribal Engagement in Sustainable Groundwater Management

California's Tribes, as stewards of the land for millennia, hold invaluable knowledge and cultural insights that can significantly enhance sustainable groundwater management. Their historical connection to natural water systems, coupled with their deep understanding of ecological balance, makes their inclusion in water management efforts both essential and mutually beneficial. However, many Tribal communities face unique challenges, including inadequate access to safe and reliable groundwater, compounded by a lack of inclusion in traditional water management frameworks. The State of California has established administrative priorities for Tribal engagement in water management and groundwater stewardship, focusing on fostering meaningful partnerships, respecting Tribal sovereignty, integrating traditional ecological knowledge (TEK), and ensuring equitable access to water resources while addressing the unique needs and rights of Tribal communities. To achieve truly equitable and climate-resilient water systems, State and local entities must actively involve Tribes in groundwater planning and decision-making, fostering collaboration, trust, and shared responsibility.

The four themes described above provide a clear pathway for engaging Tribal communities. Under the theme of "Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency," Tribal knowledge systems can guide nature-based solutions, such as the restoration of riparian zones and the integration of traditional ecological practices into groundwater recharge projects. Efforts related to the theme of "Accelerating Momentum for Sustainability," should prioritize partnerships with Tribes to ensure their groundwater needs are addressed and their voices are included in sustainability planning. Furthermore, the theme of "Strengthening Connections for Equity," underscores the importance of structured and consistent communication with Tribal governments, recognizing Tribal sovereignty, and ensuring that Tribal perspectives and priorities are integral to groundwater management policies. Finally, efforts related to the theme of "Enhancing Groundwater Data, Tools, and Analysis for Decision Support" can empower Tribes with access to critical groundwater data, tools, and training, enabling them to effectively engage in decision-making processes and advocate for

PUBLIC DRAFT

their needs. By fully integrating Tribal voices and knowledge into the State's groundwater strategies, California can advance equitable outcomes for Tribes and achieve a more holistic and resilient water future.

Some of the ways DWR has recently supported Tribal engagement in sustainable groundwater management include:

- Hosting the SGMA Tribal Advisory Group, established in 2015 to bring DWR and California Native American Tribal governments and Tribal communities together to collaborate on outreach and engagement efforts associated with the implementation of SGMA.
- Launching the Underrepresented Communities, California Tribes, and Small Farmers Groundwater Technical Assistance Program in 2021, to assess the needs, risks, and vulnerabilities of communities impacted by the implementation of SGMA. The program provides information on available technical assistance and outreach materials for both agricultural and groundwater-related needs, including Native American Tribal Water Stories Graphic Novels.
- Executing a funding agreement in 2022, that provides $15 million in direct financial assistance to Tribal communities for water supply projects, marking a significant government-to-government collaboration (State Delivers $15 Million To Support Tribal Water Infrastructure Projects).
- Hosting the Tribal Water Summit, the latest of which took place in April 2023, and included panels, workshop sessions, and Tribal Representatives and Member speakers that focused on groundwater.
- Expediting water transfers and executing an agreement in 2024, with the Santa Rosa Rancheria Tachi Yokut Tribe to meet immediate water supply needs and address long-term demands north of the Tulare Lake area (California and Tribal Partners Secure Critical Water Supply to Support Native American Farmers).

Frontline Communities and Sustainable Groundwater Management

Frontline communities — often overlapping with underrepresented or disadvantaged communities — are explicitly defined in the California Water Plan Update 2023 as "those that experience the 'first and worst' of environmental consequences." In other words, frontline communities are already living with the negative impacts of inequities in water management and thus are most susceptible to future negative changes. Residents are more exposed to existing water sector

PUBLIC DRAFT

vulnerabilities (e.g., water shortages, water quality issues, or affordability challenges) and future ones, such as the impacts of climate change."

These communities are characterized by socioeconomic vulnerabilities, including low-income, racial or ethnic minority status, or geographic isolation, which exacerbate their susceptibility to environmental and infrastructural challenges. Many reside in rural or agricultural regions where groundwater is the primary or sole source of water, yet these areas often face issues like overdrafted aquifers, dry wells, and nitrate contamination. Groundwater plays a crucial role in meeting the needs of frontline communities, particularly during California's frequent droughts. Approximately 85% of rural residents in disadvantaged areas rely on groundwater wells for drinking water and daily use. However, the over-extraction of groundwater has left many wells dry, leaving residents without essential water supplies. These communities risk experiencing deepened socioeconomic disparities as they bear the brunt of water management policies designed to achieve long-term sustainability. For example, land retirement, the process of taking agricultural land out of production, has significant implications for frontline communities. These communities, often located in rural areas dependent on agriculture for economic stability, are disproportionately affected by the loss of jobs and economic opportunities associated with land retirement. Studies show that in regions like the San Joaquin Valley, where over 50% of the population in some areas is classified as disadvantaged, land retirement linked to groundwater sustainability efforts could result in about 900,000 acres of land being fallowed or removed from intensive irrigated production (Eskriva-Bou et al. 2023). This could lead to job losses in agriculture and related industries, affecting thousands of workers, many of whom are from low-income and minority backgrounds. Additionally, the reduction in agricultural activity may affect local economies reliant on farming, from decreased tax revenue to reduced spending at local businesses. Without targeted investments in economic transition strategies, such as workforce retraining programs and infrastructure development, these communities may face lasting economic hardship, further widening existing inequities.

Equity in California's water supply sector is both a guiding principle and a persistent challenge. State efforts like the *California's Water Supply Strategy* and the SGMA program emphasize the inclusion of underrepresented groups in decision-making processes and supporting their access to State resources. State-led initiatives prioritize these vulnerable populations through technical and financial support, working to ensure they are not left behind in the broader efforts to enhance water security. By framing equity as a cornerstone of water resilience,

PUBLIC DRAFT

California acknowledges the historical neglect faced by vulnerable populations and works to correct disparities through grants, community-led projects, and transparent policy making. These efforts are complemented by technical tools like the State Water Board's Human Right to Water Portal, which tracks progress toward universal access to safe and affordable water. Collectively, these measures reflect California's commitment to addressing inequities and ensuring that the most vulnerable are prioritized in the face of climate change and evolving water challenges.

In alignment with the California Water Plan Update 2023, 2022 Central Valley Flood Protection Plan Update, and the CalGW Update 2025 themes, the State emphasizes fostering inclusive surface water and groundwater stewardship, addressing systemic inequities, and building partnerships that elevate the voices of these communities in water management decisions. The connection between frontline communities and groundwater themes is central to achieving sustainability, resilience, and equity in California's water systems.

Under the theme of "Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency," the focus is on addressing the vulnerabilities of frontline communities by enhancing infrastructure such as groundwater recharge basins and dry well mitigation programs. These initiatives provide essential relief and stability for communities disproportionately affected by overdrawn aquifers and inadequate water infrastructure. By leveraging local knowledge and the experiences of frontline communities, the State can develop infrastructure solutions that are both practical and culturally sensitive, ensuring that climate adaptation efforts benefit all Californians equitably.

The theme of "Strengthening Connections for Equity," emphasizes the necessity of structured engagement with frontline communities to include their needs and perspectives in groundwater management. Many of these communities have been historically excluded from water planning processes, leaving their critical needs unmet. Transparent and inclusive frameworks, supported by programs like the Disadvantaged Communities and Tribal Involvement Grant Program, can empower these communities with the tools, data, and representation needed to advocate effectively for sustainable groundwater solutions. Additionally, the themes of "Accelerating Momentum for Sustainability," and "Enhancing Groundwater Data, Tools, and Analysis for Decision Support" align with the goal of equity by ensuring that frontline communities gain access to accurate groundwater data, training, and resources. This enables them to actively participate in decision-making processes and fosters a shared responsibility for sustainable groundwater management. By

PUBLIC DRAFT

fully integrating frontline communities into these themes, California can achieve a more inclusive and resilient groundwater future.

Some of the ways DWR has supported frontline communities in sustainable groundwater management include:

- Providing Financial Assistance through the Sustainable Groundwater Management (SGM) Grant Program: DWR has allocated millions of dollars in funding to support disadvantaged and underrepresented communities in the development and implementation of Groundwater Sustainability Plans (GSPs). These grants prioritize projects that address critical groundwater issues impacting these communities.
- Offering Outreach and Engagement Resources: DWR has developed multilingual outreach materials, hosted community workshops, and collaborated with local organizations to ensure that underrepresented communities have access to critical groundwater information and opportunities for meaningful participation in the SGMA process.
- Establishing Partnerships for Technical Support: DWR has partnered with local agencies and nonprofits to provide technical assistance for small farmers and communities relying on groundwater, helping them better understand and manage their water resources under SGMA.
- Implementing Groundwater Resilience Strategies: DWR has supported disadvantaged communities by funding projects focused on groundwater recharge, safe drinking water access, and resilience to drought impacts, ensuring equitable benefits for those most vulnerable to water shortages.
- Conducting Community Engagement for Capacity Building: DWR has facilitated community engagement efforts to build local capacity for sustainable groundwater management, empowering frontline communities with tools and knowledge to address groundwater challenges.

1.3.3 Local Agencies; Key to Success of Sustainable Groundwater Management Program

The approach to groundwater management in California has fundamentally shifted with SGMA, prioritizing local control while establishing a framework for State oversight and support. At its core, SGMA reflects California Legislature's confidence in the capacity of local agencies to understand and address their unique groundwater challenges. GSAs, formed under SGMA, are entrusted with developing and implementing GSPs that align with the distinct hydrological, social,

PUBLIC DRAFT

and economic characteristics of their groundwater basins. This model ensures that decision-making remains rooted in local expertise and knowledge, while the State plays a supporting role, providing financial and technical resources, setting regulations, and intervening only when necessary. The early achievements in the implementation of SGMA underscore the power of this collaborative approach, highlighting the essential role of local agencies as stewards of sustainable groundwater management.

One of the hallmarks of SGMA's implementation has been the robust partnership between the State and local agencies. California has invested billions of dollars in grant funding, technical assistance, and data tools to empower GSAs. Over the past decade, State funding for groundwater management planning, infrastructure projects, groundwater recharge projects, monitoring infrastructure, and drought resilience efforts has surpassed $1 billion. Local agencies have matched and exceeded this State support, contributing through local and regional project funding, federal funding, local fees, assessments, and innovative public-private partnerships. This financial synergy underscores the shared commitment and mutual investment required to achieve sustainability goals.

The achievements of local agencies are a testament to their ingenuity and dedication, bolstered by the State's steadfast support. GSAs across California have developed innovative strategies to address critical issues such as overdraft, saltwater intrusion, and declining groundwater quality through various projects and management actions. For instance, agencies in the San Joaquin Valley have initiated recharge projects that capture high flows during wet years, replenishing depleted aquifers. Coastal GSAs have implemented advanced monitoring programs to combat seawater intrusion, while others have pioneered water trading and other incentive programs to optimize groundwater use. In the Central Coast, collaborative efforts between agricultural interested parties and local agencies have resulted in successful groundwater replenishment projects, integrating recycled water and stormwater capture systems. These localized efforts illustrate the adaptive capacity of GSAs to tailor solutions to their specific conditions, leveraging State-provided tools, funding, and guidance to make measurable progress toward sustainability goals.

The collaborative structure of SGMA exemplifies a balanced and dynamic partnership between local autonomy and State oversight. While the State provides critical guardrails — including regulations, enforcement authority, and periodic assessments — local agencies drive the day-to-day management and long-term planning necessary to achieve sustainability. This partnership extends to co-

PUBLIC DRAFT

funding critical research and pilot programs, enabling GSAs to adopt cutting-edge technologies and best practices. It is a partnership rooted in trust and mutual accountability, ensuring that local agencies retain control while benefiting from the State's broader resources and expertise.

The themes outlined in the CalGW Update 2025 initiative seamlessly align with the roles and responsibilities of local agencies under SGMA, further strengthening the partnership between State and local entities. First, the emphasis on "Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency" resonates with the local agencies' initiatives to develop infrastructure for recharge projects and drought resilience. This collaborative investment ensures that groundwater systems remain robust in the face of climate challenges. Second, "Accelerating Momentum for Sustainability" directly supports GSAs in their mission to stabilize groundwater resources, bridging the gap between immediate needs and long-term sustainability.

The theme of "Strengthening Connections for Equity" is deeply reflected in the work of many GSAs, as they engage with diverse partners and interests — including frontline communities, Tribes, agricultural and urban users — to ensure equitable access to groundwater resources. These efforts are bolstered by State programs that emphasize inclusion and address historic disparities in water management. Finally, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support" highlights the importance of the State's role in equipping local agencies with cutting-edge tools and comprehensive datasets. These resources empower GSAs to make informed decisions, track progress, and adapt their strategies to evolving challenges.

As California's groundwater challenges evolve, the continued success of SGMA will rely on the integration of these four themes into State-local partnerships and future actions. These themes serve not only as a strategic lens for understanding current pressures and opportunities, but also as the organizing principles for the recommendations and actions outlined in this report — some of which are ready for near-term implementation, while others lay the foundation for long-term resilience. These recommended actions, detailed in Appendix A, "Findings and Recommendations," span management governance, scientific studies and investigations, infrastructure, State and local investments, data and analysis, technology, equity, education, and ecosystem protection. Together, these themes not only guide the efforts of GSAs but also reinforce the dynamic collaboration between local agencies and the State — reaffirming that sustainable groundwater

PUBLIC DRAFT

management is, above all, a locally led endeavor empowered by State collaboration, coordination, and investment.

1.4 California's Groundwater – A Compendium of Information

California's Groundwater (CalGW) is the State's central informational resource on all aspects of groundwater — and includes periodic reports, data systems, analytical tools, and technologies that together form California's groundwater information infrastructure. It serves as a foundational tool to support informed decision-making by State, local, and federal agencies, as well as interested parties, and the public. In addition, it functions as a legislative resource and public education platform for understanding the status, challenges, and opportunities associated with groundwater management.

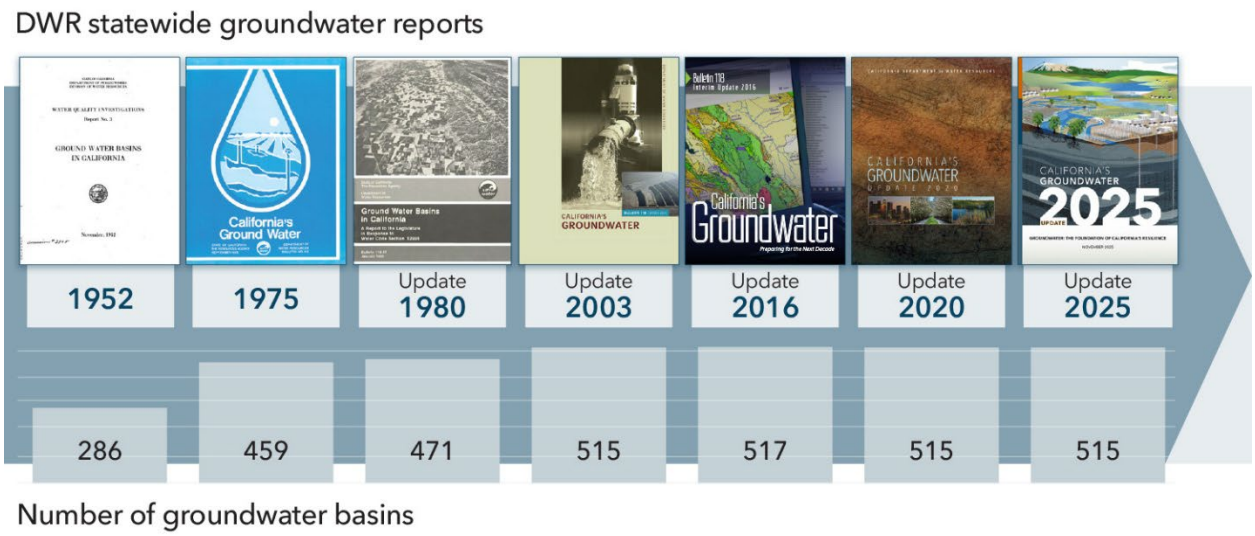
As part of CalGW, DWR publishes CalGW Updates (officially known as Bulletin 118) to meet the requirements of California Water Code Section 12924. CalGW Updates identify California's groundwater basins; provide the status of groundwater management along with challenges of climate change and extreme weather; describe groundwater conditions, monitoring efforts, and patterns of groundwater extraction within those basins; assign basin priority; designate basins subject to critical conditions of overdraft; and identify recommendations to improve groundwater management to achieve sustainability and resilience.

Over the past 70 years, the CalGW Updates and related documents have provided a source and historical archive of the State's collective knowledge and evolving understanding of the occurrence, use, and management of California's groundwater resources. This existing body of knowledge and each successive update facilitates informed decision-making by the public, local water agencies, and elected officials affecting the protection, use, and sustainable management of groundwater, and future investments in water management.

A chronological history of CalGW series of publications is provided in CalGW Update 2020 and is also available on DWR's CalGW webpage. Figure 1-3 shows the chronology of the number of groundwater basins identified in each published report from 1952 through 2025. Currently, there are 515 groundwater basins and subbasins in California based on the 2016 and 2018 basin boundary modifications.

PUBLIC DRAFT

Figure 1-3 Number of Groundwater Basins Identified in California's Groundwater Updates



Key components of California's groundwater information landscape are summarized below to provide context for the more detailed findings presented in the remainder of this report.

1.4.1 California's Groundwater: Bulletin 118 – Update 2025

California's Groundwater: Bulletin 118 — Update 2025 (CalGW Update 2025) is a follow-up to the CalGW Update 2020 and builds on the strong foundation of previous California's Groundwater updates.

CalGW Update 2025 evaluates the occurrence, use, and management of California's groundwater resources by assessing groundwater conditions using data through 2023 and incorporating more recent datasets where available. The report: inventories, assesses, and reports on data gaps; presents findings and recommendations; discusses climate change and extreme weather challenges; reviews groundwater management and a decade of progress under SGMA; evaluates statewide and regional groundwater use, supply, and well infrastructure; illustrates ways in which the knowledge of physical processes and conditions of groundwater is advancing; describes groundwater monitoring efforts and assesses groundwater conditions; includes a comprehensive discussion on managed aquifer recharge and Flood-MAR, conditions; and discusses challenges related to non-basin areas, and water shortage vulnerability.

CalGW Update 2025 is accompanied by the data-rich CalGW Live website, which provides a simple, user-friendly interactive experience that allows users to explore

PUBLIC DR

both real-time groundwater information and information presented in CalGW Update 2025.

1.4.2 California's Groundwater: Bulletin 118 – Update 2035

The next update of CalGW is scheduled for 2035, ten years from now, and will include expanded discussion and update on topics developed in CalGW Update 2025, with recent data and information. Much of the newer data and information will be obtained through the five-year updates of the groundwater sustainability plans (GSP), annual reports and data uploads from groundwater sustainability agencies (GSAs), California Statewide Groundwater Elevation Monitoring (CASGEM), and watermasters in groundwater basins with adjudications. DWR will continue to collect, compile, and analyze data and information from basins and non-basin areas that are not subject to SGMA compliance. This will be accomplished through staff research and analysis and online applications to collect, analyze, and present information on a statewide basis and by hydrologic region, groundwater basin, and non-basin areas.

1.4.3 California's Groundwater Information Products

California's Groundwater (CalGW) information products provide a comprehensive suite of tools and resources to support the understanding, management, and sustainable use of California's groundwater. At the core of these products are the CalGW Updates (officially known as Bulletin 118), which serve as foundational reports on the status and sustainability of groundwater basins across the state. These updates are complemented by CalGW Live, an interactive website that delivers near real-time access to groundwater-related data. To support data-driven groundwater management, CalGW: Semi-Annual Updates are released twice each year to provide more frequent information between the comprehensive CalGW Updates and offer additional perspective on the near-real-time data available through CalGW Live.

These tools are supported by additional SGMA-related resources, including, the SGMA Portal, which plays a vital role in supporting local agencies and interested parties in implementing SGMA. The portal provides access to essential tools, data submissions, and regulatory documents. Meanwhile, the SGMA Data Viewer serves as a centralized hub for groundwater-related data and information. Additional groundwater data and information are available through the California Natural Resources Agency (CNRA) Open Data and Water Data Library websites. Together, these products ensure robust groundwater management and accessibility to critical information for policymakers, water managers, and the public.

PUBLIC DRAFT

1.4.4 Future Basin Reports

In 2003, DWR developed a basin report for each of the 515 groundwater basins and subbasins. These reports, which are available on the CalGW webpage, contain descriptions of the boundaries, geology, hydrology, groundwater development, water budget information, water quality, and other related content.

While not part of CalGW Update 2025, DWR is updating and expanding the format of the basin reports to incorporate additional data that will become available during SGMA implementation, as well as from other groundwater programs. As the updated basin reports become available, they will be accessible on the CalGW webpage.

1.4.5 California's Groundwater Data Availability

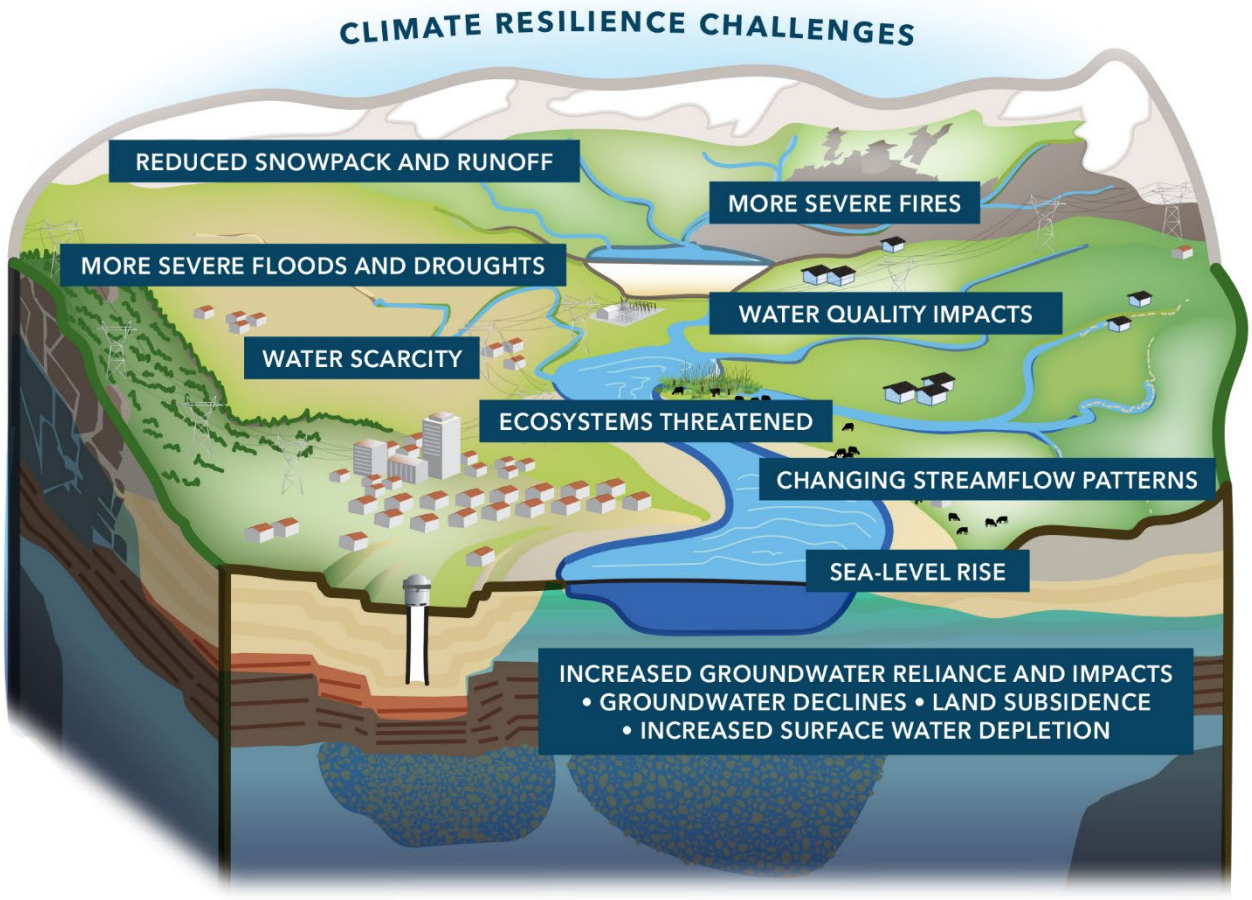
DWR's CalGW webpage provides access to current and historical groundwater documents and current groundwater basin boundary geographic information systems (GIS) data. The current and historical documents that are available at the time of this publication can be viewed online or downloaded from the website. Some documents are only available upon request. All data used in this report are available on the CNRA Open Data website or other sites as identified. Data collection and analysis will continue after CalGW Update 2025 is published. These data and analyses will be posted on the CNRA Open Data website as they become available.

PUBLIC DRAFT

1.5 Climate Change Adaptation and Sustainable Groundwater Management

Climate change is a pressing challenge, reshaping water systems worldwide and presenting California with unprecedented risks and opportunities. The challenge of climate resilience is multi-faceted (Figure 1-4), with interconnected threats that require integrated solutions. Reduced snowpack diminishes critical water supplies, exacerbating water scarcity and increasing pressure on groundwater resources. Rising temperatures contribute to more frequent and severe wildfires as well as increasing the atmosphere's capacity to hold moisture, which can intensify extreme precipitation events and flooding — threatening communities and infrastructure.

Figure 1-4 Multi-Faceted Nature of Climate Change Impacts



DRAFT

California's recent climate swings underscore this reality. When CalGW Update 2020 was released, the state was in the middle of multiple dry years — conditions that persisted into 2021 and 2022. This was followed by a dramatic shift in 2023, when intense storms and record-setting precipitation led to widespread flooding and rapid groundwater recharge. We are no longer preparing for a hypothetical future — these extremes are the new normal, and they are already reshaping how, when, and where water is available.

These changes, combined with groundwater declines, jeopardize ecosystems that depend on reliable water supplies. Additionally, sea level rise threatens coastal areas, impacting habitats, water quality, and human settlements. Together, these challenges demand holistic approaches to safeguard both natural and human systems in the face of a changing climate. As climate change reshapes the global hydrologic cycle, California stands at a critical crossroads in its effort to sustain water resources amidst intensifying extremes.

To ensure water reliability for agriculture, urban and rural areas, and ecosystems, climate adaptation for California is no longer optional — it is a necessity. By embracing innovative strategies, like using nature-based solutions and building resilient infrastructure, California can transform its water management systems to not only withstand the pressures of a changing climate but also to thrive as a model for sustainable resource stewardship. As a result, all advancements in groundwater management must be integrated into broader climate adaptation strategies to address its far-reaching impacts. Effective management must adapt to evolving climatic shifts while working in concert with surface water systems, land-use planning, and innovative technologies.

As California experiences increasing variability and intensity in precipitation and temperature due to climate change, the urgency of sustainable groundwater management becomes increasingly clear. Climate change is not a distant threat but an immediate reality, reshaping the global hydrological cycle and amplifying the challenges faced by the state's water systems. Rising temperatures, prolonged droughts, shifting precipitation patterns, and increased evaporation threaten the delicate balance of surface water and groundwater systems. Groundwater, as a critical resource, has emerged as the foundation of California's resilience to these changes, underscoring the need for innovative management approaches that align with broader climate adaptation goals. The California's Water Supply Strategy report further emphasizes the importance of integrating sustainable groundwater management into the State's overarching water strategies. This landmark document provides a roadmap for modernizing water infrastructure, improving

PUBLIC DRAFT

water storage, and building resilience in groundwater systems to prepare for the intensifying impacts of climate change.

Groundwater is at the heart of California's resilience to climate change. When managed sustainably, it serves as a critical buffer against the state's highly variable and increasingly extreme climate. However, poor management not only exacerbates existing groundwater issues but also creates new vulnerabilities. These include the expansion of land subsidence into previously unaffected areas, inland migration of saltwater intrusion due to increased coastal pumping, greater risk of shallow domestic wells running dry, infrastructure instability from falling groundwater levels, and worsening groundwater quality from contaminant mobilization and increased concentration. As California faces intensifying extremes, groundwater plays an increasingly indispensable role in sustaining water supplies.

The state's water users rely on a delicate balance of surface water and groundwater supplies. During periods of drought, groundwater becomes a lifeline, with pumping increasing to offset reduced surface water availability. Yet, this dependence puts immense strain on aquifers, especially as climate change disrupts historical patterns of snowmelt and runoff. Warmer temperatures drive higher evaporation rates and thus higher irrigation needs, while hydrological shifts concentrate runoff in winter, reducing the spring and summer flows critical for recharge and storage. These challenges underscore the urgent need for innovative, adaptive, and sustainable water management strategies.

This section explores the profound impacts of climate change on California's water systems, with a focus on groundwater's pivotal role in adapting to these growing challenges. It is organized into three parts:

1. An overview of statewide climate trends and their implications for California's groundwater resources, including effects on basin and non-basin areas and land use dynamics.
2. A discussion of how State, regional, and local planning efforts are addressing the increasing frequency and severity of climatic extremes — such as droughts and floods — through integrated water and land management strategies.
3. A summary of State and federal programs, tools, and investments designed to strengthen climate resilience and support sustainable groundwater management, including technical resources made available by DWR.

PUBLIC DRAFT

1.5.1 Climate Change Trends with Major Implications to California's Groundwater Resource

California's groundwater resources face mounting challenges from a range of interconnected climate change trends. Amplified climatic and hydrologic extremes, including prolonged droughts and intense atmospheric river (AR) storms, are reshaping water availability. The combined forces of temperature-related changes (thermodynamics) and shifting weather pattern (dynamics) are increasing unpredictability in water resources. Aridification in the southwestern United States, combined with changing precipitation patterns and heightened climatic water deficits (evaporative demand that exceeds available water), is further straining recharge processes. Additionally, land use changes — such as urbanization and agriculture — are compounding these impacts by disrupting natural infiltration pathways and intensifying groundwater extraction. A brief description of each of these critical trends follows.

Amplification of Climatic and Hydrologic Extremes: Drought and Deluge

California's climate variability and extreme weather patterns have been on display over the past two decades. Over this period, the state endured four significant drought episodes (2001–2004, 2007–2009, 2012–2016, and 2020–2022), collectively marking the driest 22-year stretch in at least 1,200 years (Williams Companies 2022). Remarkably, each drought ended with winter marked by multiple intense ARs. Some of these AR events triggered record flooding, placing critical infrastructure and communities at risk. For instance, the driest consecutive three-year period on record (2020–2022) concluded with one of the snowiest years in history (2023).

August 2021 provided stark examples of intensifying climatic extremes, described as "signposts of change." These included the Caldor and Dixie wildfires becoming the first to cross the Sierra Nevada crest and the unprecedented shutdown of the Hyatt Powerplant due to historically low water levels at Lake Oroville *(*California Department of Water Resources 2021). Such events underscore the growing challenges posed by California's increasingly erratic climate.

The amplification of climatic and hydrologic extremes is widely recognized as a hallmark of climate change. In California, climate change is expected to shorten wet seasons while intensifying them with more extreme AR events, increasing the risk of flooding. At the same time, longer dry periods and warmer temperatures will lead to more frequent and severe droughts. These changes will be accompanied by shifts in hydrological patterns, particularly in higher elevation

PUBLIC DRAFT

watersheds experiencing declining snowpacks. These changes will ripple through California's water systems in complex ways. Their ultimate impact on residents will depend heavily on the adaptive capacity of surface water and groundwater infrastructure, as well as the effectiveness of local, State, and federal water management strategies.

Dual Forces of Thermodynamic and Dynamic Climate Change

Climate change manifests in two distinct yet interconnected forms: thermodynamic and dynamic changes. Both are predicted to significantly impact California, shaping the state's future climate and water systems. Together, these forces underline the importance of adaptive water management strategies to prepare for a future of intensified droughts, floods, and hydrological shifts.

THERMODYNAMIC CLIMATE CHANGE

Thermodynamic changes are directly driven by rising global temperatures. In California, these changes have already increased the severity of recent droughts due to heightened evaporation rates (World Health Organization 2020). Likewise, atmospheric river (AR) storms have likely become more intense, as a warming atmosphere holds more moisture, amplifying precipitation during these events (Gonzales et al. 2019; Michaelis et al. 2022).

Global climate models (GCMs) consistently project that thermodynamic climate changes, such as intensified storms and prolonged droughts, will accelerate over California and the Southwest U.S. through the mid-to-late 21st century (Huang and Swain 2022). These projections are supported by robust physical theories, observed climate trends, and model simulations, which increase confidence in the direction of these changes. However, there remains some uncertainty about the exact magnitude of these changes.

DYNAMIC CLIMATE CHANGE

Dynamic climate changes, in contrast, result from shifts in atmospheric circulation patterns which influence regional weather, including precipitation and temperature. While less predictable, these changes are equally consequential, with significant implications for water availability and management. For example, a 40-year decline (1980–2018) in the frequency of deep troughs over Western North America, which often support strong AR conditions in California, has been observed (Zhang et al. 2022). Additionally, changes in atmospheric circulation patterns could drive alternating extremes of dry and wet periods — often referred to as "weather whiplash" — increasing the frequency of both droughts and floods (Swain et al. 2018).

PUBLIC DRAFT

Dynamic changes are characterized by greater regional variability and higher uncertainty compared to thermodynamic changes. While their specific impacts are harder to predict, they have the potential to significantly reshape weather patterns and water systems across California.

Aridification in the Southwestern United States

Aridification, the long-term shift toward a relatively drier climate, is increasingly impacting California, particularly in its southern and inland regions. As global temperatures rise, higher evaporation rates, declining precipitation, and reductions in snowpack all exacerbate water scarcity. The Colorado River, a critical water source for Southern California, supports over 40 million people across seven U.S. states and parts of Mexico. California alone draws around 4.4 million acre-feet annually from the river, relying on it for both urban and agricultural needs. Colorado River water irrigates over 5 million acres of cropland and supports economic activity exceeding one trillion dollars annually. However, the river is in decline, with recent estimates indicating that its flow has decreased by about 20% since 2000, primarily due to climate change. This decline significantly threatens water availability for urban, environmental, and agricultural use. Aridification threatens to further reduce this supply, leaving Southern California vulnerable to severe water shortages and worsening drought conditions. As surface water deliveries shrink, water users in Southern California are increasingly turning to groundwater to fill the gap — placing additional stress on already pressured aquifers. A study by the U.S. Geological Survey predicts that by 2050, the flow of the Colorado River could drop by as much as 31% due to continued warming (U.S. Geological Survey 2020). This will severely impact agricultural production in the Imperial Valley, which produces 80% of the nation’s winter vegetables and relies heavily on Colorado River water. Urban areas will also be forced to implement more stringent water conservation measures and explore alternative water sources to mitigate the effects of aridification. This long-term drying of the landscape not only threatens surface water sources, such as rivers and reservoirs, but also puts significant pressure on the state's groundwater resources due to reduced recharge and increased pumping. With decreasing snowpack and diminished rainfall, California's reliance on groundwater is increasing. However, this critical resource is already under strain from over-extraction. As aridification continues to worsen, groundwater basins across California may struggle to recharge at sustainable rates, further deepening the state's water crisis and creating long-term challenges for both urban and agricultural communities.

PUBLIC DRAFT

Impact of Changing Precipitation Patterns and Increased Climatic Water Deficit on Natural Groundwater Recharge

Climate change, driven by shifting precipitation patterns and rising temperatures, is profoundly altering the processes that govern groundwater recharge in California. These changes reduce the amount of water available for infiltration, disrupt recharge timing and quantity, and threaten long-term groundwater sustainability. The combination of altered precipitation timing and intensity, increased evaporation, and reduced soil moisture capacity exacerbates water scarcity for both human and ecological systems.

CHANGING PRECIPITATION PATTERNS

California's precipitation patterns are becoming more variable, with an increase in extreme wet and dry periods. Wet seasons are shorter but more intense, characterized by bursts of heavy rainfall often associated with ARs. While these events can generate significant surface runoff, they are less effective at recharging groundwater due to the rapid flow of water through watersheds, bypassing infiltration pathways. Extended dry periods further reduce the overall availability of precipitation for groundwater recharge, compounding the problem.

These effects are particularly pronounced in snowpack-dominated regions, where snowmelt traditionally provides a gradual and sustained source of water for infiltration during spring and summer. Rising temperatures are causing more precipitation to fall as rain instead of snow, and earlier snowmelt reduces the steady input that aquifers rely on, leading to seasonal shortages. In arid and semi-arid regions, where precipitation is limited and evaporation rates are high, even small changes in precipitation patterns can drastically affect groundwater recharge.

INCREASED CLIMATIC WATER DEFICIT

Warmer temperatures are increasing evapotranspiration, leading to more water evaporating from soil and vegetation. This "climatic water deficit" reduces the amount of water available for percolation into aquifers. Prolonged droughts exacerbate this deficit, as vegetation extracts water from deeper soil layers, further depleting groundwater recharge potential.

Urbanization exacerbates the problem by replacing natural recharge zones with impervious surfaces like roads and buildings, which redirect precipitation as surface runoff instead of allowing it to infiltrate the ground. The loss of natural infiltration pathways further diminishes already limited opportunities for aquifer replenishment.

PUBLIC DRAFT

IMPACTS ON GROUNDWATER RECHARGE

The combination of reduced precipitation, increased evapotranspiration, and disrupted recharge timing is destabilizing the delicate balance between recharge and discharge in California's aquifers. Declining recharge rates are leading to falling water levels, increasing reliance on already stressed groundwater reserves. This reliance is particularly problematic in agricultural regions, where over-extraction exacerbates aquifer depletion, creating a vicious cycle of reduced natural replenishment and declining water availability.

Figure 1-5 shows simulation model results in terms of the percentage change in average annual climatic water deficit (CWD) and natural recharge simulated under three climate scenarios. Scenario 1 (Warm Plus) includes a 3°C temperature rise and a 21% increase in extreme precipitation intensity. Scenarios 2 (Warm Plus/Dry) and 3 (Warm Plus/ Wet) build on Scenario 1 by incorporating a 12.5% decrease and 12.5% increase in mean precipitation, respectively. Because CWD is driven both by warming temperatures and the capacity of soils to hold precipitation that would become runoff or recharge during the wet season, CWD rises in all three scenarios, with most of the state facing a 3–6% increase in the wetter (Warm Plus/Wet) scenario (Figure 1-5f), a 6-9% increase in the Warm Plus scenario (Figure 1-5d), and 9% to more than 12% increase in the drier (Warm Plus/Dry) scenario (Figure 1-5e). This suggests a high likelihood of elevated crop irrigation water requirements needed to satisfy seasonal deficits accumulated over the water year due to warming temperatures. In addition, relatively higher increases in CWD are seen over the North Coast and Sierra Nevada ranges, which translate to more frequent and persistent hydrologic stresses on natural vegetation, especially during years with below average precipitation.

PUBLIC DRAFT

Figure 1-5 Climate Change Impacts on Groundwater Recharge

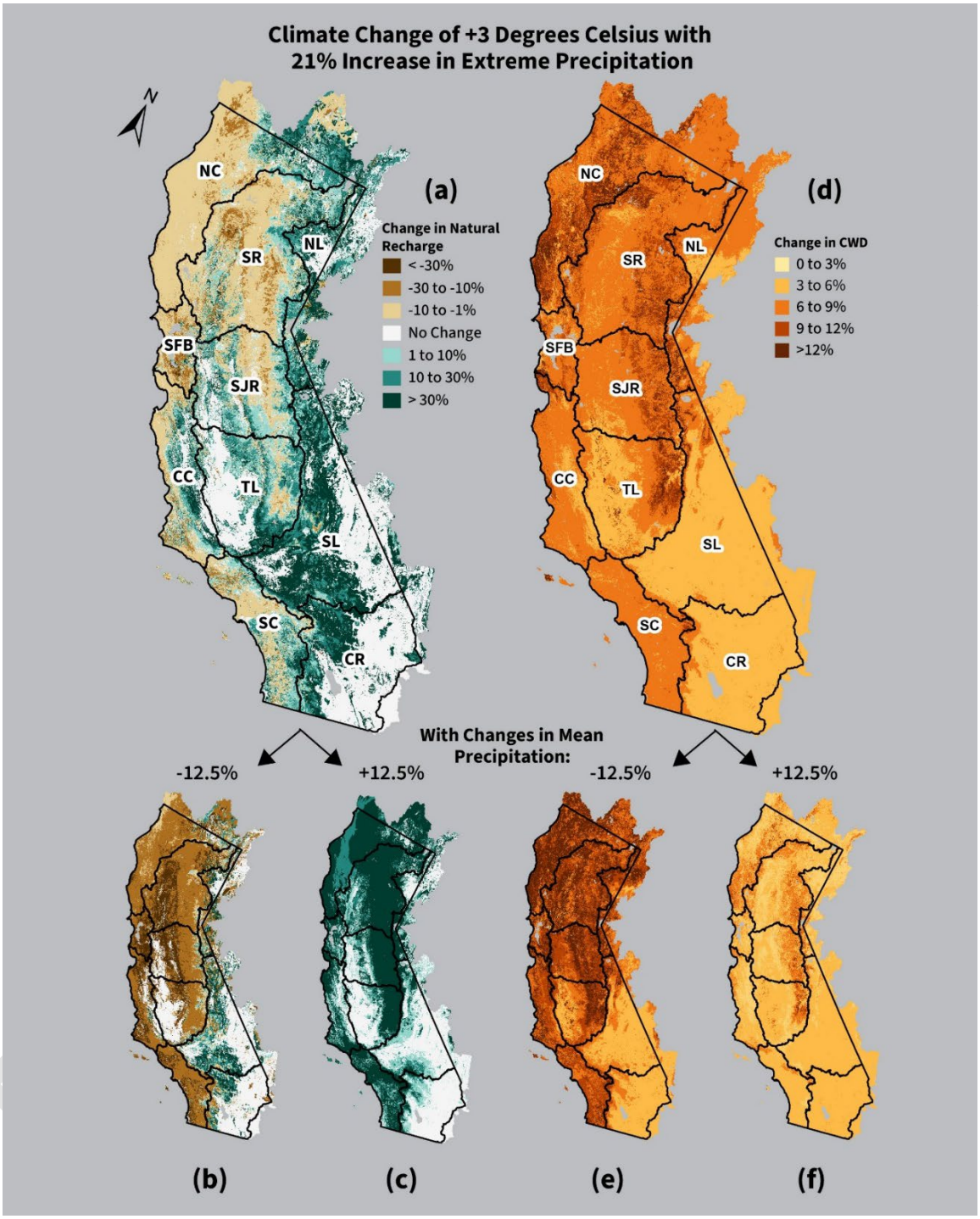


Figure 1-5 Notes: Visual representation of long-term changes in natural recharge (left) and climatic water deficit (CWD) (right) simulated by the Basin Characterization Model (BCM) under statewide weather generator climate change scenarios of +3 degrees Celsius and 21% increase in extreme precipitation intensity. The top row maps have no change in mean precipitation while the bottom row maps include a -12.5 and +12.5% change in mean precipitation.

In the Warm Plus scenario, as shown in Figure 1-5, natural recharge is reduced by 1–10% over much of the Sierra Nevada and coastal hydrologic regions. In the drier scenario (Figure 1-5b), a more than 10% reduction in natural recharge is seen throughout the Sierra Nevada and coastal hydrologic regions and a more than 30% reduction is evident in the foothills and valley floor of the Sacramento and San Joaquin hydrologic regions. On the other hand, natural recharge increases by more than 30% for the wetter scenario (Figure 1-5c), indicating the significant and dominant effect of changes in mean precipitation on recharge.

A hotter climate drives increased demand for water. When coupled with the intensification of extreme precipitation and amplification of winter storm runoff, this will place ever greater pressure on the state's water systems to provide a reliable water supply whilst managing flood risks and supporting environmental flows for healthy rivers and landscapes. Changes in mean precipitation will compound these challenges, leading to significant reductions in water supply or significantly increased flood risks. Thus, regardless of which of these three scenarios California's future climate is closer to, reliance on groundwater supply will intensify, underlining the need for actively managed aquifer replenishment in wet winters to ensure long-term groundwater sustainability.

Moreover, decreased recharge raises the risk of saltwater intrusion in coastal aquifers, threatening both water quality and quantity. These impacts vary by region:

- **Arid and Semi-Arid Regions:** These areas are especially vulnerable due to their limited precipitation and high evaporation rates, making them more prone to water scarcity.
- **Snowmelt-Dominated Regions:** Changes in snowfall patterns and earlier, faster snowmelt disrupts the steady input of water into aquifers, heightening the risk of seasonal shortages.

Chapter 7, *"Groundwater at a Glance: Hydrologic Region Summaries,"* explores the effects of these climate change scenarios for each hydrologic region in greater detail, including quantifying changes in the total amount and variability of surface water runoff.

Climate Change and Non-Basin Areas

In California, a non-basin area is defined as any region outside the 515 designated groundwater basins or subbasins. These areas typically include mountainous regions and other landscapes not underlain by large alluvial groundwater basins.

PUBLIC DRAFT

Non-basin areas are characterized by impermeable granitic, metamorphic, volcanic, or sedimentary rocks, where groundwater is stored in fractures or other void spaces. These regions include the Sierra Nevada, Cascades, Klamath Mountains, Modoc Plateau, and Coast Ranges. Approximately 60 percent of California is a non-basin area. The groundwater production in this area accounted for only approximately 1.3 million acre-feet in 2014, which is about 5.7% of the statewide total groundwater production.

Non-basin areas play a critical role in California's water system, serving as the source of snowpack, snowmelt, springs, and surface runoff that sustain major water projects like the State Water Project (SWP) and Central Valley Project (CVP). These areas also contribute groundwater to adjacent alluvial basins through Mountain System Recharge and support ecosystems like meadows that buffer streamflow fluctuations and promote water quality. However, as climate change intensifies, the unique hydrological dynamics and limited storage capacity of non-basin areas make them particularly vulnerable to extreme weather events and water management challenges.

Climate change is reshaping precipitation patterns, increasing temperatures, and narrowing California's annual snowpack cycle, which has profound implications for non-basin groundwater systems. Rising temperatures are causing more precipitation to fall as rain rather than snow, leading to reduced snowpack and earlier snowmelt. This not only limits groundwater recharge in fractured rock areas, where snowmelt infiltrates more effectively than rainfall, but also shortens the duration of water availability, with less water flowing during the critical summer months when demand is highest. Snowmelt, which historically accounted for about a third of the state's water supply, is projected to decline significantly — dropping to two-thirds of historical levels by 2050 and potentially as low as one-third by 2100. Earlier snowmelt also threatens reservoir management, as runoff occurs before reservoirs are ready to store it, increasing flood risks and leaving less water available during dry periods.

In addition to the impacts on water supply, wildfires fueled by a warming climate pose significant threats to non-basin groundwater systems. Wildfires can lead to hydrophobic soils, which reduce groundwater infiltration and increase surface runoff while degrading water quality through the erosion of sediments and the mobilization of harmful pollutants. Post-wildfire changes to vegetation and soil properties can alter the hydrological cycle, affecting both surface and groundwater flows. The escalating intensity and frequency of wildfires in California underscore

PUBLIC DRAFT

the need for proactive watershed restoration and fire resilience strategies to protect these critical non-basin areas.

Meadows in non-basin areas are critical components of California's natural groundwater infrastructure. These ecosystems act as sponges, storing water during spring runoff and gradually releasing it during the dry season, thereby supporting stream baseflows and downstream water quality during hot summer months. Functioning and healthy meadows are essential for building resilience against climate change impacts. Collaborative restoration efforts under the 30x30 State goal, which aims to conserve and restore 30% of California's lands and coastal waters by 2030, have made significant progress in enhancing meadow ecosystems. Between 2020 and 2022, 71 projects restored approximately 12,000 acres of meadows, with an additional 5,300 acres restored in 2023 through block grant funding. Notable projects, such as Osa Meadow, West Walker River, and Childs Meadow, demonstrate the effectiveness of meadow restoration in bolstering groundwater recharge and sustaining regional water supplies.

In addition to improving water recharge, restored meadows help regulate stream temperatures, reduce sediment loads, and enhance ecological health, all of which are vital for mitigating the impacts of climate change. These projects also support local and regional groundwater recharge to fractured rock non-basin areas and alluvial basins. By preserving natural infrastructure, such as meadows, California is better equipped to adapt to the challenges posed by rising temperatures, earlier snowmelt, and extreme weather events. Continued investment in meadow restoration, innovative techniques like process-based restoration, and collaborative partnerships are crucial for ensuring the resilience of non-basin areas and their contribution to the state's water system. Through these efforts, California is building a sustainable future where natural and managed water systems work together to address the mounting pressures of climate change.

Land Use Changes

The relationship between land use, water use, and climate change in California is complex, reflecting how land management practices contribute to climate change and are, in turn, shaped by its impacts. Intensifying climate stressors, such as severe droughts and wildfires, are driving significant shifts in land use across the state. Over the past decade, farmers have increasingly adapted their irrigation practices, shifting to high-value perennial crops like fruits and nuts which offer better economic returns than less profitable annual crops. While these changes

PUBLIC DRAFT

optimize economic returns, they alter the agricultural landscape and increase vulnerability to future climate challenges.

Over the long term, land use changes profoundly influence the exposure and sensitivity of surface water and groundwater systems to climate impacts. As surface water supplies become less reliable and crop water demands rise due to higher temperatures, the availability and protection of groundwater reserves during dry years are critical to avoiding significant agricultural economic losses (Medellín-Azuara et al. 2018).

Addressing these challenges necessitates integrating climate adaptation strategies, such as water-efficient irrigation and crop diversification, with sustainable land and water management practices. For instance, applying compost to rangelands can improve soil organic matter and water retention, simultaneously mitigating emissions and enhancing drought resilience (Silver et al. 2018). Policymakers and land managers must carefully balance urban development, agricultural demands, and conservation efforts to bolster resilience against the growing impacts of climate change.

1.5.2 Preparing for Climatic Extremes and Planning Toward Sustainable Water Management in a Changing Climate

DWR is conducting studies at multiple scales to better understand the interconnected dynamics of surface water and groundwater management under climate change. It is also evaluating how innovative water management strategies, such as Flood-MAR, can help adapt to intensifying climatic extremes. Flood-MAR involves diverting high flows to underground storage, offering a potential solution to address both water supply shortages and flood risks. The following sections summarize key findings from these studies.

To highlight the need for risk-based planning and adaptive management, the following sections synthesize recent technical analyses and modeling studies that examine the interconnected impacts of climate change on groundwater, surface water, and land systems. They include scenario-based evaluations of future water supply vulnerabilities, assessments of physical and social risks in rural communities, and integrated management strategies — such as Flood-MAR, Forecast-Informed Reservoir Operations, and conveyance modernization — designed to advance groundwater sustainability and multi-benefit water resilience. Advanced tools for climate planning and probabilistic weather simulation are also introduced to support more robust, risk-informed decision-making.

PUBLIC DRAFT

The Interconnected Nature of Water Resource Vulnerabilities to Climate Change

Groundwater, surface water, and land use in California are interdependent, forming a complex system where vulnerabilities in one element inevitably impact the others, particularly under the pressures of climate change. The following sections provide case studies and examples that demonstrate how this interdependence amplifies both challenges and opportunities in managing water resources sustainably.

WATER PLAN UPDATE 2023 FUTURE SCENARIOS

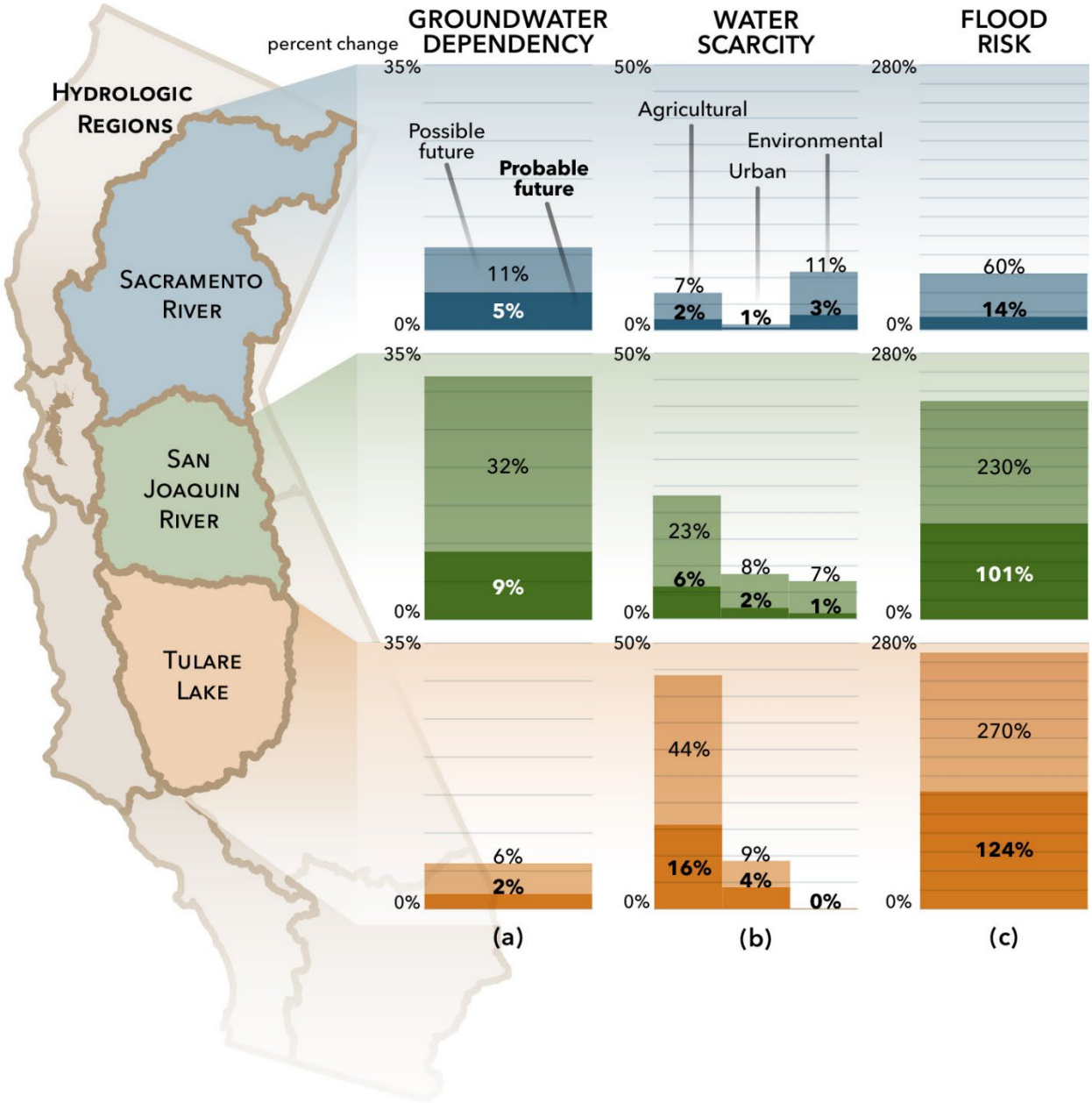
The future scenarios analysis for California Water Plan Update 2023 clearly demonstrates the interconnected nature of water resources vulnerabilities to climate change. Using the Water Evaluation Planning Model (WEAP), the analysis assessed the risks climate change poses to water supply through 2070 across three major hydrologic regions (HRs) — Sacramento River, San Joaquin River, and Tulare Lake.

Key findings, as shown in Figure 1-6 include:

1. **Groundwater Dependency:** A most probable (shown as the bottom darker portion of the bars) projected increase of 2–9% in groundwater dependency, with San Joaquin HR facing the largest increase of 9% (see Figure 1-6a). When climate uncertainties are included in the analysis, the possible increases (shown as the top lighter portion of the bars) in groundwater dependency could be as high as 11% in Sacramento HR, 32% in San Joaquin HR, and 6% in Tulare HR. If groundwater supplies become inaccessible or require conservation measures to avoid chronic depletions of aquifer storage, users may need to find new water supply sources or implement drastic water use reduction measures.
2. **Water Scarcity:** A most probable increase in unmet water demands of 2–16% in agriculture, 1–4% in urban, and 1–3% in the environment sector. Unmet water demands could be significantly higher under climate uncertainty, as shown in Figure 1-6b.
3. **Flood Risk:** A most probable increase of 14–124% in high flows at flood control points, with Tulare HR facing the largest probable increase of 124% (see Figure 1-6c). When climate uncertainties are included in the analysis, the possible increases in high flows could be as high as 60% in Sacramento HR, 230% in San Joaquin HR, and 270% in Tulare HR, respectively.

PUBLIC DRAFT

Figure 1-6 Future Scenarios of Groundwater Dependency, Water Scarcity, and Flood Risk (Water Plan Update 2023)



The future scenarios analysis shows that all three HRs are expected to face greater flood risks under climate change. Rising temperatures lead to earlier snowmelt and increased winter runoff, resulting to higher flows that strain flood control infrastructure. The San Joaquin River and Tulare Lake HRs are particularly vulnerable to these hydrologic shifts, highlighting the need for proactive flood management strategies.

These findings emphasize the interconnected impacts of groundwater dependency, water scarcity, and flood risks underscoring the necessity for a comprehensive multi-resource strategy. Such a strategy should adapt to the seasonality and variability of these impacts to ensure sustainable and resilient water management.

WATER SHORTAGE VULNERABILITY FOR RURAL COMMUNITIES

Under Senate Bill 552 (SB 552), enacted in September 2021, DWR is responsible for maintaining and updating a tool to assess the water shortage vulnerability of small water suppliers and rural communities, including frontline communities, across the state. In response, DWR developed the Water Shortage Vulnerability Scoring and Tool. This initiative is a critical step toward enhancing drought preparedness and ensuring reliable water supplies for these communities as they face increasing risks from climate change and resource constraints.

DWR's Water Shortage Vulnerability Scoring and Tool evaluates water shortage vulnerabilities through two key dimensions. First, physical vulnerability refers to the susceptibility of physical systems to damage or failure when exposed to hazards and is assessed by examining factors such as existing infrastructure conditions, historical water shortages, and exposure to climate change risks (Figure 1-7). Second, social vulnerability refers to the susceptibility of a population to harm based on demographic and socioeconomic characteristics, such as income levels, community resources, and access to infrastructure, which affect a community's ability to respond to and recover from water shortages (Figure 1-8). The tool allows users to explore these vulnerabilities at a fine spatial resolution. This resource is primarily intended to empower counties and water managers to make informed decisions by visualizing physical and social vulnerabilities and their intersections.

Currently, many small water systems and domestic wells are identified as having both high physical and social vulnerability to water shortages. These vulnerabilities are expected to worsen as climate change alters surface water and groundwater conditions, further increasing the risk of water shortages. By integrating scenarios of climate-driven changes with vulnerabilities identified in the tool, communities can better anticipate and prepare for potential impacts on their water supplies.

By proactively assessing and addressing water shortage vulnerabilities, California is taking significant steps to build more resilient water systems capable of withstanding the impacts of climate change. These efforts ensure that small water suppliers and rural communities have the resources and strategies needed to secure reliable water supplies for the future.

PUBLIC DRAFT

Figure 1-7 Areas of Physical Water Shortage Vulnerabilities with Small Water Systems and Domestic Wells

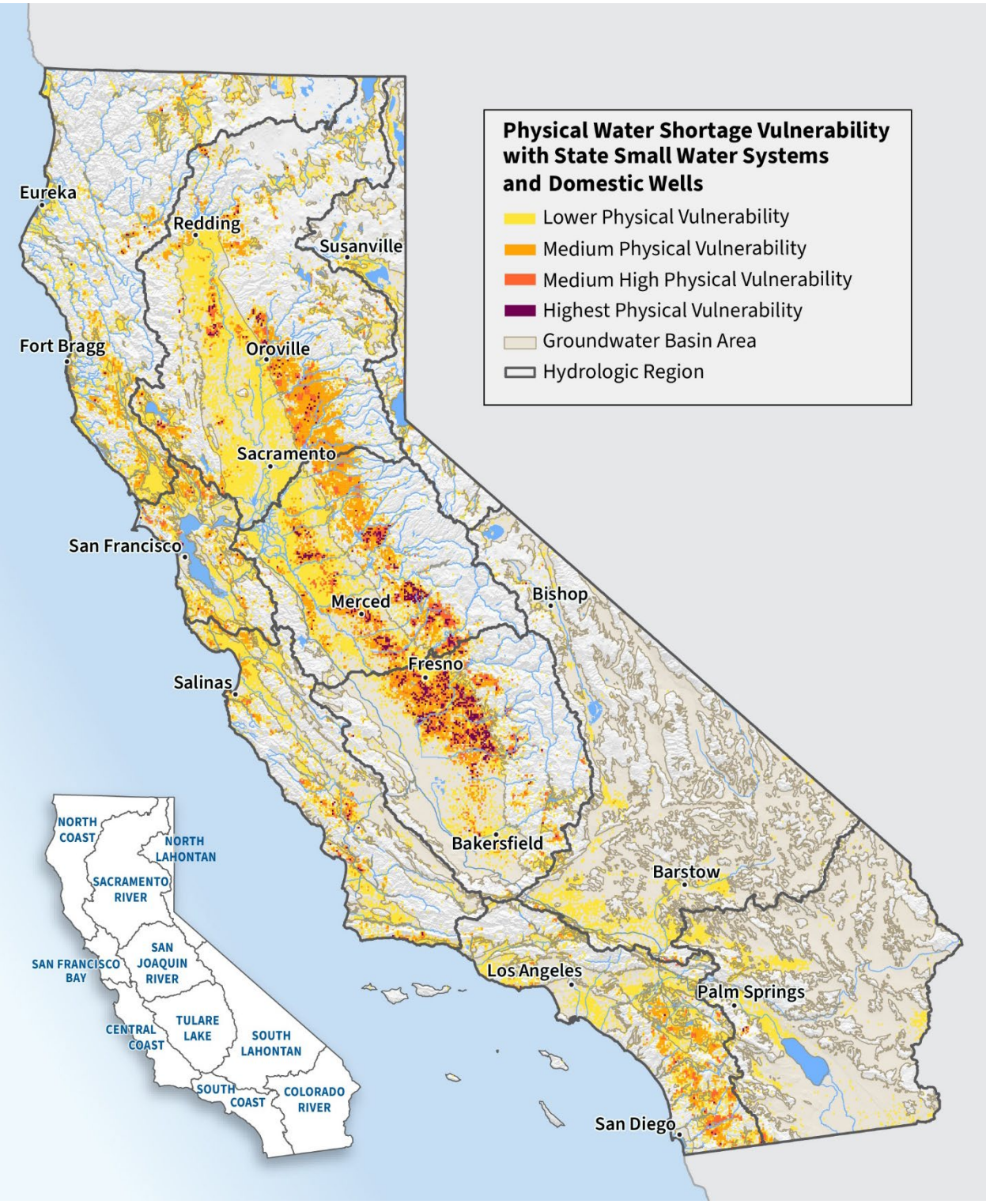
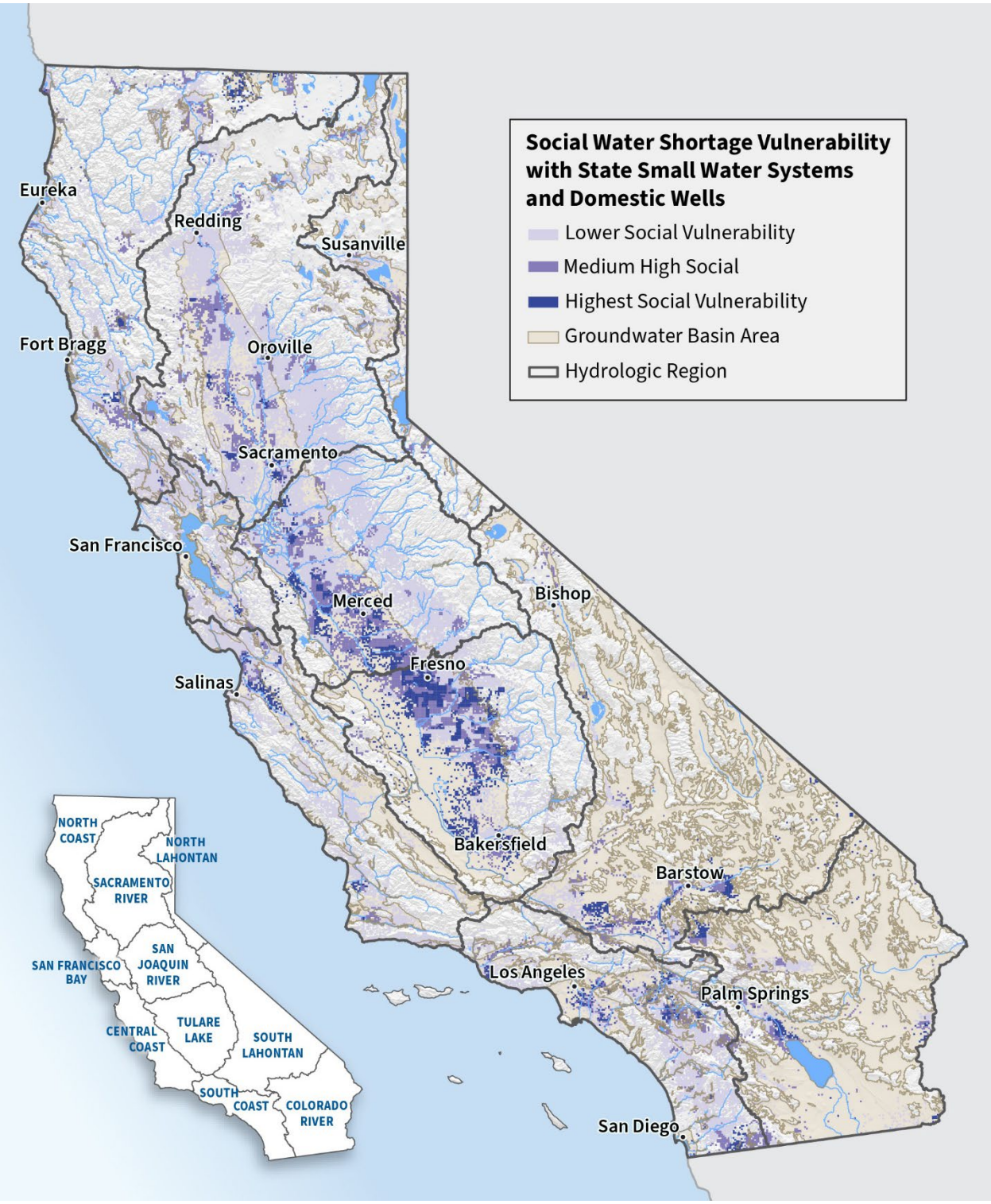


Figure 1-8 Areas of Social Water Shortage Vulnerabilities with Small Water Systems and Domestic Wells



Embracing Watershed-Scale Integrated Strategies and Modernizing the State's Backbone Infrastructure

California's escalating water management challenges necessitate a shift toward integrated, watershed-scale solutions that tackle the interconnected issues of elevated flood risk, reduced and increasingly variable surface water supply, and over-reliance on overdrafted groundwater basins, resulting in land subsidence and damage to critical water supply infrastructure, and the deterioration of ecosystems. Nowhere are these challenges more pronounced than in the San Joaquin Valley, a region at the forefront of the state's water crisis. The DWR studies highlighted below underscore the impacts of climate change and the urgent need for innovative, integrated approaches to achieve groundwater sustainability and ensure long-term water resilience and security.

One such approach is the advancement of Forecast-Informed Reservoir Operations (FIRO), which leverages improved weather and streamflow forecasting to better manage reservoir releases. By optimizing the timing and volume of water stored or released, FIRO increases opportunities for groundwater recharge while enhancing flood protection — making it a key tool in integrated, climate-smart water management strategies. When combined with managed aquifer recharge in a strategy known as FIRO-MAR this approach exemplifies how California can turn climate risk into resilience. The study presented below illustrates how these innovations are being applied on the ground to deliver multiple benefits across flood, groundwater, and ecosystem systems.

MERCED RIVER WATERSHED FLOOD-MAR RECONNAISSANCE STUDY

The Merced River Watershed Flood-MAR Reconnaissance Study, focusing on one of the key tributaries to the San Joaquin River, offers a pivotal case study in how innovative strategies like Flood-MAR can transform water management (California Department of Water Resources 2024b).

Figure 1-9 illustrates the impacts of climate change on the Merced River Watershed and highlights the potential benefits of Flood-MAR adaptation strategies. It depicts results for an advanced Flood-MAR strategy which combines managed aquifer recharge (MAR) with Forecast-Informed Reservoir Operations (FIRO) — i.e., "FIRO-MAR." Each plot (Figure 1-9a through 1-9e) displays 100 years of simulated watershed conditions, reservoir operations, and groundwater dynamics, ordered by total runoff along the x-axis, from the wettest to driest water years. Figure 1-9a shows the percent exceedance (i.e., the likelihood of flow equal to or greater than) of total water year runoff with a 2070 climate scenario superimposed over the current climate scenario. Wetter years present greater

PUBLIC DRAFT

flood risks, while drier years heighten drought risks. Although Figure 1-9a indicates an overall increase in runoff under the 2070 climate scenario, Figure 1-9b highlights a seasonal shift: higher fall and winter flows and reduced spring and summer flows. This seasonal shift in hydrology places greater pressure on Lake McClure, the watershed's major reservoir, which must manage increased flood risks during winter storms while facing reduced water availability for irrigation during the growing season of spring and summer.

At the same time, these changes present an opportunity for Flood-MAR to mitigate these risks. Figure 1-9c indicates that under the 2070 climate scenario, the Flood-MAR actions show a potential aquifer recharge of over 250,000 acre-feet in about 10% of the years and over 50,000 acre-feet in about 50% of the years of the 100-year study period. By diverting the high flows to aquifer storage, Figure 1-9d shows how the peak flow in the Merced River is reduced by as much as 50% in some years, helping to reduce the flood risk vulnerability to climate change.

Under the 2070 climate scenario, declining spring and summer runoff, combined with chronically reduced reservoir storage, decreases surface water availability for irrigators. This decrease leads to increased groundwater pumping to compensate for the lack of surface water, particularly in a warmer climate with higher agricultural water demands. Figure 1-9e shows how under the 2070 climate scenario, groundwater storage increased significantly in wetter years with Flood-MAR FIRO-MAR, reducing the long-term chronic depletion of groundwater storage.

In summary, Figure 1-9 shows how an advanced Flood-MAR strategy that integrates aquifer recharge with forecast-informed reservoir operations could mitigate flood and drought risks in the Merced River Watershed under climate change. This strategy, which integrates hydrology, reservoir management, and groundwater recharge, highlights the potential to create a more resilient water system through innovative, multi-benefit approaches.

While initial Flood-MAR actions are often temporary and conducted on a smaller scale, they serve as a first step in planning, designing, and implementing larger, watershed-scale solutions. DWR supports these efforts by providing technical assistance, collaborating with local agencies, and working with the State Water Board and California Department of Fish and Wildlife to streamline permitting processes. These partnerships and actions aim to overcome barriers and demonstrate the effectiveness of Flood-MAR strategies and evaluate recharge-related adaptation strategies in other tributary watersheds of the San Joaquin River — including the Calaveras, Stanislaus, Tuolumne, and Upper San Joaquin.

PUBLIC DRAFT

Figure 1-9 (a-e) Climate-Driven Flood and Drought Risk Mitigation with Flood-MAR in the Merced River Watershed

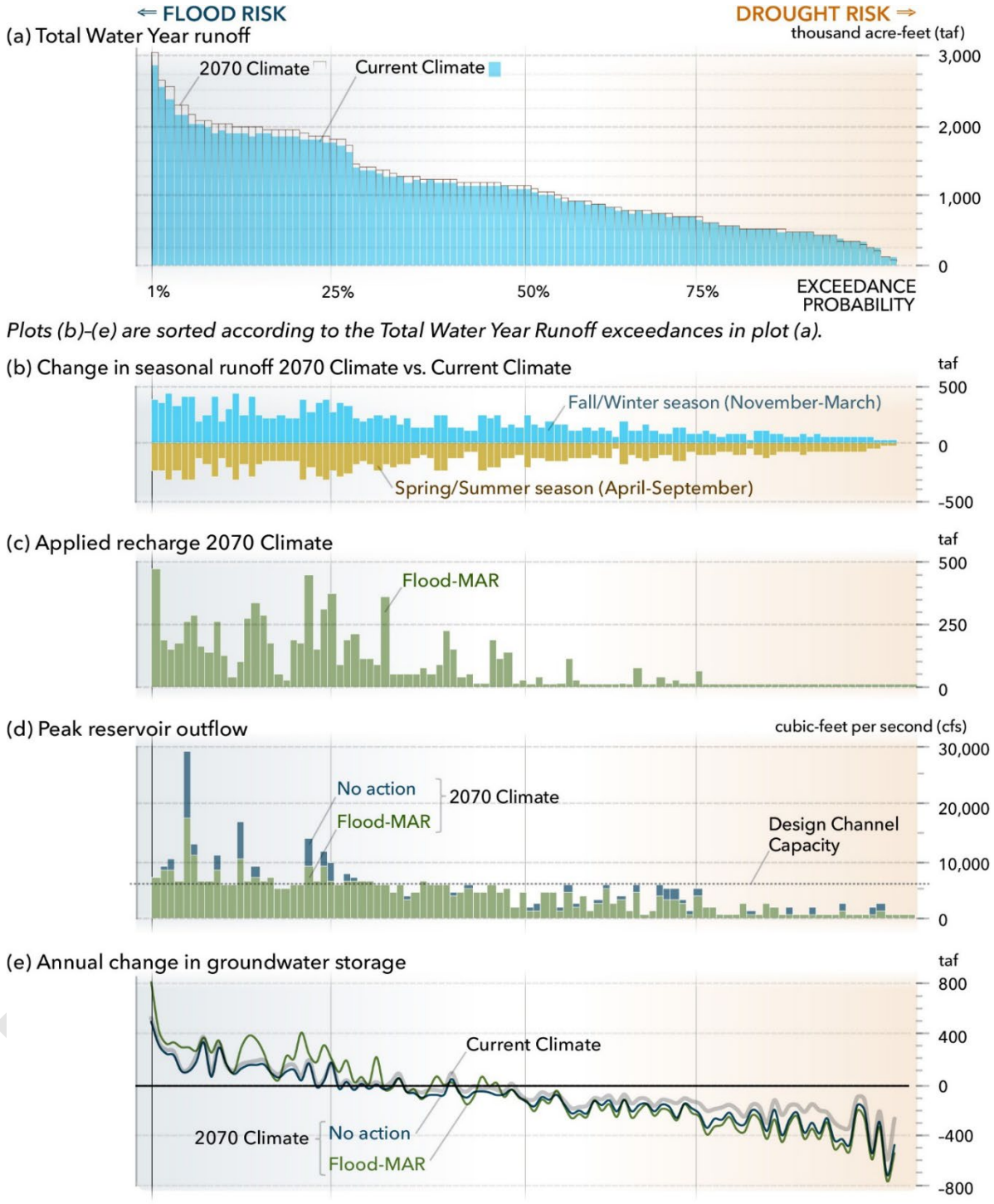


Figure 1-9 Note: FIRO-MAR is an advanced Flood-MAR strategy which combines managed aquifer recharge (MAR) with forecast-informed reservoir operations (FIRO).

STATE WATER PROJECT ADAPTATION TO CLIMATE CHANGE

The State Water Project (SWP) is a cornerstone of California's water system, providing critical support for local and regional water supplies. It plays a vital role in sustaining a prosperous agricultural economy by delivering reliable water supplies and reducing reliance on already strained groundwater resources. As a key component of California's backbone infrastructure — defined as human-constructed infrastructure that provides water management benefits to communities, ecosystems, and economies across regional and watershed boundaries — the SWP enables large-scale water conveyance, storage, and delivery throughout the state. Failure to protect and adapt the SWP to future climate change challenges would threaten California's overall water supply, economic stability, and progress toward sustainable groundwater management.

Climate change is expected to reduce the reliability of water supply and delivery for both the SWP and the Central Valley Project (CVP), which collectively support millions of residents and farming communities. Rising air and water temperatures, altered hydrology in upper watersheds, and higher sea levels leading to increased seawater and brackish water intrusion into the Delta will degrade water quality, heighten risks of operational interruptions, and reduce the flexibility of SWP operations. Additionally, climate change is projected to intensify short-duration, high-intensity winter rainstorms, creating brief periods of high flows in the Delta.

STATE WATER PROJECT ADAPTATION STRATEGY

In recognition of this critical State asset, and the growing threats posed by climate change, including drought, land subsidence, and sea level rise, DWR developed a dedicated SWP Adaptation Strategy (2025) as part of its *Climate Action Plan — Phase III*. The strategy outlines a forward-looking framework to modernize the SWP and safeguard its ability to sustain water deliveries, while meeting water quality and ecosystem protection objectives.

The *SWP Adaptation Strategy* identifies and evaluates 17 adaptation strategies organized into three categories:

- Structural strategies (e.g., Delta Conveyance Project, California Aqueduct Subsidence Remediation, and increased South of Delta Storage).
- Operational and management strategies (e.g., Forecast-Informed Reservoir Operations, enhanced asset management, and improved forecasting and modeling).
- Nature-based solutions (e.g., environmental restoration, Delta island land management, and Feather River watershed management).

PUBLIC DRAFT

Among the 17 strategies, five strategies have been identified as being the most promising, and are within the SWP's authority to implement, but require consistent and sustained commitment to develop and implement. These five strategies have been organized into four adaptation portfolios and have been compared to a run-to-failure/minimal investment future and a baseline future in which only maintenance is completed, and no adaptation investments are made. Multiple climate and sea level rise scenarios were explored to evaluate the benefits of these investments at two future timeframes, 2043 and 2085.

One of the most urgent climate-related vulnerabilities identified in the SWP Adaptation Strategy is continued land subsidence in the San Joaquin Valley, which has already reduced the carrying capacity of the California Aqueduct. This constraint limits the SWP's ability to deliver surface water south of the Delta, particularly for groundwater recharge and drought resilience. Restoring this lost conveyance capacity is foundational; no other adaptation strategy can succeed without first stabilizing and repairing this critical infrastructure.

The analysis also makes clear that the most effective and resilient outcomes will not come from implementing isolated strategies. Rather, integrated portfolios that combine structural upgrades, such as the Delta Conveyance Project (DCP) and subsidence fixes, with operational reforms and nature-based solutions consistently outperformed standalone approaches across a wide range of modeled climate futures. In particular, DCP emerged as the most impactful individual investment, and its inclusion significantly amplifies the benefits of other strategies — by improving conveyance reliability, enabling capture of high-flow events, and increasing operational flexibility systemwide.

The *SWP Adaptation Strategy* supports and aligns with statewide goals articulated in *California Water Plan Update 2023*, the *California's Water Supply Strategy* and *Delta Adapts*. As a key component of California's backbone infrastructure, the SWP must evolve to meet the challenges of a hotter, drier, and more volatile climate. By implementing this strategy, DWR advances a resilient approach to water management that strengthens groundwater sustainability, protects vulnerable communities, and ensures the continued function of this vital system well into the future.

SAN JOAQUIN CONVEYANCE STUDY

The San Joaquin Valley Conveyance Study, conducted by DWR, is a forward-looking initiative aimed at addressing the region's critical water management challenges by modernizing its water conveyance infrastructure. The San Joaquin

PUBLIC DRAFT

Valley, a vital contributor to California's agricultural economy, heavily depends on groundwater to meet its substantial water demands. However, many of the valley's groundwater basins are critically overdrafted, posing serious threats to long-term water sustainability.

The study evaluates the ability of existing conveyance systems to transport and store water and explores potential improvements to enhance water delivery under changing hydrological conditions. By improving surface water conveyance, the study aims to reduce reliance on groundwater, thereby supporting sustainable water management practices, and ensuring that water delivery systems effectively meet the agricultural, urban, and ecological needs of the region amidst climate change.

The study plays a pivotal role in California's broader climate adaptation efforts by identifying strategies to mitigate flood risks, enhance water supply reliability, and promote groundwater sustainability. Its findings guide the development of integrated water management solutions that balance the competing demands of various sectors while safeguarding environmental resources. This effort helps the San Joaquin Valley build resilience to the escalating impacts of climate change and aligns with the State's long-term vision for sustainable and adaptive water systems.

Data and Resources Provided by DWR for Climate Change Planning

DWR plays a critical role in equipping water managers, local agencies, and policymakers with the tools and data necessary to plan for climate change impacts. By leveraging cutting-edge technology, comprehensive datasets, and advanced modeling frameworks, DWR provides actionable insights to support sustainable water management. Through its commitment to data-driven decision-making, DWR prepares California to meet its water resilience goals in the face of evolving climate challenges.

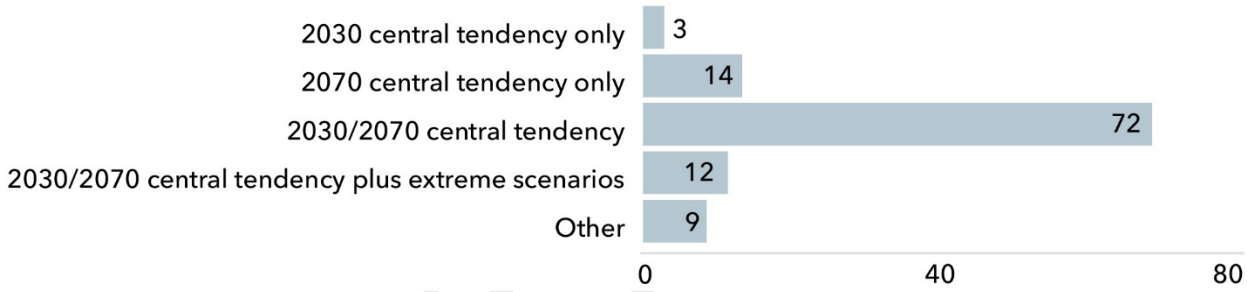
CLIMATE CHANGE DATA IN GROUNDWATER SUSTAINABILITY PLANNING

Simulations of the Earth's climate using GCMs remain an invaluable tool for anticipating future climate changes. However, the volume and complexity of hundreds of available GCM simulations pose significant challenges for users and decision-makers. To address this, DWR developed a streamlined subset of GCM-driven scenarios that include climatological, hydrological, and water system operations data. These scenarios are specifically tailored to assist GSAs in developing GSPs (California Department of Water Resources 2018).

PUBLIC DRAFT

GSAs have utilized these datasets to evaluate the resiliency of groundwater basins under projected climate change. Figure 1-10 illustrates a high-level survey of how these data were applied in preparing GSP water budget components. Most plans relied on DWR's central tendency dataset for both the 2030 and 2070 horizons (72 plans), while a smaller number focused exclusively on either the shorter-term 2030 horizon (three plans) or the longer-term 2070 horizon (14 plans). Additionally, 12 plans incorporated the more extreme climate scenarios. In general, while the climate change data proved valuable for understanding how water budgets and groundwater storage respond to different climate conditions, this information was not commonly used as the basis for assessing specific projects or management actions.

Figure 1-10 Survey and Examples of Climate Change Data Use in Groundwater Sustainability Planning, by Number of GSPs



THE NEXT GENERATION OF DATA FOR CLIMATE-RISK BASED PLANNING IN CALIFORNIA: STOCHASTIC WEATHER GENERATOR

The thermodynamic and dynamic forces of climate change — some projected to occur with greater confidence than others — present significant challenges for surface and groundwater resource managers. Ensuring safe, sustainable, and reliable water services over the next several decades requires addressing these complex changes. While downscaled climate scenarios from GCMs have traditionally been the preferred planning tools, GCM simulations — by design — contain a mixture of thermodynamic and dynamic changes. For water resource planners, separating these changes is crucial, as signals of change driven by thermodynamic mechanisms are more consistently detectable than dynamic changes that have lower scientific consensus and are harder to distinguish from natural variability.

To address this challenge, DWR, in partnership with researchers at Cornell University, developed a Stochastic Weather Generator (WGEN) (Najibi and Steinschneider 2023). This innovative tool, which covers the entire state, enables systematic and rigorous exploration of both thermodynamic and dynamic climate

PUBLIC DRAFT

change. The WGEN is a vital component for bottom-up climate change vulnerability assessments. When used alongside GCM-based climate data, the WGEN supports climate risk-based planning for California's surface and groundwater systems. The tool generates long-term sequences of daily weather data that are statistically rooted in California's historical observations but project a range of possible weather conditions.

The WGEN is particularly valuable because it allows exploration of a wide array of potential future weather scenarios, including combinations of extreme events such as floods and droughts that may not have been observed historically but are statically plausible. This capability enables water managers to prepare not only for typical weather patterns but also rarer, more extreme events, while also quantifying the robustness of adaptation strategies under climate change uncertainty. A suite of WGEN climate change scenarios and 1,000-year-long stochastic weather time series have already been generated for the state and are accessible via CNRA Open Data website. This resource provides a robust foundation for advancing climate-resilient water management in California.

1.5.3 State Efforts at Building Resilience and Sustainability

California is at the forefront of addressing climate change and extreme weather and ensuring water security through a multifaceted approach. The State's initiatives combine overarching strategies, legislative frameworks, planning documents, targeted programs, and investments in infrastructure to enhance resilience and sustainability. Below is an exploration of California's approach. For a more comprehensive inventory of the State's climate resilience efforts refer to Chapter 4 of the California Water Plan Update 2023.

State Adaptation Strategy: Building Climate Resilience

The *California Climate Adaptation Strategy* is a comprehensive policy framework that coordinates and integrates the State's efforts to address climate change impacts. It serves as a high-level guiding document that integrates the State's current and planned climate adaptation efforts. While it primarily focuses on broader climate adaptation strategies, it acknowledges the critical role of groundwater management in enhancing resilience to climate change, and aligns groundwater management efforts with six key climate resilience priorities:

1. **Strengthen Protections for Climate-Vulnerable Communities —** Ensuring equity in addressing the disproportionate impacts of climate change on vulnerable populations.

PUBLIC DRAFT

2. **Bolster Public Health and Safety to Protect Against Increasing Climate Risks —** Preparing for and mitigating health impacts from climate-induced risks such as extreme heat and wildfires.
3. **Build a Climate-Resilient Economy —** Supporting economic adaptation strategies to sustain livelihoods and businesses amid climate disruptions.
4. **Accelerate Nature-Based Climate Solutions and Strengthen the Resilience of Natural Systems —** Promoting ecosystem restoration and conservation as vital tools for climate adaptation.
5. **Make Decisions Based on the Best Available Climate Science —** Leveraging cutting-edge research and data to inform State policies and initiatives.
6. **Partner and Collaborate to Leverage Resources —** Engaging partners across sectors and levels of government to amplify the impact of adaptation efforts.

These strategies underscore California's holistic approach to addressing the challenges posed by a changing climate, with a strong emphasis on collaboration and science-driven solutions.

California's Fourth and Fifth Climate Change Assessments

The State's Climate Change Assessments deliver vital information to enhance resilience to climate impacts, including temperature increases, wildfire threats, water scarcity, sea level rise, and governance challenges. The Fourth Assessment, released in 2018, incorporated 33 State-funded research projects, contributions from 11 externally funded researchers, and the development of detailed climate projections tailored to California.

The forthcoming Fifth Assessment, expected in 2025, builds on this foundation with updated climate data and scenarios based on the latest global climate models from the Coupled Model Intercomparison Project Phase 6. This assessment will include a series of regional, topical, and statewide synthesis reports. Importantly, it will emphasize equity by translating advanced research into actionable strategies tailored to the diverse needs and contexts of California's regions, ensuring that all communities benefit from the State's resilience-building efforts.

Water Resilience Portfolio

The Water Resilience Portfolio, finalized by the Newsom administration in 2020, outlines a blueprint for helping California adapt to increasingly extreme droughts,

PUBLIC DRAFT

floods, and rising temperatures. It identifies four broad approaches essential for preparing the state's water systems and ensuring sustainable groundwater management in a warmer, more variable climate. DWR plays a key role in advancing the implementation of these approaches, in coordination with other State, federal, and local agencies. Groundwater-related actions that support this implementation are discussed throughout CalGW Update 2025.

- **Maintain and Diversify Water Supplies:** Diversification of water supplies enhances water system flexibility to manage degrading reliability and increased variability of surface water imports and local runoff. The portfolio of diversified supply will differ region to region, but strategies such as recycled water treatment, more efficient water use, increased capture of stormwater runoff, desalination, and bringing overdrawn groundwater basins into sustainable conditions, can all provide a crucial buffer to cope with drought and climate change.
- **Protect and Enhance Natural Systems:** Climate change poses serious threats to the health of natural ecosystems. Warmer air and water temperatures place greater stress on aquatic and terrestrial species, as well as on the vegetation that is their habitat. More dynamic integration of environmental protection and enhancement into water management is needed, but it requires investment in the assessment of ecosystem needs and ecological flows. Green infrastructure, including wetlands, upper watersheds, soils, and floodplains, is crucial for reliable functioning of water systems in the face of climate change. Broad-benefit water management projects can sustain the state's biodiversity and serve important water system benefits including groundwater recharge, water filtration, and flood peak attenuation. DWR is working to improve the condition of natural ecosystems by implementing the *Central Valley Flood Protection Plan Conservation Strategy*, which includes a comprehensive and science-based approach to vegetation management, improvements to habitats and benefits for fish and wildlife, and clear ecological targets with measurable objectives.
- **Build Connections:** Climate change effects are felt most acutely by the most vulnerable communities in the state and by the most vulnerable aspects of water systems. Building on integrated regional water management and other regional efforts to conduct watershed-based vulnerability assessments and adaptation plans can help prioritize actions and investments that increase community-wide resilience to climate change. Modernization and increasing the capacity of the state's inter-regional conveyance systems builds redundancy, reliability, and transferability of water supplies in a highly variable climate. Coordination, networking, and

PUBLIC DRAFT

interested party engagement are critical to enhancing the value and application of the best available climate science, which water managers and decision-makers can leverage to better manage water supplies and flood risk. The sharing of information, ideas, and potential solutions, and bringing together local water managers and users with experts in climate science and infrastructure, will increase the ability to respond to the challenges facing California in the coming decades.

- **Be Prepared:** As climate change intensifies California's weather patterns, greater preparation for the years of "too much" and "too little" is of paramount importance. At the core of preparing for climate change is supporting regional decision making with watershed-based climate vulnerability and adaptation assessments. Risk-based planning that considers the full range of projected conditions sheds light on opportunities for improving the performance of water systems and identifies which strategies are robust to multiple potential futures. Enhanced monitoring of weather and watershed conditions can help water managers adjust and cope with changing conditions in real time. Groundwater monitoring and data management systems help groundwater managers to better characterize groundwater basins and adapt groundwater management plans to changing conditions over the long term. DWR has and will continue to contribute to the development, sharing, and broader implementation of innovative approaches in evaluating climate change vulnerabilities and adaptation strategies for California water systems by creating scientific and engineering product(s) for watershed-based vulnerability and adaptation analysis.

Water Supply Strategy – Adapting to a Hotter Drier Future

The California's Water Supply Strategy, unveiled in 2022, outlines a comprehensive approach to adapt to the state's increasing water scarcity caused by intensifying impacts of climate change. With projections indicating a 10% reduction in California's overall water supply by 2040 due to climate change, the strategy sets ambitious targets to bolster water resilience.

At the heart of *California's Water Supply Strategy* is the goal to increase water storage capacity by 4 million acre-feet (maf) by 2040. This effort includes boosting annual groundwater recharge by 500,000 acre-feet, a critical step to address long-standing groundwater depletion and improve resilience to drought. The strategy recognizes the essential role of groundwater as a buffer against dry periods and emphasizes managed aquifer recharge (MAR) initiatives that utilize stormwater and flood flows to replenish depleted aquifers. These efforts are pivotal for

PUBLIC DRAFT

achieving long-term water sustainability, particularly in regions heavily reliant on groundwater for agricultural, municipal, and environmental needs.

To complement these groundwater initiatives, the strategy sets a target to conserve 500,000 acre-feet of water annually through urban and agricultural efficiency improvements. This includes promoting advanced irrigation technologies, leak detection systems, and water-efficient appliances across California as well as public education and financial incentives.

Recognizing the need to diversify water sources, the State aims to expand recycled water use to 800,000 acre-feet annually by investing in cutting-edge treatment facilities and direct potable reuse systems. Recycled water initiatives are crucial for sustaining urban growth while protecting natural ecosystems.

The strategy also prioritizes stormwater capture, targeting an increase of 250,000 acre-feet annually through urban infrastructure upgrades. Enhanced stormwater systems, such as green roofs, permeable pavements, and retention basins, will capture runoff to replenish local supplies and reduce urban flooding risks. Additionally, the State is advancing desalination projects to add 84,000 acre-feet of water annually through seawater and brackish water (including groundwater) desalination technologies, particularly in coastal and arid regions.

In total, *California's Water Supply Strategy* outlines a bold, integrated approach to adapt to the challenges of increasing variability and intensity in precipitation and temperature due to climate change. By expanding storage, enhancing conservation, promoting recycling, and leveraging innovative technologies, the State aims to secure a resilient and reliable water future that meets the needs of its communities, economy, and environment.

Watershed Resilience Program

The California Water Plan Update 2023 underscores the importance of better preparation and planning for increasing climate extremes through watershed-based solutions, climate resilience, and equity. Responding effectively to climate change demands enhanced collaboration across sectors, including water supply, flood management, groundwater management, forest conservation, ecosystem preservation, and land use planning. A comprehensive systems approach is essential for understanding and managing climate impacts at the regional watershed level, integrating upper and lower watersheds, groundwater aquifers, and receiving water outlets. Building on the vision and framework described in the

PUBLIC DRAFT

California Water Plan Update 2023, the Watershed Resilience Program is providing financial and technical support to five pilot program recipients across the state to:

1. Holistically manage headwaters to groundwater to outflow, at a watershed scale.
2. Integrate and prioritize equity and inclusiveness.
3. Analyze climate change vulnerabilities and adaptations.
4. Collaborate across water supply, flood, groundwater, water quality, forest/fire, ecosystem, and land use sectors.
5. Develop performance indicators and metrics to monitor outcomes.

To support the Program, DWR envisions the creation of local watershed networks grounded in inclusive governance, collaborative decision-making, cutting-edge climate science, and strategic planning at appropriate watershed scales. These networks will rely on strengthening and enhancing coordination between existing programs and partnerships, such as Integrated Regional Water Management (IRWM) groups and GSAs, to achieve effective watershed resilience planning.

The IRWM approach, developed and refined over the past two decades, has established a strong foundation for the type of watershed networks the Watershed Resilience Program aims to build. However, meeting the increasingly complex climate challenges impacting our watersheds requires the active involvement of GSAs. As primary stewards of groundwater resources, GSAs offer essential expertise and established governance structures that can shape watershed boundaries, identify pressing challenges, and ensure that sustainable water management practices are woven into comprehensive resilience strategies.

Flood-MAR Resource Management Strategy

Flood-MAR is a resource management strategy that offers a transformative approach to California's water challenges by capturing floodwater during high-flow events and redirecting it to agricultural lands, open spaces, recharge basins, or managed natural lands. This innovative strategy can reduce flood risks while promoting groundwater recharge and is an important multi-benefit strategy statewide, but particularly in the Central Valley — where flood risk is high and groundwater depletion is a critical concern. A summary from Flood-MAR activities in flood-MAR Hub notes that the San Joaquin Valley’s long-term groundwater deficit is nearly 2 million acre-feet per year — a gap that managed aquifer recharge efforts could help close. Pilot projects in Fresno and Madera Counties have showcased Flood-MAR's effectiveness, demonstrating how agricultural fields

PUBLIC DRAFT

can serve as temporary water detention and infiltration zones, replenishing aquifers while reducing flood damage.

Flood-MAR projects can also create inundated floodplain and seasonal wetland habitats, providing vital breeding and feeding grounds for fish and wildlife, including endangered species. DWR has investigated multi-benefit floodplain restoration opportunities in several watersheds in the state. The Dos Rios restoration project, led by River Partners and located at the confluence of the Tuolumne and the San Joaquin rivers, is an excellent example of a multi-benefit Flood-MAR project. This restoration project provides habitat for several protected species, reduces flood risk, replenishes groundwater, and provides recreational opportunities as California's newest state park.

Flood-MAR aligns with California's water management goals identified in the *Water Resilience Portfolio*, offering multiple benefits such as improved water supply reliability, enhanced ecosystems, reduced flood risks, and enhanced climate resilience. As climate change intensifies hydrological extremes, Flood-MAR represents a scalable and adaptive solution to secure water resources while restoring inundated habitat.

Flood Diversion and Recharge Enhancement (FDRE) projects are an example of a Flood-MAR project type that leverages existing facilities, such as canals and agricultural fields, to divert and infiltrate floodwater into groundwater basins. DWR launched FDRE projects in April 2023 in response to ongoing flooding to help maximize flood diversions and reduce flood risk with the incidental benefit of groundwater recharge. This effort continues to provide local agencies with support to rent or purchase temporary pumps, design and purchase protective screens, conduct land clearing, develop temporary flood basins, and provide temporary conveyance to increase the implementation of Flood-MAR strategy.

A prime example of FDRE success is the 2023 pilot project in Tulare County, which recharged approximately 11,160 acre-feet of water into local aquifers. This initiative demonstrated the potential of using agricultural lands and irrigation networks as temporary floodwater catchment areas. Beyond replenishing groundwater, the project reduced flood damage in vulnerable areas, highlighting the value of FDRE as a flood risk reduction and climate adaptation strategy. The pilot also provided insights into optimizing infrastructure and regulatory processes to scale up such efforts across the state.

PUBLIC DRAFT

By integrating flood and groundwater management, Flood-MAR and FDRE projects contribute to California's long-term resilience against both drought and extreme weather and climatic events, offering a model for regions facing similar challenges worldwide.

Human Right to Water: Ensuring Equity and Access for All

The Human Right to Water Act (AB 685), enacted in 2012, affirms that all Californians are entitled to access safe, clean, and affordable drinking water for personal and domestic use. This landmark legislation has been a driving force behind statewide efforts to address water inequities, focusing particularly on disadvantaged communities disproportionately impacted by water scarcity, contamination, and failing infrastructure. Many of these communities rely on small, aging water systems or private wells, which are often more vulnerable to contamination from pollutants such as nitrates and arsenic. State and local programs have worked to upgrade water systems, improve groundwater quality, and provide emergency drinking water supplies to areas facing acute shortages. For example, significant efforts have been made to connect rural communities in the Central Valley and other regions to larger, more reliable water systems, ensuring sustainable long-term access.

DWR adopted its Human Right to Water Policy in April 2021, which was incorporated into Departmental policy to further DWR's mission "to manage the water resources of California for sustainability and resilience to benefit the state's people and environment." DWR has pledged to continue working with local, State, federal, and Tribal governments, non-governmental and community-based organizations, and businesses to empower communities to build long-term capacity in the development and delivery of its work, including its grant programs, SGMA implementation, flood management, operation of the SWP, and more.

Safe and Affordable Funding for Equity and Resilience (SAFER)

The State Water Board's Safe and Affordable Funding for Equity and Resilience (SAFER) program plays a pivotal role in advancing the Human Right to Water mandate, providing $130 million annually to improve water infrastructure in areas with unsafe or unreliable drinking water. Using short- and long-term strategies, SAFER is designed to ensure Californians who lack safe, adequate, and affordable drinking water receive it as quickly as possible, and that the water systems serving them establish sustainable solutions. Since the start of the SAFER program in July 2019, it has provided more than 276 communities with interim drinking water solutions, 433 communities with technical assistance or planning assistance,

PUBLIC DRAFT

and 150 communities with long-term solutions. The Aquifer Risk Map includes socio-economic drought risk for water systems with five to 15 connections, as well as domestic wells.

Drought Contingency Planning

To improve water conservation and water shortage planning as directed under Assembly Bill 1668, DWR has identified small suppliers and rural communities at risk of drought and water shortage vulnerability and developed recommendations for improving drought contingency planning for those areas. In coordination with multiple State agencies and vetted through an extensive interested party process, DWR developed recommendations that would allow small water suppliers and rural communities to meet their drought and water shortage planning needs.

Drought Resilience Interagency Partners (DRIP)

DWR's Drought Resilience Interagency Partners (DRIP) Collaborative strengthens coordination among California's State agencies, enabling a unified and efficient response to drought emergencies. By streamlining resource allocation, fostering interagency collaboration, and ensuring consistent public messaging, DRIP enhances the State's ability to address the complex challenges posed by prolonged droughts. Recent DRIP efforts include deploying mobile desalination units to support remote coastal communities with limited access to fresh water, a critical lifeline during water shortages. Additionally, DRIP has prioritized fast-tracking permits for groundwater recharge projects, expediting the implementation of managed aquifer recharge to replenish depleted aquifers and improve water resilience. Through these targeted actions, DRIP demonstrates California's commitment to adaptive and proactive water management, ensuring that both urban and rural communities can better withstand the impacts of drought.

Drought Executive Orders

On March 28, 2022, Governor Newsom issued Executive Order N-7-22, which included new well permitting requirements for local agencies to prepare for and lessen the effects of drought conditions (Action 9), and the suspension under specific circumstances of the California Environmental Quality Act, also known as CEQA (Action 13). Executive Order N-7-22 Action 9 was superseded by Executive Order N-3-23, Action 4 on February 13, 2023, and ultimately rescinded by Executive Order N-3-24 on September 5, 2024.

PUBLIC DRAFT

The original Action 9 and follow-up Action 4 applied to local well permitting agencies, such as cities, counties, or water agencies, who have the authority to adopt local well ordinances and issue or approve well permits. These actions were applicable to proposed wells located in a medium- or high-priority basins that have GSAs. The Executive Orders specified additional considerations for local agencies to make when considering permitting wells to improve the understanding of the potential the effects of new or modified wells, such as potential interference with nearby, existing wells and adverse land subsidence impacts. DWR's Groundwater Well Permitting: Observations and Analysis of Executive Orders N-7-22 and N-3-23 report (March 2024) includes a summary of various approaches taken by local agencies to comply with the Executive Orders, observations of groundwater conditions that occurred while these actions were taken, and policy recommendations that can be used to develop future solutions to align land use planning, well permitting, and groundwater management and use.

To qualify for the CEQA suspension, projects had to be consistent with Executive Order Action 13 requirements. Groundwater recharge projects had to occur on open and/or working lands, be funded by the SGMA Grant Program, or be designated as a Flood-MAR Recharge project and needed to offset or mitigate drought impacts on groundwater. Local agencies implementing recharge projects and seeking CEQA suspension were required to submit a self-certification form to DWR for review and concurrence that the proposed activities were eligible under the Executive Order provisions. Approved Suspension Requests were granted by DWR for 23 groundwater recharge projects in 2023 and 2024.

Drought Funding

Since 2021, California has committed $2 billion in drought relief funding to support communities, strengthen water infrastructure, and address the immediate impacts of water shortages. This includes $800 million allocated for infrastructure grants, enabling critical projects such as upgrading water storage facilities, expanding groundwater recharge systems, and improving water distribution networks. Additionally, $500 million has been directed toward direct assistance for affected households, providing immediate relief to families facing dry wells and inadequate water supplies. Emergency programs funded through this initiative have deployed bottled water supplies to communities in crisis and facilitated the drilling of interim wells in areas where water systems have failed. These efforts not only address short-term emergencies but also lay the groundwork for enhanced resilience, ensuring that California is better equipped to face future droughts. By balancing

PUBLIC DRAFT

immediate relief with long-term investments, the State continues to lead in proactive and equitable water management.

Dry Well Reporting and Dry Well Susceptibility Tool

Originally developed during the 2012–2016 drought, DWR has continued to maintain and update the Dry Well Reporting System, a user-friendly online system for reporting incidents of household drinking water wells that have gone dry due to drought impacts. The system immediately notifies local agencies, including county officials, water agencies, and GSAs, when household water supply-well outages are reported in their region. In coordination with the State Water Board, DWR has also launched a Dry Well Susceptibility Tool that identifies areas in groundwater basins across the state that may be prone to domestic well outages. This tool has been developed as a resource for local monitoring and early warning to help increase general awareness of where domestic water wells may be susceptible to going dry to help communities proactively plan for potential well outages.

Additionally, DWR launched the "Be Well Prepared" Program in May 2023 to ensure safe and reliable drinking water for households and communities dependent on groundwater. DWR provides tools and resources to help communities that are dependent on groundwater prepare for potential impacts to household water supplies, which include domestic well owners and residents that use and maintain their own well.

LandFlex

Authorized by the California Legislature pursuant to the Budget Act of 2021, DWR developed the LandFlex Grant Program (Land*Flex*) to provide immediate drought relief to drinking water wells in drought-stricken communities and limit unsustainable groundwater pumping in critically overdrafted basins.

Through Land*Flex*, block grants were awarded to GSAs, enabling them to work directly with growers to reduce agricultural water use. These grants were structured to compensate growers for voluntarily fallowing land or significantly limiting water use, particularly in areas where groundwater pumping threatens drinking water wells. GSAs collaborated with growers to identify specific parcels of land where pumping reductions would have the greatest benefit to nearby communities, ensuring that the program targeted the most vulnerable areas. Land*Flex* focused on maximizing the dual benefits of protecting essential drinking water supplies and supporting agricultural interested parties in transitioning to more sustainable practices. The program also emphasized equitable outcomes by

PUBLIC DRAFT

prioritizing disadvantaged communities where drinking water access is most at risk. Additionally, DWR provided technical assistance and outreach to ensure program accessibility and effective implementation.

By directly linking land management decisions to community water needs, Land*Flex* represents a critical step in addressing the immediate impacts of drought while contributing to long-term groundwater sustainability goals. This program serves as a model for integrating drought resilience, groundwater management, and community well-being into a unified approach.

EcoFIP / Multi-benefit Floodplain Restoration

DWR's Flood-MAR and CVFPP Conservation Strategy teams have partnered to develop a decision support toolset to identify the best opportunities to restore and expand floodplains to enhance habitat, increase groundwater recharge, reduce flood risk, and provide other benefits. The effort builds upon past work of both programs to evaluate multi-benefit opportunities for floodplain restoration and expansion and work with local partners to collaboratively develop restoration concepts at priority locations. A systematic approach has been developed that can be applied at large scales to evaluate multi-benefit floodplain restoration and expansion projects. The approach includes:

- Identifying the best opportunities to provide multiple benefits.
- Identifying potential areas of alignment with other local and regional efforts and willing landowners.
- Developing restoration and recharge concepts that support local and regional priorities.
- Implementing pilots or projects to expedite and expand implementation of multi-benefit projects on floodplains.

This approach uses the Ecological Floodplain Inundation Potential (EcoFIP) toolset (Tillmann et al. 2023) to evaluate acre-days of inundated areas, acre-days of suitable salmonid habitat, and potential recharge volumes over a range of water years. EcoFIP comprehensively assesses physical opportunities for floodplain restoration and managed aquifer recharge at the parcel or river-mile scale, while providing conceptual design analysis at the project scale.

DWR has piloted this approach in the Upper and Mid San Joaquin, Pajaro, and Cosumnes watersheds in partnership with local flood and groundwater managers and NGOs. The study approach applied for the pilots was unique to each location.

PUBLIC DRAFT

Local priorities and objectives were used to inform each evaluation, and objectives were prioritized as primary, secondary, or opportunistic so if tradeoffs need to be made the objective with greater priority will drive project formulation.

This approach also progresses several California Natural Resources Agency initiatives, including expanding nature-based solutions and cutting green tape, by utilizing floodplains to achieve statewide climate change and biodiversity goals and promoting partnerships and coordination to implement ecological restoration opportunities more efficiently.

Water Conservation Initiatives

Water conservation initiatives are central to California's efforts to balance limited water supplies with growing demands in more extreme climate. These initiatives blend regulatory measures and incentive-based programs to promote efficiency across urban, agricultural, and residential sectors. Urban areas are increasingly deploying smart metering systems, enabling households and businesses to monitor and reduce water usage in real-time, leading to measurable savings. In agriculture, grants for advanced irrigation technologies, such as drip irrigation systems and soil moisture monitoring tools, empower farmers to optimize water use while maintaining crop yields. Public engagement also plays a critical role, with campaigns like "Save Our Water" raising awareness about the importance of conservation. These efforts have already helped achieve significant milestones, such as reducing household water use per capita by 20% by 2030. Landscaping rebates further complement these programs, encouraging homeowners to replace water-intensive lawns with drought-tolerant plants, transforming yards into sustainable spaces. Together, these initiatives demonstrate California's commitment to fostering a culture of water stewardship through innovation, education, and collaboration.

Investments in Water Infrastructure

California has committed $8.6 billion over three years to modernize and enhance its water infrastructure, addressing critical vulnerabilities in the face of climate change and water scarcity. A significant portion of this funding, $1.3 billion, is dedicated to modernizing the Friant-Kern Canal, a vital artery for agricultural water supply that has been severely impacted by land subsidence, reducing its capacity and operational efficiency. Another $500 million is allocated to expand groundwater recharge facilities, enabling the capture and storage of excess floodwater to replenish aquifers and combat over-extraction. The funds also support major storage projects such as the Sites Reservoir, which will add 1.5

PUBLIC DRAFT

million acre-feet of storage capacity, enhancing the State's ability to manage water during droughts and wet periods. Upgrades to the SWP are another priority, improving delivery reliability for millions of Californians who depend on its supply. Additionally, the State has earmarked $750 million for water recycling initiatives, funding advanced treatment plants capable of producing high-quality potable water from wastewater. These investments collectively represent a forward-thinking approach to building a more resilient and sustainable water system, ensuring that California can meet the challenges of a more extreme climate.

Proposition 4 Bond Funding (Passed in November 2024)

California's Proposition 4, approved by voters in November 2024, authorizes the State to issue $10 billion in general obligation bonds to fund a wide range of projects aimed at enhancing water security, preventing wildfires, and protecting communities and natural lands from the escalating risks of climate change. A substantial portion of this funding is connected with groundwater-related projects, reinforcing the State's commitment to sustainable water management. Of the $3.8 billion allocated for drought, flood, and water supply initiatives, significant resources are dedicated to bolstering groundwater recharge infrastructure and cleaning polluted water to ensure it is safe for drinking. These efforts directly address groundwater sustainability by increasing aquifer storage capacity and improving groundwater quality, critical for meeting the needs of California’s communities and agricultural sectors during prolonged droughts. Additionally, $100 million has been allocated for integrated regional water management projects that will enhance climate resilience on a watershed scale, further advancing DWR’s Watershed Resilience Program and supporting sustainable water management across the state.

Another $1.5 billion earmarked for forest health and wildfire prevention has indirect but meaningful impacts on groundwater. Healthy forest ecosystems play a vital role in supporting natural water infiltration and storage by reducing runoff and enhancing the recharge of underlying aquifers. Furthermore, Proposition 4 provides funding for innovative water recycling technologies and advanced water treatment systems, further reducing reliance on overdrawn groundwater supplies. This comprehensive investment ensures that California’s groundwater basins are better equipped to serve as a reliable drought buffer and a critical component of the state’s water resilience strategy, addressing both current needs and long-term climate challenges.

PUBLIC DRAFT

1.6 The Future of Sustainable Groundwater Management

Groundwater is indisputably the foundation of California's resilience, underpinning the state's ability to navigate the challenges of a hotter, drier climate marked by extreme weather and climatic events. As surface water supplies become increasingly unreliable, sustainable groundwater management emerges not only as a necessity but as a cornerstone of California's water future. Groundwater serves as both a lifeline during droughts and a critical buffer against floods, offering unparalleled flexibility in addressing the state's diverse water needs. Recognizing this, California has undertaken a multi-faceted approach to safeguard and enhance its groundwater resources, aligning these efforts with the overarching vision of achieving water security for all. This vision is advanced through the four key themes of CalGW Update 2025: "Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency," "Accelerating Momentum for Sustainability," "Strengthening Connections for Equity," and "Enhancing Data, Tools, and Analysis for Decision Support."

Groundwater conditions across California are highly diverse, shaped by regional differences in water sources, geologic settings, climate pressures, and community needs. As a result, SGMA implementation is not a one-size-fits-all endeavor. While some basins have decades of experience and infrastructure in place, others are still building capacity and require additional support. Sustainable groundwater management must be tailored locally — grounded in the realities of each basin — while remaining connected to broader regional and statewide systems.

The State's commitment to sustainable groundwater management is firmly rooted in equity, ensuring that the Human Right to Water is upheld for all Californians, including the most vulnerable communities. Programs under SGMA not only support ambitious sustainability goals set by GSAs, but also emphasize inclusive decision-making, ensuring disadvantaged communities and Tribes have a voice in water planning. By prioritizing equitable access to clean and reliable groundwater, the State is addressing long-standing disparities while advancing climate resilience. Strategic investments, such as expanding groundwater recharge infrastructure, modernizing monitoring technologies, and addressing contamination in underserved areas, exemplify California's determination to build a more equitable and resilient water system. DWR is the primary technical assistance and oversight agency responsible for assessing and evaluating groundwater basin compliance with SGMA. In this role, DWR commemorated the 10-year anniversary of the signing of SGMA in the Fall of 2024, recognizing the

PUBLIC DRAFT

efforts, successes, and challenges of GSAs and groundwater managers over the last decade.

In addition to implementing ambitious programs, the State provides critical assistance to local agencies, which are at the forefront of SGMA implementation. This support includes financial aid through grants and funding programs for infrastructure improvements, recharge projects, and sustainable management initiatives. Technical assistance is also a priority, with DWR offering tools, modeling expertise, and workshops to help local GSAs develop and execute effective GSPs. Language services (written translation and verbal interpretation) and facilitation services further strengthen inclusion, education, and collaboration, fostering partnerships among local governments, Tribes, community leaders, and water districts to address region-specific challenges. This comprehensive support underscores California's recognition that achieving groundwater sustainability is a shared responsibility and that local actions must be empowered by robust State resources and guidance.

However, many of California's groundwater challenges extend beyond basin boundaries. Issues such as land subsidence, water trading, flood risks, and aquifer depletion cross jurisdictions and resource sectors. Addressing these interconnected threats requires regional and watershed-scale solutions that fully leverage the state's natural and built infrastructure — from aquifers and reservoirs to canals, recharge basins, and forecasting tools. DWR plays a dual role in this context: both as a regulatory authority ensuring local agencies meet SGMA requirements, and as a partner providing guidance, technical support, and funding to foster innovation and long-term capacity.

As California progresses toward its vision of sustainable groundwater management, the integration of innovative strategies and comprehensive planning reinforces the importance of groundwater as "natural infrastructure." The State is leveraging data-driven tools and advanced technologies to improve groundwater forecasting, real-time monitoring, and decision-making, as emphasized in the CalGW Update 2025. Climate adaptation strategies like Flood-MAR, enhanced stormwater capture, and nature-based solutions further align with these goals, transforming policy into actionable outcomes. Together, these efforts ensure that groundwater will remain the backbone of California's resilience, securing a sustainable and equitable water future for communities, ecosystems, and the economy in an era of unprecedented environmental change.

PUBLIC DRAFT

CalGW Update 2025 represents a pivotal step forward in implementing the State's vision, building upon California's broader policy frameworks, including SGMA, the Human Right to Water Act, the *Water Resilience Portfolio*, and the *DWR Strategic Plan*. The initiatives outlined in this report — and the four organizing themes — draw strength from the foundational work of local agencies and interested parties, reinforcing that groundwater sustainability must be both locally driven and systemically supported.

1.7 Organization of CalGW Update 2025

California's Groundwater: Bulletin 118 — Update 2025 (CalGW Update 2025) is organized as follows:

Highlights
A stand-alone summary document that captures the value, condition, and evolving role of groundwater in California. It presents key findings, major trends, and actionable recommendations drawn from the full CalGW Update 2025 report. Designed for decision-makers, interested parties, and the public, the Highlights document offers a high-level synthesis of critical insights — framing the most urgent groundwater challenges and the opportunities for advancing sustainable and equitable management across the state.

Chapter 1. Vision and Context for Sustainable Groundwater Management (this chapter)
This chapter lays the groundwork for understanding California's groundwater challenges and the initiatives aimed at sustainable management, describes the overarching themes for CalGW Update 2025, and provides a brief history and organization of CalGW Update 2025. It also includes an expanded discussion on the multi-faceted nature of climate adaptation and resilience and the importance of integrated strategies to address groundwater sustainability in the face of extreme and accelerating climate impacts.

Chapter 2. Progress Toward Sustainable Groundwater Management
This chapter summarizes California's journey toward sustainable groundwater practices, setting the stage for understanding the critical advancements and challenges. It provides an overview of the accomplishments by State and local agencies toward sustainable groundwater management, including highlights of key legislative, regulatory, and administrative milestones.

PUBLIC DRAFT

Chapter 3. California's Natural and Built Groundwater Infrastructure
This chapter explores the complex systems that sustain California's groundwater resources, covering both natural and constructed elements essential to water management. It describes California's groundwater aquifers and the locations of groundwater resources, highlighting the role of natural and built infrastructure in maintaining the state's water security and State's efforts to characterize and understand them.

Chapter 4. Groundwater: Use, Extraction, and Water Budgets
This chapter examines California's groundwater usage patterns, extraction practices, and the crucial role of water budgeting in sustainable water management. It reports on the groundwater and surface water use for agricultural, urban, and a subset of environmental uses referred to as *managed wetlands uses*, both statewide and within hydrologic regions. This chapter also discusses statewide recharge efforts and water use data for groundwater basin, non-basin, agricultural, and urban areas.

Chapter 5. Groundwater Monitoring
This chapter provides detailed information on groundwater monitoring throughout the state, including monitoring of groundwater levels, groundwater quality, land subsidence, groundwater and surface water interaction, and seawater intrusion.

Chapter 6. Groundwater Conditions
This chapter provides an overview of the groundwater conditions throughout the state, including an extensive analysis of groundwater levels, groundwater quality, and land subsidence.

Chapter 7. Groundwater at a Glance: Hydrologic Region Summaries
Using much of the data that are reported in the first six chapters, the hydrologic region summaries provide brief, data-rich summaries for each of the 10 hydrologic regions. The summaries include details concerning water use, groundwater management, production well infrastructure, groundwater monitoring, groundwater conditions, and local assistance in each hydrologic region.

Appendix A. Findings and Recommendations
This appendix provides a list of all findings and recommendations included in the Highlights document.

PUBLIC DRAFT

Appendix B. Glossary
This appendix provides a list of key groundwater terms and definitions found in CalGW Update 2025.

Appendix C. Methods and Assumptions
This appendix provides the details on methods and assumptions that were used to create the figures and tables in CalGW Update 2025. These methods and assumptions focus only on new data and analysis. Figures and tables are briefly discussed along with the datasets used to create them, where applicable.

Appendix D. Citations, Reference Materials, and Links
This appendix contains the citations identified throughout CalGW Update 2025 and a comprehensive list of recommended additional reference material and data. This appendix may be updated periodically to reflect new information.

Appendix E. Hydrologic Region Basin Maps with Basin Tables
This appendix contains a complete list of groundwater basins in each of the 10 hydrologic regions along with hydrologic region maps to aid the reader in locating individual basins and subbasins.

Appendix F. Water Use Data
This appendix contains supplemental water use data that were used in processing of the information presented in Chapter 4, "Groundwater: Use, Extraction, and Water Budgets," and elsewhere in CalGW Update 2025.

Appendix G. Hydrologic Region, Basin, and County Data
This appendix contains supplemental hydrologic region, groundwater basin, and county data.

PUBLIC DRAFT

Appendix H. California's Groundwater: Semi-Annual Updates
This appendix provides an online inventory of California's Groundwater: Semi-Annual Updates. These updates serve as more frequent supplements to the comprehensive ten-year CalGW Updates and offer additional perspective on the near-real-time data available through CalGW Live.

Appendix I. Land Subsidence
This appendix provides detailed information on select sites modeled for projected future subsidence, as well as an updated inventory of major subsiding areas in the state. It is an update of the *Land Subsidence from Groundwater Use in California* (Borchers and Carpenter 2014) report, originally prepared for the California Water Foundation.

Appendix J. Projects and Management Actions
This appendix contains a summary of available data on Projects and Management Actions from the PMA module, including their categories, quantified benefits, costs, timelines, and related sustainability indicators.

PUBLIC DRAFT

2 . Progress Toward Sustainable Groundwater Management

Chapter Summary

Chapter 2, "Progress Toward Sustainable Groundwater Management," of *California's Groundwater: Bulletin 118 — Update 2025* (CalGW Update 2025), discusses California's journey toward sustainable groundwater management practices, setting the stage for understanding critical advancements and challenges. Marking 10 years since the passage of the Sustainable Groundwater Management Act (SGMA) in 2014, this chapter begins with an overview of the accomplishments of State and local agencies in advancing sustainable groundwater management. The chapter highlights key legislative, regulatory, assistance, and administrative milestones as it discusses the evolution of groundwater management within the state, illustrating the development of legal frameworks, local ordinances, and special districts. The collaboration among State, federal, and local agencies, including water management and land-use agencies, is also emphasized, showing how these efforts contribute to holistic resource management.

DWR's Sustainable Groundwater Management Program is a cornerstone of the chapter, detailing statutory responsibilities such as basin prioritization, technical assistance, regulatory oversight, and support for Groundwater Sustainability Agency (GSA) formation. Furthermore, the chapter describes DWR's efforts in technical, planning, and financial assistance, including grant programs, groundwater recharge support, and innovative strategies such as using flood flows for managed aquifer recharge (Flood-MAR). The development of data, tools, best management practices, and technical resources by the California Department of Water Resources (DWR) underscores its commitment to aiding local agencies and GSAs in achieving sustainable groundwater management across California.

This chapter discusses local SGMA implementation by defining, measuring, and managing sustainable management criteria for the six sustainability indicators specified in the law. By summarizing local approaches, projects, and management actions, it provides a comprehensive view of how agencies are working toward achieving groundwater sustainability, ultimately framing a roadmap for the future of California's groundwater management. Additionally, it explores the role of water

PUBLIC DRAFT

accounting, markets, and transfers as tools for optimizing water resources to address supply and demand imbalances across California. By facilitating water transfers, these markets enhance flexibility in managing limited water supplies, especially in times of drought.

The chapter concludes with a description of the State Water Resources Control Board's (State Water Board) authority to intervene when basins fail to comply with the SGMA requirements. This intervention includes consulting with DWR to assess basin conditions, designating basins as probationary if sustainable groundwater management practices are not met, and developing interim plans to guide these basins toward compliance.

Chapter 2, "*Progress Toward Sustainable Groundwater Management,"* aligns with Themes 2, 3, and 4 of CalGW Update 2025. By emphasizing the progress toward sustainable groundwater management through the concerted efforts of local and State agencies, this chapter highlights California's commitment to Theme 2, "Accelerating Momentum for Sustainability," and Theme 3, "Strengthening Connections for Equity." By documenting technical and financial assistance for data, tools, and projects, this chapter highlights the importance of Theme 4, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support," for achieving sustainable groundwater management.

2.1 Introduction

Groundwater provides about 40 percent of California's total annual water use in average years—and up to 60 percent during dry years — making it one of the most critical components of the state's water portfolio. It sustains millions of residents, supports one of the most productive agricultural economies in the world, and provides essential baseflow for ecosystems across diverse landscapes. Yet for most of the state's history, groundwater was managed locally and inconsistently, with no statewide framework or requirements for sustainability. Aquifers were pumped at will with few reporting requirements, and the effects of long-term overdraft — such as chronic lowering of groundwater levels, land subsidence, degraded water quality, depleted streams, seawater intrusion, and dry wells — unfolded quietly underground.

This approach to groundwater management began to shift in the early 2000s but changed decisively in response to the historic drought that gripped California from 2012 to 2016. As surface water supplies plummeted, groundwater use surged to record levels. Thousands of wells in rural communities went dry, overdraft

PUBLIC DRAFT

accelerated in critically stressed basins, and satellite imagery revealed alarming rates of land subsidence in key agricultural regions. The drought exposed the vulnerability of California's fragmented groundwater management system and elevated groundwater from a technical issue to a central policy priority. What had once been invisible became visible — ecologically, socially, and politically.

In response, California enacted the Sustainable Groundwater Management Act (SGMA) in 2014, marking a turning point in the state's approach to groundwater management. SGMA established a regulatory framework in which local Groundwater Sustainability Agencies (GSAs) are empowered to manage groundwater basins while the state provides standards, guidance, oversight, and financial and technical assistance. This model of shared responsibility has transformed groundwater governance into a more integrated, accountable, and transparent process. It has also catalyzed new forms of collaboration across state, federal, regional, and local levels, including the emergence of water markets, data platforms, and multi-benefit recharge strategies. The first decade of SGMA reflects more than policy implementation — it signals a cultural transformation in how Californians value, manage, and steward groundwater for generations to come.

2.2 Ten Years of the Sustainable Groundwater Management Act

September 16, 2024, marked the 10th anniversary of the signing of the Sustainable Groundwater Management Act (SGMA), California's landmark groundwater legislation. Figure 2-1 highlights key DWR accomplishments and statewide GSA milestones achieved during the first decade of SGMA implementation.

SGMA established a statewide framework to protect groundwater resources and empower local agencies to manage their groundwater basins, at the local level, for long-term sustainability. Under SGMA, GSAs and other local agencies are implementing creative solutions in more than 100 groundwater basins to achieve sustainability. A notable example of these efforts is the implementation of innovative local recharge initiatives which, with State support, resulted in 4.1 million acre-feet of managed aquifer recharge — nearly equivalent to the storage capacity of Shasta Lake — in 2023. In some basins, decisions have been made to manage groundwater demand and develop projects and management actions to reduce groundwater pumping and associated overdraft. While these decisions are challenging, GSAs that are developing new demand management and groundwater allocation programs are leading the way in achieving groundwater conditions that

PUBLIC DRAFT

support access to water for all beneficial uses and users while promoting long-term sustainability and resilience in groundwater management. Some of those challenges and lessons learned were highlighted at DWR's public event held on November 18, 2024, which commemorated the 10th anniversary of SGMA's historic passage. Local GSAs, community organizations, State leaders, and others in the SGMA community shared insights and reflected on a decade of progress. Speakers also outlined goals for the next 10 years, emphasizing the importance of advancing sustainable groundwater management by implementing the plans developed so far.

Beyond coordinating basin-wide governance and planning for sustainable groundwater basins, SGMA, along with the State Water Board's Safe and Affordable Funding for Equity and Resilience (SAFER) program, has played a crucial role in protecting wells leading to significant improvements in drinking water reliability. The legislation has also driven infrastructure enhancements, such as the development of groundwater recharge basins, and has helped reduce both the rate of land subsidence and the potential for it to occur in some areas. Additionally, SGMA has played a crucial role in climate adaptation efforts, helping to ensure that California's various water management strategies remain resilient in the face of changing climate conditions.

Over the past decade, the implementation of SGMA has transformed water management across the state and has mandated additional coordination and consultation between California's water supply and management agencies and California's land use planning agencies. Thanks to the efforts of local agencies and GSAs, as well as State support, California is making steady progress toward a sustainable groundwater future.

The adoption of Groundwater Sustainability Plans (GSPs) and alternatives to GSPs (Alternatives) has led to significant advancements in groundwater management in California. The formation of a GSA and the preparation of a GSP or an Alternative are only required in California's 94 high- and medium-priority basins, but many low- and very low-priority basins have voluntarily chosen to follow SGMA's groundwater management structure. Of the state's 515 basins and subbasins, a plan has been prepared and adopted in 102 basins, and a GSA has been formed in 142 basins, as further described in the "Regulatory Oversight" section of this chapter. DWR supported GSP development through technical services assistance and has provided nearly $140 million in three rounds of planning grants for development of GSPs and updates and revisions to approved Alternatives.

PUBLIC DRAFT

DWR also supports plan implementation through technical services, monitoring assistance, data collection and sharing, tool development, and by awarding over $360 million in implementation grants for sustainable groundwater management. Enhanced data collection has deepened our understanding of California's groundwater basins and conditions, facilitating greater collaboration among interested parties. This has led to efforts to address critical issues such as land subsidence and dry wells, while innovative strategies like groundwater recharge and demand management are being implemented to safeguard water resources.

During the last decade, public awareness about the importance of groundwater has grown, fostering proactive and collaborative management efforts. Through the implementation of SGMA, local agencies and GSAs are planning for sustainable management of groundwater basins and are working to ensure water availability during future droughts to support communities, agriculture, and ecosystems. Proposition 4, approved by voters in November 2024, will provide additional funding for GSP implementation and is expected to build upon the progress achieved in the past 10 years.

PUBLIC DRAFT

Figure 2-1 Accomplishments in the First Ten Years of SGMA

2014

SEPTEMBER 16
SGMA signed into law

2015

JANUARY 31
Department of Water Resources (DWR) releases initial basin prioritization

FEBRUARY
DWR begins providing public access to Statewide Satellite-Based Land Subsidence Data

OCTOBER 21
DWR finalizes regulations to adjust basin boundaries

2015
DWR begins identifying basins subject to critical conditions of overdraft (COD basins)

2016

MARCH
DWR's Sustainable Groundwater Management (SGM) Grant Program awards $6.7 million (M) in local assistance grants to 21 counties for development of groundwater ordinances

APRIL 1
Adjudicated basins submit final judgment to DWR and begin submitting annual reports to DWR

APRIL
DWR publishes Water Available for Groundwater Replenishment Report

MAY 18
DWR finalizes Groundwater Sustainability Plan (GSP) Regulations

JULY
DWR launches Facilitation Support Services Program

DECEMBER
DWR publishes Bulletin-118 Interim Update

2016
DWR completes Basin Boundary Modifications, Round 1

2017

JANUARY 1
Local agencies submit Alternatives to a GSP to DWR for review

JANUARY
DWR releases seven Best Management Practices and Framework publications for sustainable management of groundwater

JUNE 30
More than 250 local Groundwater Sustainability Agencies (GSAs) are established, covering all high- and medium-priority basins

2017
DWR takes on management of voluntary Dry Well Reporting System and Resource platform (originally "My Dry Well")

2018

APRIL
DWR's SGM Grant Program awards $85.8M to 78 applicants for the development of GSPs in COD basins

FALL
DWR initiates Technical Support Services Program

2019

FEBRUARY
DWR completes Basin Boundary Modifications, Round 2

MARCH
DWR establishes participation in annual Groundwater Awareness Week in California, sharing groundwater education and outreach materials

JUNE
DWR completes evaluations of Alternatives to GSPs

DECEMBER
DWR completes Basin Prioritization, Round 2

2020

JANUARY 31
All COD basins meet deadline to submit first-ever GSPs

FEBRUARY
DWR launches Written Translation Services

MARCH
DWR's SGM Grant Program awards $47M to 53 applicants for the development of GSPs in non-COD basins

APRIL 1
2020 COD basins submit first Annual Reports to DWR for review

2021

MAY
DWR's SGM Grant Program awards $26M to 6 COD basins for projects that support the implementation of GSPs

JUNE
DWR releases first assessments of COD basin GSPs

NOVEMBER
- DWR releases second round of assessments of GSPs
- DWR publishes *California's Groundwater (CalGW) Bulletin 118 - Update 2020*

DECEMBER
DWR and State Water Board finalize 'Groundwater Management Principles and Strategies', addressing drought impacts on drinking water wells

2022

JANUARY
DWR completes reviews and issues determinations on GSPs submitted for COD basins

JANUARY 31
All remaining high- and medium-priority basins meet deadline to submit GSPs

APRIL 1
GSP basins submit first Annual Reports to DWR for review

JUNE
- DWR releases Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim) Version 1.0
- DWR launches 'Be Well Prepared' Program and releases Dry Domestic Well Susceptibility Tool
- DWR's SGM Grant Program awards $150.5M to all 21 COD basins

AUGUST
DWR launches new web-based mapping tool showing nearly 3,000 groundwater sustainability projects

SEPTEMBER
DWR publishes 'Spring 2022 -California's Groundwater Conditions, Semi-Annual Update', marking the transition to more frequent supplements to 5-year CalGW Updates

NOVEMBER
DWR launches California's Groundwater Live online interactive tool

2023	**MARCH**	**SPRING**	**SEPTEMBER 12**	**OCTOBER**	**NOVEMBER**
	• Six basins deemed 'Inadequate' by DWR and move under State Water Board jurisdiction • DWR releases 'Considerations for Identifying and Addressing Drinking Water Well Impacts' guidance • DWR launches Flood Diversion and Recharge Enhancement (FDRE) program, providing funding for temporary pumps and land clearing activities	DWR launches Groundwater Recharge (March) and 'Be Well Prepared' websites (May)	DWR's SGM Grant Program awards $187M to 32 basins	DWR releases 'Groundwater Sustainability Plan Implementation: A guide to Annual Reports, Periodic Evaluation, and Plan Amendments'	DWR completes Statewide Airborne Electromagnetic (AEM) Surveys

2024	**JANUARY**	**MARCH**	**MAY**	**JUNE**	**SEPTEMBER**
	DWR completes reviews and issues determinations on GSPs for Non-COD basins	• DWR releases 'Groundwater Well Permitting: Observations and Analysis of Executive Orders N-7-22 and N-3-23' report • DWR releases 'Resource Guide for Funding Sustainable Groundwater Management Act (SGMA) Implementation'	DWR launches Verbal Interpretative Services Program	DWR completes periodic review of periodic evaluations of nine Alternatives to GSPs	DWR releases all three technical papers on interconnected surface water

2.3 Evolution of Groundwater Management in California

Historically, groundwater use in California was not managed and was simply based on landowners' rights to "capture" water beneath their lands for use above. Over time, additional legal concepts and constraints were developed and applied to groundwater use to address conflict and societal needs, such as the doctrines of reasonable and beneficial use and correlative rights.

As the practice of largely unregulated extraction of groundwater resources persisted through the 1900s, aquifers within many of the state's groundwater basins were increasingly relied upon, and in some cases overdrafted, to meet growing water demands. It became apparent that groundwater was not an infinite resource, and its unfettered use could lead to adverse conditions that threatened the quality and sustainability of the groundwater stored within aquifers.

In response to the growing reliance, conflicts, and impacts regarding groundwater use, groundwater adjudications were filed in the courts beginning around the 1920s. Courts overseeing adjudications often issued detailed judgments addressing and assigning groundwater rights and ongoing management responsibilities and activities to eliminate overdraft and promote continued use of the aquifer. Groundwater management under these previous groundwater adjudications is still occurring in the applicable basins. A streamlined adjudication process was added to the Code of Civil Procedure in 2016 and also incorporated in Chapter 12 of the SGMA law. Future adjudication actions to determine rights to groundwater in a basin must be conducted according to the new streamlined

PUBLIC DRAFT

procedures, and several new streamlined adjudications have been filed since 2016 (Water Code Section 10737). In the new streamlined adjudication actions for a basin required to have a GSP, the courts are required to manage the proceedings in a manner that minimizes interference with the timely completion and implementation of a GSP, avoids redundancy and unnecessary costs in the development of technical information and a physical solution, and is consistent with the attainment of sustainable groundwater management. Additionally, courts may not approve entry of judgments unless the court finds that the judgment will not substantially impair the ability of GSAs, the State Water Board, or DWR to comply with SGMA and to achieve sustainable groundwater management (see Water Code Sections 10737.2, 10737.8).

Voluntary groundwater management with incentives for proactive planning was enacted by the Legislature in the 1990s and 2000s. Prior to 1992 when Assembly Bill (AB) 3030 was enacted, groundwater management authority was generally granted to the local agencies that had been created by the Legislature to address various aspects of water resource management. At that time — and still true today — local governments such as cities and counties also had the authority to adopt ordinances to regulate groundwater. The detailed evolution of groundwater management in California, including the passage of SGMA in 2014, is summarized below.

2.3.1 Water Rights

The State Water Board is the California agency that grants and regulates surface water rights and also has a role in the management of groundwater rights; the Division of Water Rights handles the day-to-day water rights responsibilities of the State Water Board. The State Water Board's responsibilities include allocating surface water rights, enforcing water rights laws, tracking water rights information, and designating beneficial use. The State Water Board also tracks water rights information on water right permits, licenses, claims, registrations, and certificates. In 2025, the State Water Board plans to launch CalWATRS, a modern electronic platform for accounting, tracking, and reporting of water rights data. At the State level, California does not have a general permit process to apply for and regulate groundwater rights or use, although the State Water Board, other State agencies, and courts have authorities that may implicate or affect the exercise of groundwater rights or groundwater use in specific instances.

"Beneficial use of water" is defined in the California Code of Regulations (CCR), Title 23 (Waters). In the context of water rights, "beneficial use" refers to the

PUBLIC DRAFT

useful purpose to which water is applied. Common beneficial uses include domestic, irrigation, power generation, municipal, and industrial uses. Beneficial uses can also include uses that occur in a stream or reservoir, such as fish and wildlife enhancement or recreation, recognizing the ecological and social value of maintaining healthy aquatic ecosystems. Beneficial use does not include unreasonable or wasteful use of water. The California Constitution mandates that water use must be both reasonable and beneficial, prohibiting waste.

In 1928, the electorate adopted a constitutional provision proposed by the Legislature concerning the use of water in California. This provision, currently designated Article X, Section 2 ("Section 2"), declares that the right to use water "does not extend to unreasonable use or unreasonable method of use or … diversion of water." The mandates of Section 2 apply to the use of all surface water and groundwater, under whatever right the use may be enjoyed and to every method of diversion, making Section 2's reasonable use requirement the overriding principle governing the use of water in California.

The concept of reasonableness in water use is dynamic and context dependent. The California Supreme Court, in the landmark case Joslin v. Marin Municipal Water District (1967), emphasized that what constitutes reasonable use varies based on circumstances and can change over time. The court stated that reasonableness "depends on the circumstances appearing in each particular case," highlighting the necessity to adapt water use practices to current conditions and societal needs. This principle ensures that water rights and uses evolve in response to changing environmental, economic, and social factors, promoting sustainable management of California's water resources.

In addition to being reasonable, uses of water must be beneficial. The Legislature has expressly recognized several uses of water as beneficial. The highest use of water is "domestic purposes" (Water Code Section 106), such as drinking water, household uses, and domestic livestock. The second highest use of water is for irrigation (Water Code Section 106). Other beneficial uses of water include recreation and the preservation of fish and wildlife resources (Water Code Section 1243).

Groundwater Rights

Groundwater use in California generally falls under three types of groundwater rights: overlying rights, appropriative rights, and prescriptive rights. State and local agencies have authority in particular circumstances to regulate groundwater

PUBLIC DRAFT

extractions and use under these rights, and with the introduction of SGMA and the new powers and authorities granted to GSAs once they adopt a GSP and submit it to DWR for review, groundwater extraction may be regulated to attain a basin's sustainability goal.

Overlying groundwater rights are the most common type of right. These rights afford the landowner who overlies a groundwater supply a general right to use groundwater on the landowner's overlying lands, taking into account the competing demands of all other overlying landowners.

Appropriative groundwater rights relate to groundwater that is "surplus" to the needs of overlying landowners without causing overdraft and generally apply in two situations — when the groundwater pumper does not own the overlying land or when the overlying landowner intends to use the pumped water outside of the groundwater basin. Appropriative rights require continued use of the resource, and any appreciable gap in the continued use could result in the loss of that right. Overlying groundwater rights generally have a higher priority than appropriative rights, and among appropriators those initiated earlier in time generally have higher priority over those initiated later.

A prescriptive groundwater right is a right that may be acquired when a groundwater appropriator continues to pump groundwater from a basin when there is no surplus available, usually when the basin is being overdrafted. Prescriptive rights were recognized by the California Supreme Court in the 1949 Pasadena v. Alhambra case. The court decided "that various users, including appropriators, had acquired prescriptive rights — rights to infringe upon the established water right of others by means of trespass or unauthorized taking." The court held that prescriptive rights were determined based upon demonstrated use from the previous five years. Prescriptive groundwater rights are further complicated because prescription does not generally apply to public agencies and overlying landowners who continue to pump during overdraft and the prescriptive period may be able to assert so-called "self-help defenses" against claims of prescription.

Refer to Appendix D, "Citations, Reference Materials, and Links," for additional information on California's water rights from the State Water Board.

PUBLIC DRAFT

Surface Water Rights and Groundwater Recharge

In California, the two most common types of surface water rights are riparian and appropriative. Riparian water rights usually arise from ownership of land adjacent to a water source, attach to natural flows in the watercourse, and generally require that the diverted water be used on the riparian parcel and within the watershed. Riparian rights do not include storage rights and therefore they cannot be used to directly recharge groundwater. In most cases, an appropriative water right is needed to divert surface water for underground storage (or recharge). Surface water may be diverted for groundwater recharge under an existing water right, a new water right, or through specific pathways outside the general water rights process. Less common types of surface water rights in California, which are not discussed in this chapter, include reserved rights (federal), pueblo rights, and prescriptive rights.

A diverter may use an existing appropriative water right to conduct recharge activities, if that right authorizes underground storage as a method of diversion. The diversion for recharge must be conducted according to the terms and conditions of the existing permit, such as method of diversion, diversion season, volume, rate, purpose, and place of use. If needed to implement the recharge project, some water right permit or license conditions may be changed under a change petition, but others, such as changing the diversion season, volume, or rate would likely require a new water right.

If a new appropriative water right is needed to allow diversion of surface water for recharge, a diverter may consider a temporary or standard permit pathway. Temporary permits can be obtained for 180 days or five years and are best for short-term or pilot diversion activities. Standard permits are best suited for long-term activities.

If a project meets certain criteria, a streamlined pathway for temporary or standard permits is available to assist local agencies in advancing projects that divert high surface water flows for underground storage and help local agencies reach their groundwater sustainability goals faster. These criteria include:

- Applicant is a GSA or local agency.
- Project proposes to divert water to underground storage.
- Diversions must occur between December 1 and March 31 (when using Option 1, as described below).

PUBLIC DRAFT

- Diversion criteria must be based on 90th percentile daily flows or a defined flood condition.

The streamlined pathway allows applicants to use a simplified water availability analysis to determine when high flows are occurring that allow for diversion and minimize the potential for injury to other water right holders or the environment. The analysis options include:

- Option 1. This option is commonly called the "90/20 Method." For this method, a statistical analysis is conducted on historical stream gage data to determine the 90th percentile daily flows. Each day during the diversion season (December 1 through March 31) will have a unique value, and actual flows above the 90th percentile daily flow value will determine if diversion can occur that day. Diversions must be capped at 20% of the daily flow and not cause flows to dip below the 90th percentile daily flow value.
- Option 2. This analysis option relies on a known stage or flow (i.e., flood threshold) that indicates the presence or imminent threat of flood conditions. Flows above the flood threshold will indicate if water is available for the groundwater recharge project. It should be noted that the State Water Board has approved permits that use the threat of flood conditions as the diversion criteria and has allowed diversions past March 31 when the applicant has demonstrated that flood conditions have occurred past March 31 in the project area (e.g., flows driven by snowmelt that usually peak in spring).
- Hybrid. Some applicants have used both Options 1 and 2 in their applications where Option 1 triggers diversions December through March and Option 2 triggers diversions after March 31.

There are some instances when surface water may be diverted outside of the general water rights process. For example, a single-purpose flood risk reduction project does not need a water right. The purpose of projects that manage floodwater to prevent or reduce flooding is to avoid a hazard, not to achieve a beneficial use. Single-purpose flood risk reduction projects may provide incidental recharge of groundwater, but the project is not designed specifically to enhance or conduct recharge; therefore, a water right is not needed. However, some multi-benefit flood projects may be designed to increase groundwater recharge for later beneficial use and those multi-benefit projects may need a water right.

More recently, other regulatory pathways have been developed to allow diversions that maximize groundwater recharge during flood events. In response to the 2023 high flow events and flood conditions throughout the state, Governor Newsom

PUBLIC DRAFT

executed Executive Orders N-4-23 and N-7-23, which allowed for diversion of flood flows, or high surface water flows, for recharge that met certain conditions, such as a local agency had provided public notification that flood conditions existed on the source waterbody. Under the provisions allowed in the Executive Orders, over 400,000 acre-feet of surface water was diverted for recharge in 2023 on over 90,000 acres of land. Although these Executive Orders have since terminated, others like them may be released during future flood events.

In 2024, Water Code Section 1242.1 was enacted to build on the 2023 Executive Orders and allow for diversion of floodwaters for recharge outside the water rights process, provided certain conditions were met. These conditions include definition of flood flows, local planning requirements, public notification, recharge land restrictions, Delta conditions, and others. Due to limited flood flows, no diversions under Section 1242.1 had been made as of December 2024. In January 2025, Governor Newsom issued Executive Order N-16-25 to facilitate the capture and storage of water from atmospheric river storms in Northern California. This order streamlined the process for diverting flood flows for groundwater recharge by waiving certain requirements under Water Code Section 1242.1, thereby enabling local agencies to act more swiftly in response to flood conditions. As a result, in February and March 2025, the Dunnigan Water District and Rancho Murieta Community Services District became the first local agencies to implement flood diversions under the streamlined provisions, effectively enhancing groundwater recharge efforts during the flood events.

2.3.2 Pre-SGMA Groundwater Adjudications

Court adjudications of groundwater rights have occurred in California for over 100 years. In the early twentieth century, the increased water needs of a growing population and agricultural industry resulted in an increased reliance on groundwater as part of California's water supply. As precursors to formal groundwater management, groundwater adjudications were used to address disputes in groundwater rights and the adverse effects of over-use.

Prior to the passage of SGMA in 2014, adjudications often focused on determining the "safe yield" of groundwater basins and allocating that yield among the participating parties. "Safe yield" was generally treated as the average amount of water that could annually be pumped from a basin in perpetuity without causing overdraft or permanently depleting the groundwater supply. The court determinations considered all available evidence and often proposed settlements or compromises of claims provided by parties participating in the adjudications,

PUBLIC DRAFT

which often excluded consideration of, among other things, environmental uses and users of groundwater, the interconnected nature of groundwater and surface water, and certain groundwater uses and users that were not represented or underrepresented in the adjudications, such as Native American Tribes, disadvantaged communities, individual domestic pumpers, and landowners with unexercised overlying rights. The pre-SGMA adjudications primarily focused on resolving the water rights disputes of individuals, not necessarily considering the long-term sustainability of a basin, and not all the adjudication actions established a safe yield for the adjudicated area.

Many adjudications included a "physical solution" as part of managing the basin, which often included fees, monitoring, and implementation of projects to conserve or augment water supplies in the adjudicated area. Continued enforcement of the court's judgment and implementation of any physical solution was usually delegated to a "watermaster," which could be a person, entity, or agency that performed day-to-day oversight with periodic reporting to the court, and further involvement of the court when needed.

In 2014, the SGMA legislation identified 26 groundwater areas that had previously undergone court proceedings to adjudicate or settle groundwater rights, as well as three other areas. Antelope Valley, Inyo County, and the Los Osos Groundwater Basin had adjudications in process and have since finalized those adjudications. Some of the adjudicated areas listed in Water Code Section 10720.8 have combined with adjacent adjudications (for example, the San Bernardino Basin Area, Riverside Basin, and Lytle Basin) and some have established management areas for reporting purposes (see Santa Maria Valley Basin).

Groundwater adjudications can cover an entire basin, a portion of a basin, or a group of basins, and may include non-basin areas. The adjudicated areas identified in the Water Code cover all, or significant portions, of the 42 groundwater basins listed below in Table 2-1 and illustrated in Figure 2-2. For the purposes of implementing SGMA, all areas listed in Water Code Section 10720.8 are considered adjudicated areas and the provisions of SGMA that require GSA formation and GSP preparation do not apply to those areas. However, for groundwater basins that are partially covered by an adjudication, the non-adjudicated portion could be prioritized as high or medium. Of the basins listed in Table 2-1, only two — San Gorgonio Pass and Scott River Valley — are prioritized as high or medium and both of those basins have approved GSPs.

PUBLIC DRAFT

Table 2-1 Groundwater Basins with Adjudicated Areas Prior to SGMA[1]

Map ID	Adjudicated Area Name[2]	Court Judgment Date	Basin(s) Wholly or Partially Covered by the Adjudicated Area
A01	Beaumont Basin (1)	2004	8-002.08 San Timoteo 7-021.04 San Gorgonio Pass
A02	Chino Basin (4)	1978	8-002.01 Chino
A03	Cucamonga Basin (5)	1978	8-002.02 Cucamonga
A04	Central Basin (3)	1965	4-011.04 Central
A05	West Coast Basin (26)	1961	4-011.03 West Coast
A06	Wright Judgement (7)	1989	3-016 Goleta Basin
A07	Main San Gabriel Basin (9)	1968	4-013 San Gabriel Valley
A08	Mojave Basin Area (10)	1996	6-037 Coyote Lake Valley 6-038 Caves Canyon Valley 6-040 Lower Mojave River Valley 6-041 Middle Mojave River Valley 6-042 Upper Mojave River Valley 6-043 El Mirage Valley 6-047 Harper Valley 6-089 Kane Wash Area 7-019 Lucerne Valley 6-044 Antelope Valley 6-049 Superior Valley 6-050 Cuddeback Valley 7-015 Bessemer Valley 7-018.01 Soggy Lake
A09	Raymond Basin (12)	1944	4-023 Raymond
A10	San Bernardino Basin Area (8,14,15) Includes Riverside Basin Area North, Riverside Basin Area South, and Lytle Basin adjudicated areas.	1969	8-002.03 Riverside-Arlington 8-002.04 Rialto-Colton 8-002.06 San Bernardino (formerly Bunker Hill Subbasin) 8-005 San Jacinto
A11	Rialto-Colton Basin (13) Included in the San Bernardino Basin Area adjudication.	1961	8-002.04 Rialto-Colton

PUBLIC DRAFT

Map ID	Adjudicated Area Name[1]	Court Judgment Date	Basin(s) Wholly or Partially Covered by the Adjudicated Area
A12	Santa Margarita River Watershed (17)	1966	8-005 San Jacinto 9-004 Santa Margarita Valley 9-005 Temecula Valley 9-006 Cahuilla Valley
A13	Santa Maria Valley Basin (18) Includes three management areas – Santa Maria Valley Management Area, Nipomo Management Area, and Northern Cities Management Area.	2008	3-012.01 Santa Maria
A14	Santa Paula Basin (19)	1996	4-004.04 Santa Paula
A15	Scott River Stream System (20)	1980	1-005 Scott River Valley
A16	Seaside Basin (21)	2006	3-004.08 Seaside
A17	Six Basins (22)	1998	4-013 San Gabriel Valley
A18	Tehachapi Basin (23)	1971	5-028 Tehachapi Valley West 6-045 Tehachapi Valley East
A19	Cummings Basin (6)	1972	5-027 Cummings Valley
A20	Brite Basin (2)	1970	5-080 Brite Valley
A21	Upper Los Angeles River Area (24)	1979	4-012 San Fernando Valley
A22	Puente Basin (11)	1987	4-013 San Gabriel Valley
A23	Warren Valley Basin (25)	1997	7-012 Warren Valley
A24	Hemet-San Jacinto Basin (16)	2013	8-005 San Jacinto
A25	Los Osos Basin	2015	3-008.01 Los Osos Area
A26	Antelope Valley	2015	6-044 Antelope Valley
A27	Inyo County Basins	1991	6-012.01 Owens Valley
A28	Nipomo Mesa Management Area	2014	3-012.01 Santa Maria

PUBLIC DRAFT

Map ID	Adjudicated Area Name[1]	Court Judgment Date	Basin(s) Wholly or Partially Covered by the Adjudicated Area
A29	Northern Cities Management Area	2015	3-012.01 Santa Maria
A30	Lytle Basin (8) This adjudication has been absorbed by the San Bernardino Basin Area adjudication.	1924	8-002.06 San Bernardino (formerly Bunker Hill)

Table 2-1 Notes:

1. *The list of basins wholly or partially covered by adjudicated areas was developed as part of the 2018 Basin Prioritization process. Several basins were excluded because the adjudication did not encompass significant areas of the basin and therefore lacked substantial influence on basin management.*
2. *The number in parenthesis is the identification assigned by SGMA in Water Code 10720.8(a).*

The watermaster for each of the adjudicated areas listed in Water Code Section 10720.8(a) was required to submit a copy of a governing final judgement, or other judicial order or decree, to DWR by April 1, 2016. In addition, to the extent the information is available per Water Code Section 10720.8(e), a report containing the following was required to be submitted to DWR by April 1, 2016, and annually thereafter.

- Groundwater elevation data unless otherwise submitted pursuant to Water Code Section 10932.
- Annual aggregated data identifying groundwater extraction for the preceding water year.
- Surface water supply used for or available for use for groundwater recharge or in-lieu use.
- Total water use.
- Change in groundwater storage.
- The annual report submitted to the court.

All available information, and Adjudicated Area Annual Reports submitted on behalf of the adjudicated areas are posted on DWR's SGMA Portal website. Additional information about California's new adjudicated actions since the passage of SGMA is provided in the "Regulatory Oversight" section of this chapter.

PUBLIC DRAFT

Figure 2-2 Areas with Pre-SGMA Groundwater Adjudications



2.3.3 Groundwater Management Special Act Districts

Special districts are public agencies created to provide one or more specific services to a community, such as water service, sewer service, parks, fire protection, and others. Special districts first arose in California in the late 1800s to meet the needs of farmers in the San Joaquin Valley. The Turlock Irrigation District was the first publicly owned special district formed in California in 1887 under the Wright Act, which allowed farming regions to form and bond irrigation districts for the purpose of pooling resources to develop infrastructure to get water to where it was needed. Special districts are limited in purpose and are separate from cities and counties. In California, there are over 3,300 special districts that range in size from a few acres to hundreds of square miles, with nearly 1,300 providing some form of water service. In California there is a difference between a "special district" and a "special act district." Special act districts are created through specific legislation tailored to meet the unique water management needs of a particular region; they provide local agencies with additional management authorities. While all special act districts are special districts, not all special districts are special act districts.

In California, there are about 120 special act districts. Many of these special act districts, established by the Legislature, consist of various authorities, which may include groundwater management.

In response to specific local groundwater management concerns over the years, the Legislature granted a greater level of authority to manage groundwater to a few local agencies or districts referred to as "groundwater management special act districts." As part of SGMA, in Water Code Section 10723(c)(1), 18 agencies are recognized as having the ability to manage groundwater by statute and, as a result, were deemed "exclusive local agencies" with authority to form a GSA and manage groundwater basins within their statutory boundaries. The specific authority of each agency varies, but they are generally able to conduct the following activities:

- Develop a groundwater management plan.
- Control groundwater-related exports.
- Collect fees or taxes on groundwater pumping or for other groundwater-related activities.
- Regulate or require the reporting of groundwater pumping.

PUBLIC DRAFT

- In some situations, special act districts have authority for other groundwater management activities such as recharge and conjunctive use.

Of the 18 exclusive local agencies listed in SGMA, 13 elected to become a GSA in one or more high- or medium-priority basins underlying their service area. Table 2-2 provides a list of the groundwater management special act districts along with information on overlying basins, basin priority, and GSA, GSP, or Alternative status.

Table 2-2 Groundwater Management Special Act Districts in SGMA

Special Act District[1]	Basin Name (Basin ID)	Basin Priority[2]	GSA Formed	GSP Status[3]	Alternative Status
Alameda County Flood Control and Water Conservation District, Zone 7	Livermore Valley (2-010)	Medium	Yes	—	Approved
Alameda County Water District	Niles Cone (2-009.01)	Medium	Yes	—	Approved
Desert Water Agency	Indio (7-021.01)	Medium	Yes	—	Approved
Desert Water Agency	Mission Creek (7-021.02)	Medium	Yes	—	Approved
Fox Canyon Groundwater Management Agency	Oxnard (4-004.02)	High	Yes	Approved	—
Fox Canyon Groundwater Management Agency	Pleasant Valley (4-006)	High	Yes	Approved	—
Fox Canyon Groundwater Management Agency	Las Posas (4-008)	High	Yes	Approved	—
Fox Canyon Groundwater Management Agency	Arroyo Santa Rosa Valley (4-007)	Very Low	Yes	Approved	—
Honey Lake Valley Groundwater Management District	Honey Lake Valley (6-004)	Low	No	—	—
Kings River East Groundwater Sustainability Agency	Kings (5-022.08)	High (COB)	Yes	Approved	—

PUBLIC DRAFT

Special Act District[1]	Basin Name (Basin ID)	Basin Priority[2]	GSA Formed	GSP Status[3]	Alternative Status
Long Valley Groundwater Management District	Long Valley (6-104)	Very Low	No	—	—
Mendocino City Community Services District	Fort Bragg Terrace Area (1-021)	Very Low	No	—	—
Mono County Tri-Valley Groundwater Management District	Fish Slough (6-012.02)	Very Low	Yes	—	—
Mono County Tri-Valley Groundwater Management District	Owens Valley (6-012.02)	Low	Yes	Incomplete	—
Monterey Peninsula Water Management District	Carmel Valley (3-007)	Medium	Yes	Not Required	—
North Fork Kings Groundwater Sustainability Agency	Kings (5-022.08)	High (COB)	Yes	Approved	—
Ojai Groundwater Management Agency	Ojai Valley (4-002)	High	Yes	Approved	—
Orange County Water District	Coastal Plain of Orange County (8-001)	Medium	No	—	Approved
Pajaro Valley Water Management Agency	Pajaro Valley (3-002.01)	High (COB)	Yes	—	Approved
San Joaquin River Exchange Contractors GSA	Delta-Mendota (5-022.07)	High (COB)	Yes	Inadequate	—
Santa Clara Valley Water District	Santa Clara (2-009.02)	High	Yes	—	Approved
Santa Clara Valley Water District	Llagas (3-003.01)	High	Yes	—	Approved
Sierra Valley Groundwater Management District	Sierra Valley (5-012.01)	Medium	Yes	—	Approved
Willow Creek Groundwater Management Agency	Willow Creek (6-003)	Very Low	No	—	—

Table 2-2 Notes:

1. *The special act districts listed here are defined in Water Code Section 10723(c)(1).*
2. *COB (critically overdrafted basin) indicates whether the basin is subject to critical conditions of overdraft.*

PUBLIC DRAFT

3. *Groundwater Sustainability Plan (GSP) status determinations are current as of August 2025.*

2.3.4 County Groundwater Ordinances

Groundwater ordinances are regulatory tools that counties, cities, and other local agencies can elect to draft and enforce to manage their groundwater resources. For the purposes of this section, DWR has only reviewed ordinances enacted by California's 58 counties. Counties periodically update their ordinances, often prompted by local or regional emergencies such as droughts and wildfires or the passage of groundwater management legislation like SGMA. The drafting of an ordinance should support the declaration in the Government Code (Section 65352.5(a)) that "it is vital that there be close coordination and consultation between California's water supply or management agencies and California's land use approval agencies to ensure that proper water supply and management planning occurs to accommodate projects that will result in increased demands on water supplies or impact water resource management."

Based on DWR's review, most, if not all, of California's 58 counties have adopted groundwater ordinances that focus on addressing issues related to well construction and well destruction, in addition to other aspects of groundwater management. Most of these ordinances were enacted prior to SGMA and are intended to prevent undesirable results associated with three of SGMA's six sustainability indicators — chronic lowering of groundwater levels, reduction of groundwater storage, and degraded water quality. Some county ordinances also address the remaining three sustainability indicators, as summarized in Table 2-3 below, and are intended to prevent land subsidence, mitigate for seawater intrusion, and avoid unreasonable depletions of interconnected surface water. A comprehensive list of county ordinances, organized by DWR Region Office boundaries, is provided as Appendix G, "Hydrologic Region, Basin, and County Data."

PUBLIC DRAFT

Table 2-3 County Ordinances Addressing Seawater Intrusion, Land Subsidence, and Depletion of Interconnect Surface Water

County Ordinances on	Adopting Counties
Seawater Intrusion	Alameda, Del Norte, Humboldt, Marin, Napa, San Francisco, San Luis Obispo, San Mateo, Santa Barbara, Santa Cruz, and Sonoma
Land Subsidence	Butte, Fresno, Glenn, Imperial, Kern, Merced, and San Luis Obispo
Depletion of Interconnected Surface Water	Butte, Imperial, Fresno, Los Angeles, Merced, San Luis Obispo, Sonoma, Stanislaus, and Sutter

Table 2-3 Note: Based on DWR's review of county ordinances, most of California's 58 counties have some type of ordinance related to chronic lowering of groundwater levels, reduction of groundwater storage, and degraded water quality. Appendix G includes a comprehensive list of county ordinances.

In addition to ordinances addressing SGMA's six sustainability indicators, several counties have adopted ordinances covering other aspects of groundwater management, such as the export of groundwater from the county. Examples of counties that have ordinances requiring permits for the direct or indirect export of groundwater include Alpine, Butte, Calaveras, Glenn, Imperial, Inyo, Kings, Lake, Lassen, Merced, Modoc, Sacramento, San Joaquin, San Luis Obispo, Shasta, Sierra, Siskiyou, Tehama, and Yolo.

While these ordinances do not prohibit groundwater export outright, they generally require a permit for such activities. However, some county ordinances state that the export of groundwater is allowed without a permit. Many ordinances also include exemptions, such as allowing landowners to bypass permitting requirements if groundwater export is conducted to address flooding or root saturation on the landowner's property. Additionally, some ordinances incorporate long-term sustainability and environmental considerations. A few examples are given below:

- **Butte County** adopted an ordinance in 1996 stating that a permit for groundwater extraction shall only be granted if the extraction will not cause or increase groundwater overdraft, cause or increase saltwater intrusion, cause subsidence, exceed the aquifer's designated safe yield, or cause uncompensated injury to other water users.
- **Glenn County's** 2012 ordinance for groundwater substitution and groundwater export requires a permit which includes real-time monitoring programs and corrective actions should those activities lead to injury by

PUBLIC DRAFT

other legal water users. A Water Advisory Committee monitors the Basin Management Objectives, established in 2000, which define acceptable groundwater levels, groundwater quality, and land subsidence.

- **Imperial County** adopted an ordinance in 2006 that includes provisions to reduce or suspend groundwater extractions or exports if there is evidence of, or potential for, overdraft.
- **Inyo County** adopted ordinances in 1980 and 1994, later amended in 1998, requiring a groundwater export permit approval process to evaluate factors such as impacts on groundwater levels, springs and seeps, potential for overdraft, recharge capacity, basin storage capacity, potential for land subsidence, water quality, instream uses and users, and groundwater-dependent ecosystems.

Since the enactment of SGMA in 2014, many counties across California have updated existing ordinances and passed new ordinances to protect groundwater resources. Multiple counties have also updated their water well construction and permitting requirements. Counties have designated areas of concern either for water scarcity or water quality and require new well permit applicants to conduct additional hydrologic studies to evaluate the impact on local resources. Other counties seek to protect groundwater supplies by offsetting demand through establishing landscaping limits during dry years, requesting justification of water supply needs for new well permits, and promoting the use of alternative water sources, including non-potable water. Counties have also adopted and updated ordinances in response to drought Executive Orders N-7-22 and N-3-23 that included new well permitting requirements for local agencies to prepare for and lessen the effects of drought conditions. Table 2-4 summarizes some of the county ordinances that were adopted after the SGMA legislation was passed.

PUBLIC DRAFT

Table 2-4 County Ordinances Updated or Adopted Post-SGMA

New and Updated Ordinances Adopted Post-SGMA	Adopted by the Following Counties
General amendment of well construction and permitting guidelines	Alameda, Butte, El Dorado, Glenn, Tehama, Placer, Riverside, San Diego, San Luis Obispo, Sonoma, Tulare, and Ventura
To monitor groundwater levels	Madera and Merced
To avoid depletion of interconnected surface water	Alameda, Butte, Glenn, Placer, Sonoma, and Ventura
To augment groundwater recharge	Madera, San Diego, and Sierra
To assist with demand management	Del Norte, El Dorado, Kings, Madera, Mendocino, Merced, Placer, San Francisco, Sierra, Sonoma, Tehama, and Trinity

As previously mentioned, new county ordinances intended to control demand and ensure an adequate supply of groundwater for residents include a broad spectrum of approaches. Many county-wide provisions center around SGMA's undesirable results and sometimes require additional hydrogeologic studies to evaluate potential impacts on other uses and users of groundwater. A few examples are provided below:

- **Glenn County's** 2023 updates to its well permitting process require a consultant review to evaluate that groundwater extraction from the proposed well will not interfere with groundwater levels in existing wells, will not result in changes in groundwater storage, will not increase the risk of land subsidence, and will not impact surface water operations of navigable waters.
- **Kings County** adopted a new ordinance in 2022, requiring permits for exporting groundwater outside the county. The permit review process evaluates whether the proposed extraction and export complies with applicable GSPs and ensures no undesirable results under SGMA, along with other aspects of long-term sustainability.
- **San Luis Obispo County** amended its 2015 groundwater export ordinance in 2022, allowing for the transfer of groundwater between two agencies during a water supply emergency.

PUBLIC DRAFT

2.3.5 Groundwater Management Legislation

California instituted a comprehensive regulatory framework for surface water supplies in 1914 but did not attempt such regulation of groundwater supplies statewide until SGMA went into effect in 2015. The evolution of groundwater management legislation in California progressed from individual legislative efforts to address specific local or regional groundwater concerns or needs toward more comprehensive efforts and, as discussed below, continues to focus on local control by local agencies and GSAs, consistent with California's policy that sustainable groundwater management is best achieved locally through the development, implementation, and updating of plans and programs based on the best available science (Water Code Section 113).

Pre-SGMA Groundwater Management Legislation

In 1991, California Legislature passed Assembly Bill (AB) 255, which authorized local agencies overlying basins subject to critical conditions of overdraft, as identified in DWR's Bulletin 118-1980, to levy fees and establish programs for groundwater management within their service areas. In 1992, the State provided local agencies with an opportunity for formal, albeit voluntary, groundwater management with the passage of AB 3030, the Groundwater Management Act. AB 3030 outlined the procedure and recommended content to be included in a groundwater management plan (GWMP) for either a groundwater basin, a portion of a basin, or multiple basins. The AB 3030 legislation also established a systematic process for developing a GWMP for all groundwater basins defined in Bulletin 118-1980, not just those basins that are subject to critical conditions of overdraft. It established DWR's role in groundwater management as providing technical and financial assistance to support local agencies in their groundwater management efforts.

In 2002, Senate Bill (SB) 1938 was signed into law, modifying Water Code Section 10750 *et seq*. to require public agencies seeking grant funding for groundwater projects to prepare a GWMP with required and recommended components (see Water Code Sections 10753.7 and 10753.8). The SB 1938 requirements included both basin and non-basin areas, depending on groundwater management responsibilities of the local agency drafting the GWMP.

The Water Conservation Act of 2009 (SB X7-6) established collaboration between local monitoring parties and DWR to collect statewide groundwater elevation measurements and have that data be made available to the public. In response to the law, DWR developed the California Statewide Groundwater Elevation

PUBLIC DRAFT

Monitoring (CASGEM) Program, which allowed local agencies and other entities to voluntarily create a monitoring program and upload groundwater level data to the publicly available CASGEM website, with the focus on spring (seasonal high) and fall (seasonal low) measurements. The monitoring entities participating in the CASGEM Program were at an advantage if they had an existing GWMP for their basin and could use wells in their monitoring program for their CASGEM monitoring network.

AB 359 was signed into law in 2011 and directed local agencies to identify and define groundwater recharge areas. The legislation also required that GWMPs, for the first time, be submitted to DWR where they are required to be publicly available. DWR maintains a list of more than 125 GWMPs on its Non-SGMA Groundwater Management website; however, most of the GWMPs have been replaced by GSPs.

Sustainable Groundwater Management Act

SGMA was signed into law in September 2014 amidst the five-year drought of 2012–2016 that exacerbated groundwater conditions and demonstrated the threats facing California's water resources. During this drought, groundwater levels declined throughout the state, overdraft continued in many basins, land subsidence damaged infrastructure, seawater intrusion threatened coastal aquifers, and degraded groundwater quality posed health risks, including risks to the state's most vulnerable and economically disadvantaged populations.

SGMA was comprised of three separate bills: AB 1739, SB 1168, and SB 1319. These bills collectively and fundamentally changed the course of California's groundwater management by creating a new regulatory framework for sustainable groundwater management while recognizing and preserving the authority of cities and counties to manage groundwater according to their existing powers. SGMA was enacted on the premise that groundwater is best managed at the local level and that the State's primary role is to provide assistance, and regulatory oversight and intervention.

The legislative intent of SGMA, as defined in Water Code Section 10720.1, is to do all of the following:

- "To provide for the sustainable management of groundwater basins."
- "To enhance local management of groundwater consistent with rights to use or store groundwater and Section 2 of Article X of the California Constitution. It is the intent of the Legislature to preserve the security of water rights in

PUBLIC DRAFT

the state to the greatest extent possible consistent with the sustainable management of groundwater."

- "To establish minimum standards for sustainable groundwater management."
- "To provide local groundwater agencies with the authority and the technical and financial assistance necessary to sustainably manage groundwater."
- "To avoid or minimize subsidence."
- "To improve data collection and understanding about groundwater."
- "To increase groundwater storage and remove impediments to recharge."
- "To manage groundwater basins through the actions of local governmental agencies to the greatest extent feasible, while minimizing state intervention to only when necessary to ensure that local agencies manage groundwater in a sustainable manner."
- "To provide a more efficient and cost-effective groundwater adjudication process that protects water rights, ensures due process, prevents unnecessary delay, and furthers the objectives of this part."

While SGMA applies to all 515 groundwater basins in California, compliance with the SGMA requirements is mandatory for only 94 high- and medium-priority groundwater basins. Basin priority is established by DWR through the basin prioritization process discussed below in this chapter. Local agencies in the state's high- and medium-priority groundwater basins are authorized to form GSAs, develop and implement GSPs or submit Alternatives (functionally equivalent GSPs), and achieve groundwater sustainability within 20 years of adopting and submitting those respective plans. DWR may extend this deadline if GSAs demonstrate sufficient progress and need (Water Code Section 10727.2(b)(3)).

Roles and Responsibilities of Agencies Implementing SGMA

Local agencies have always played an important role in California's groundwater management, whether preparing and implementing an AB 3030 GWMP for a portion of a groundwater basin, crafting and implementing city or county ordinances, or deciding to become a GSA and preparing and implementing a GSP for an entire basin.

Water Code Section 10752(g), which was established as part of AB 3030 in 1992, defines "local agency" as "a local public agency that provides water service to all or a portion of its service area, and includes a joint powers authority formed by

PUBLIC DRAFT

local public agencies that provide water service." SGMA defines "local agency" in Water Code Section 10721(n) as "a local public agency that has water supply, water management, or land use responsibilities within a groundwater basin." Only local agencies meeting AB 3030's definition can prepare GWMPs, and only local agencies meeting SGMA's definition can decide to become GSAs and develop and adopt GSPs.

Counties play an important role in groundwater management. In addition to historically crafting and enforcing groundwater ordinances and locally managing groundwater, SGMA provides counties with a backstop role to become GSAs and manage all or portions of their basins to avoid potential intervention by the State Water Board. As stated in Water Code Section 10724(a), "In the event that there is an area within a high- or medium-priority basin that is not within the management area of a GSA, the county within which that unmanaged area lies will be presumed to be the GSA for that area."

DWR has four main roles in implementing SGMA, and each of these roles are discussed in this chapter:

1. A statutory and regulatory role, which includes development and implementation of the regulations governing basin boundaries and GSP development, evaluation and assessment of plans and plan amendments, review of annual reports, continued assessment of periodic evaluations, and consultation with the State Water Board in certain circumstances.
2. A planning assistance role, which includes facilitation support services, written translation, and verbal interpretation services to help keep the beneficial uses and users of groundwater informed.
3. A technical assistance role, which includes providing technical information, groundwater basin characterization, groundwater monitoring, models, planning tools, guidance documents and Best Management Practices, and data to help local agencies and GSAs make informed decisions.
4. A financial support role to help local agencies and GSAs develop and implement their groundwater sustainability programs.

In high- or medium-priority groundwater basins subject to SGMA where GSAs are unable or unwilling to sustainably manage their groundwater basins, SGMA allows for State Water Board intervention. During the intervention process, the State Water Board works with the GSAs to resolve deficiencies in their GSPs or implementation efforts while also working directly with pumpers to collect information.

PUBLIC DRAFT

When DWR, in consultation with the State Water Board, determines that a basin's GSP or its implementation are "inadequate," primary oversight and jurisdiction shift to the State Water Board. At that point, state intervention may progress through several phases:

1. The State Water Board considers the basin GSP, or GSPs, and efforts to address deficiencies and whether to notice a public hearing.
2. The State Water Board holds a public hearing and decides whether to designate the groundwater basin as probationary.
3. If the deficiencies are not resolved after at least one year of probation, the State Water Board further decides whether to notice another public hearing where it may adopt an interim plan for the basin.

The State Water Board's decision to designate a basin as probationary is not automatic and does not begin immediately. Similarly, the decision as to whether an interim plan is necessary cannot be made until at least one year of probation has occurred. SGMA requires that an interim plan adopted by the State Water Board must include corrective actions to stop overdraft, a schedule for the corrective actions, and a monitoring plan. It is important to note that the state intervention process can end at any point before or during these phases if GSAs address the deficiencies identified in the GSP, or GSPs, for the basin.

SGMA recognizes that an interim plan may implement actions to help protect groundwater resources, such as groundwater pumping restrictions. The most direct example of groundwater pumping restrictions is enforcing a groundwater extraction allocation, which sets limits on how much groundwater each well owner in a probationary basin is allowed to pump. Another potential action identified in SGMA for an interim plan is the development of a physical solution. A physical solution, as it pertains to an interim plan, may be infrastructure that is used to help manage groundwater or increase water supplies. An engineered basin that allows water to percolate into an underlying aquifer, known as a recharge basin, is an example of a physical solution. Physical solutions can be used to help increase the supply or quality of groundwater.

2.3.6 Coordination Between Water Agencies and Land Use Agencies

According to the Governor's Office of Land Use and Climate Innovation (formerly the Governor's Office of Planning and Research), a general plan is a "local government's blueprint for meeting the community's long-term vision for the

PUBLIC DRAFT

future," the purpose of which is to guide land use planning decisions. California law, as specified in Government Code Section 65300, requires that each of the 58 counties and 482 cities develop and adopt a general plan. The Government Code, as amended by SGMA, in Title 7 (Planning and Land Use), Division 1, Chapter 3 (Local Planning), Article 6 (Preparation, Adoption, and Amendment of the General Plan), Section 65352.5(a) and (b) states, among other coordination aspects, that:

- The Legislature finds and declares that it is vital that there be close coordination and consultation between California's water supply or management agencies and California's land use approval agencies to ensure that proper water supply and management planning occurs to accommodate projects that will result in increased demands on water supplies or impact water resource management.
- It is, therefore, the intent of the Legislature to provide a standardized process for determining the adequacy of existing and planned future water supplies to meet existing and planned future demands on these water supplies and the impact of land use decisions on the management of California's water supply resources.

There are additional requirements, introduced in 2015 and updated in 2016, for local land use planning agencies to coordinate with GSAs and entities managing a basin under an Alternative, as well as the State Water Board if a basin is under probation. Among other items, upon receiving notification of a city or county's proposed action to adopt or amend a general plan, those entities are required to provide information to the planning agencies, including a report describing the anticipated effect of the proposed land use changes on the implementation of a GSP. One of the goals of this statutory addition is to ensure the vision for long-range planning in California is met and to ensure that land use decisions consider the availability of water supplies, and vice versa.

Among the planning and technical considerations introduced by SGMA in 2015 and 2016, the Water Code states in Section 10726.9 that, "A [GSP] shall take into account the most recent planning assumptions stated in local general plans of jurisdictions overlying the basin." A GSP is also required, per Water Code Section 10727.2(g), to provide a description of the consideration given to the applicable county and city general plans, as well as a description of the various adopted water resources related plans and programs, with an assessment of how the GSP may affect those plans. Accordingly, SGMA added to the Government Code in Section 65350.5 a requirement for general plans to consider GSPs, basin

PUBLIC DRAFT

adjudications, and intervention actions of the State Water Board before the adoption or any substantial amendment of a general plan.

In a December 2024 search of the California General Plan Database Mapping Tool developed in 2023 by the University of California, Davis, general plans from 56 out of 58 counties mention "water," while 453 out of 482 city general plans mention the word "water." When searching for the word "groundwater," the word is found in about the same number of general plans — 57 of 58 county plans mention "groundwater" while 448 out of 482 city plans mention the topic. However, when searching for the term "sustainable groundwater management," a term introduced by SGMA in 2015, the term is found in only 13 county and 34 city general plans. Generally, cities and counties adopt or amend their general plans only after several or more years have passed, and so the number of plans addressing SGMA is expected to increase as time passes. General Plan Guidance Documents can be found on the Governor's Land Use and Climate Innovation website.

In addition to plans governing groundwater, which include GSPs prepared in accordance with Part 2.74 of the Water Code, Alternatives, basin adjudications, and GWMPs prepared in accordance with Part 2.75 of the Water Code, additional water-related plans should also be considered when making land use decisions. Examples of these plans are provided below:

- City and County General Plans.
- Delta Conveyance Project Operations Plan.
- Flood Planning and Studies.
    - Central Valley Flood Protection Plan (CVFPP).
    - CVFPP Conservation Strategy.
    - CVFPP Basin-Wide Feasibility Studies.
    - Regional Flood Management Plans.
- Water Quality Control Plans.
    - Water Quality Control Plan for the San Francisco. Bay/Sacramento-San Joaquin Delta Estuary.
    - Nine Regional Board Water Quality Control Plans (Basin Plans).
    - California Ocean Plan.
- The Delta Plan.
- Delta Protection Commission Land Use and Resource Management Plan.

PUBLIC DRAFT

2.3.7 Other Related Local and Regional Groundwater Management Plans and Programs

Because groundwater is a key water source for urban and agricultural users, groundwater information is also presented in other required or voluntary plans as listed below. There may also be other local or regional plans, efforts, or projects that may have a nexus to groundwater resources that contain information that may be useful for local, regional, and statewide groundwater planning.

- Urban Water Management Plans.
- Agricultural Water Management Plans.
- Integrated Regional Water Management Plans.
- Needs Assessment Reports under DWR's Disadvantaged Community and Tribal Involvement Grant Program.
- Salt and Nutrient Management Plans.
- Irrigated Lands Regulatory Program.
- Safe and Affordable Funding for Equity and Resilience.
- Storm Water Resource Plans.

2.4 DWR's Sustainable Groundwater Management Program

Effective statewide groundwater management is vital to ensuring the state's future water supply is reliable and continues to be resilient. While surface water has been regulated statewide for over a century, groundwater resources have not. Past practices of excessive groundwater use, particularly during dry periods, have resulted in critically overdrafted conditions in 21 basins that cover about one fifth of the total groundwater basin area in California. When the SGMA was passed in 2014, these 21 basins cumulatively extracted 63% of the state's total groundwater pumped; and contributed to California's agricultural economy; provided drinking water to communities, including underrepresented communities; and supplied groundwater for the natural environment.

With groundwater serving as a cornerstone of California's water system, proactive local, regional, and statewide actions are needed to protect California's groundwater resources that support our communities, environment, economy, and agriculture in the most equitable way feasible. SGMA provides the foundation for bolstering local management of groundwater resources. The State continues to

PUBLIC DRAFT

have a critical oversight and assistance role in groundwater management that includes providing data and technical planning support and assistance; ensuring strong alignment with other local and regional plans and programs; and continuing to invest in groundwater recharge, demand reduction, infrastructure, and conveyance options. The State's assistance enables local and regional agencies to comprehensively manage surface water and groundwater, provide water quality improvements, develop drinking water solutions, achieve agricultural efficiencies, and support ecosystem health. These coordinated efforts aim to align State actions, enhance support for local agencies, and foster inclusivity, engagement, public awareness, and education around groundwater management.

DWR established the Sustainable Groundwater Management Program in October 2014 to support the implementation of SGMA, thereby continuing its broader mission to advance sustainable groundwater management across California.

2.4.1 Statutory Responsibilities

The first 12 chapters of Water Code, Division 6, Part 2.74, established a roadmap for DWR and other State and local agencies to build the foundation of California's first groundwater regulatory program. Below is a summary of each of SGMA's 12 chapters and a summary of DWR's statutory roles and responsibilities in implementing SGMA.

- Chapters 1 and 2
    - Present the legislative intent of SGMA.
    - Outline what portions of California are subject to SGMA.
    - Establish initial planning deadlines.
    - Provide definitions for the technical terms that apply to SGMA.
- Chapter 3
    - Reiterates that the State's groundwater basin boundaries are memorialized in Bulletin 118.
    - Requires DWR to create and adopt regulations by January 1, 2016, to allow local agencies to request that a basin's boundaries be modified based on scientific or jurisdictional criteria.
    - Requires DWR to establish an initial priority for each basin by January 31, 2015, and to reprioritize all the State's groundwater basins any time it updates Bulletin 118 basin boundaries.
- Chapters 4, 5, 8, and 9

PUBLIC DRAFT

    - Address the formation and responsibilities of GSAs.
    - Chapter 4 outlines the process that local agencies must follow to become a GSA and defines the ministerial role that DWR has in posting complete GSA formation notifications.
    - Once a GSA is formed, Chapters 5, 8, and 9 list the powers and authorities, financial authorities, and enforcement roles, respectively, given to GSAs once they adopt and submit a GSP to DWR for review and assessment.
- Chapter 6 outlines the preparation, structure and contents of a GSP.
- Chapter 7 authorizes DWR to provide various forms of technical assistance and guidance and exempts these efforts from the Administrative Procedure Act.
- Chapter 10 stipulates how DWR staff must evaluate a GSP and an Alternative for adequacy.
- Chapter 11 describes the intervention role of the State Water Board when a GSA in a high- or medium-priority basin does not form and has unmanaged areas, or when DWR determines a GSP to be inadequate, or when DWR determines a GSP is not being adequately implemented.
- Chapter 12, added in 2016, prescribes certain procedures to integrate new streamlined adjudication actions with SGMA requirements.

Groundwater Sustainability Agency Formation

SGMA established a new structure for managing California's groundwater resources at the local level by local agencies. SGMA defines "local agency" as a local public agency that has water supply, water management, or land use responsibilities within a groundwater basin. Any local agency or combination of local agencies overlying a groundwater basin can form a GSA using either a joint powers agreement (JPA), a memorandum of agreement, or other legal agreement. DWR's role in GSA formation is to post complete notifications on its SGMA Portal and track the designation of exclusive GSAs.

SGMA, as set out in Chapter 4 (Water Code Section 10723 *et seq*.), required GSAs to form in the state's high- and medium-priority basins by June 30, 2017, resulting in formation of approximately 260 GSAs in 140 basins by that initial planning milestone. At that time, many GSAs were formed in low and very-low priority basins. Some GSAs were formed by one local agency in a small portion of a single basin, while other GSAs were formed by one or more local agencies that covered

PUBLIC DRAFT

all or portions of multiple basins. Many GSAs, such as those formed by counties or large water districts, have groundwater management responsibilities in multiple basins. Depending on the sustainability goal defined in a basin's GSP, a GSA's groundwater management program in one basin could be different than its management program in an adjacent basin.

Since the initial formation milestone for GSAs, additional GSAs have been formed, and some have disbanded to adapt to basin management needs. Numerous exclusive GSAs have made non-material changes to their posted notifications, generally to make small modifications to their intended management area because of changes in service area coverage (land annexation) or to better align with basin boundaries. Some GSAs have withdrawn individual notices and resubmitted as a coordinated JPA effort, while other GSAs have merged multiple notifications into a single notification to better organize governance. Some local agencies have withdrawn from legal agreements to form stand-alone GSAs.

PUBLIC DRAFT

Figure 2-3 Number of GSAs in Each Groundwater Basin (December 2024)

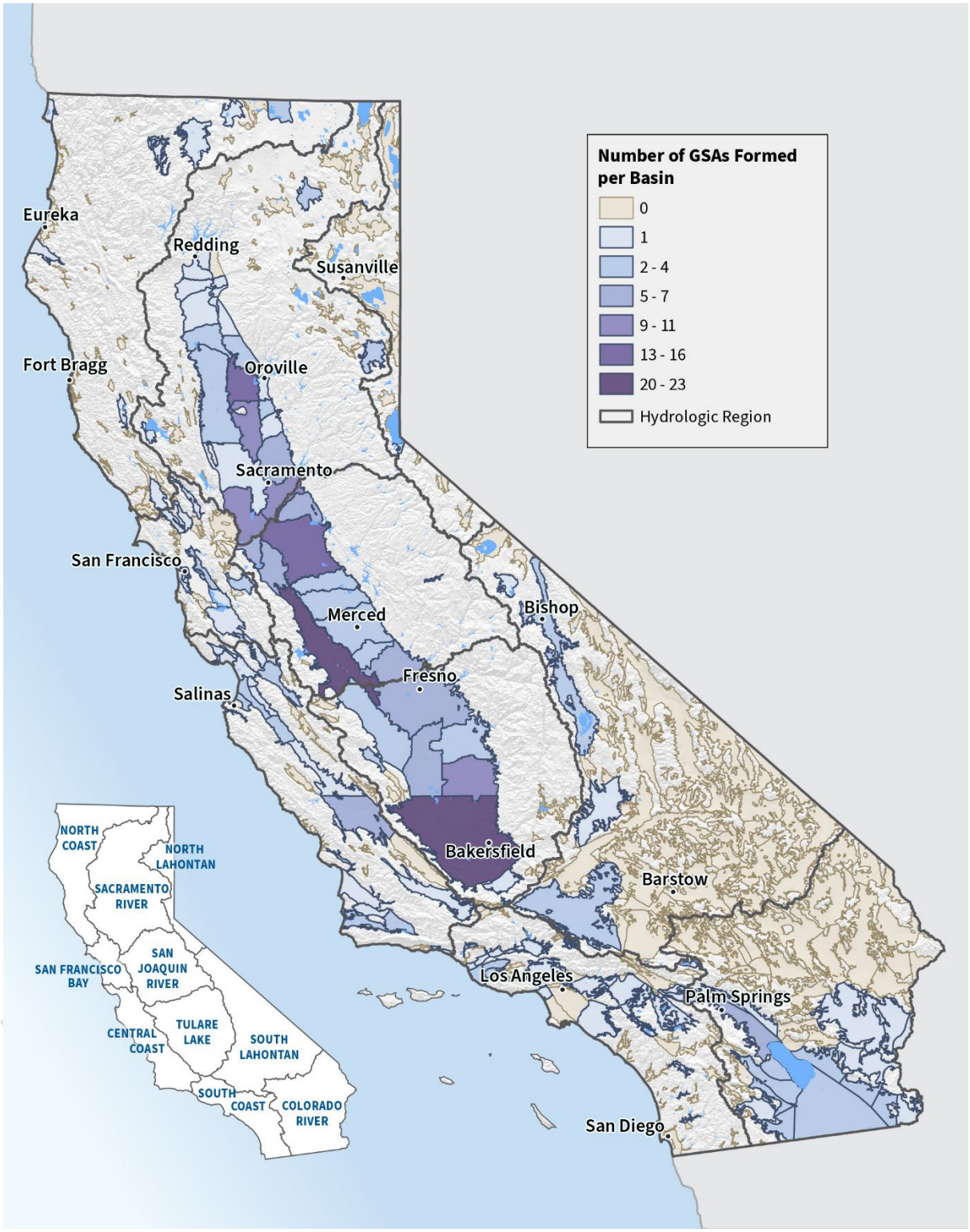


Figure 2-3 Note: Numbers not included in the legend indicate that there are no basins with that number of GSAs.

As of December 2024, a total of 257 GSAs have formed across 142 basins, established either by a single local agency or a combination of local agencies. For data reporting purposes, GSAs covering more than one basin are separated into basin-specific GSAs on DWR's SGMA Portal. Some of those basin-specific GSAs include multiple notifications within the same basin which reflect local governance decisions, and some are for "fringe areas" in basins that are mostly adjudicated. Figure 2-3 is a statewide map showing the geographic distribution of basin-specific GSAs, or in other words, the number of GSAs formed in each basin. As SGMA implementation continues, new GSAs may be formed, and existing GSAs may reorganize, consolidate, or withdraw from managing all or part of a basin.

Basin Boundary Regulations

With the passage of SGMA, Section 10722.2 was added to the Water Code allowing local agencies, or an entity directed by the court in a groundwater adjudication, to request that DWR revise the boundaries of a basin, including the establishment of new subbasins. Water Code Section 10722.2 also required DWR to adopt regulations regarding the information required for the submittal and consideration of basin boundary modification requests by January 1, 2016. The basin boundary regulations (California Code of Regulations, Title 23, Division 2, Chapter 1.5, Subchapter 1 [CCR Title 23 Section 340 *et seq*., or Basin Boundary Regulations]) were adopted by DWR on October 21, 2015, and the provisions of the Basin Boundary Regulations became effective on November 16, 2015.

The 2016 Basin Boundary Modifications (approved by DWR on October 16, 2016) were the first round of modifications corresponding to the adopted Basin Boundary Regulations. The 2016 modifications were developed through DWR's technical review of modification requests and public comments made during the submission period, which was January 1 through March 31, 2016. During this submission period, DWR received 54 basin boundary modification requests, as shown in Table 2-5. Of these, 39 requests were approved, 12 were denied, and three were not accepted because they were incomplete. At the conclusion of the first round of modifications in 2016, there were 517 basins, up from the 515 identified in 2003.

A second round of basin boundary modifications (2018 Basin Boundary Modifications) were released by DWR on February 11, 2019. In this round, DWR received 43 modification requests, of which 35 were approved, four were denied, and four were partially approved. At the conclusion of the 2018 boundary adjustments, there were — and remain as of 2025 — 515 groundwater basins and subbasins, down from the 517 identified in 2016. All the basin boundary

PUBLIC DRAFT

modification requests, supporting information, and public comments for the 2016 and 2018 basin boundary modification rounds can be viewed online at DWR's Basin Boundary Modifications website.

Table 2-5 Basin Boundary Modification Requests

Year	Requests Received	Requests Approved	Requests Denied	Requests Not Accepted (Incomplete)	Requests Partially Approved	Resulting Number of Basins	Change
2016	54	39	12	3	0	517	Up 2 from 2003
2018	43	35	4	0	4	515	Down 2 from 2016

Keeping in line with the intent of the Basin Boundary Regulations and the State's commitment to achieving sustainable groundwater management, DWR does not currently have plans to open a new round of basin boundary modifications for the State's 515 groundwater basins. GSAs have begun implementing their respective GSPs using the powers and authorities granted to them by SGMA, and maintaining basin boundaries provides continuity as sustainable conditions are pursued and corrective planning actions are addressed. However, DWR continues to evaluate the need for basin boundary modifications in alignment with SGMA objectives and may consider future opportunities as appropriate. Additionally, as provided by the Basin Boundary Regulations in Section 346.6 and defined in Section 341(b), DWR can make minor administrative adjustments to basin boundaries to reflect their intended area, either as needed or upon local request.

Basin Prioritization

Basin prioritization is a technical process that uses the best available data and information to classify California's groundwater basins into one of four categories: high, medium, low, or very low priority. DWR is required to prioritize basins using a technical process based on eight components that are identified in Water Code Section 10933(b):

1. The population overlying the basin or subbasin.
2. The rate of current and projected growth of the population overlying the basin or subbasin.

PUBLIC DRAFT

3. The number of public supply wells that draw from the basin or subbasin.
4. The total number of wells that draw from the basin or subbasin.
5. The irrigated acreage overlying the basin or subbasin.
6. The degree to which persons overlying the basin or subbasin rely on groundwater as their primary source of water.
7. Any documented impacts on the groundwater within the basin or subbasin, including overdraft, subsidence, saline intrusion, and other water quality degradation.
8. Any other information determined to be relevant by DWR, including adverse impacts on local habitat and local streamflows.

Before passage of SGMA, basin prioritization was first required as part of California's 2009 Comprehensive Water Package, which established Part 2.11, "Groundwater Monitoring," of the Water Code. Part 2.11 added general provisions that required DWR to identify the extent of groundwater elevation monitoring undertaken within each basin and directed DWR to prioritize basins for that purpose. In response to those new requirements, DWR established the California Statewide Groundwater Elevation Monitoring (CASGEM) Program and began prioritizing groundwater basins for the first time. In June 2014, DWR released the first prioritization for the state's groundwater basins as the CASGEM 2014 Basin Prioritization.

With the passage of SGMA, DWR was required to update basin priority for each groundwater basin no later than January 31, 2015 (Water Code Section 10722.4[b]). SGMA also requires DWR to reassess basin prioritization any time groundwater basin boundaries are changed (Water Code Section 10722.4[c]) and added the evaluation of adverse effects on local habitat and local stream flows to the prioritization criteria listed in Water Code Section 10933(b). The initial SGMA 2015 Basin Prioritization utilized the CASGEM 2014 Basin Prioritization, which categorized 127 of the 515 groundwater basins in the state as high- or medium-priority.

In the fall of 2016, DWR released the 2016 Basin Boundary Modifications and began the process of updating the priority of the newly-modified 517 groundwater basins. In May of 2018, DWR released the draft basin prioritization results for those 517 basins and held a 94-day public comment period. Simultaneously, local agencies requested a subsequent round of basin boundary modifications, resulting in the 2018 Basin Boundary Modifications that reduced the number of groundwater

PUBLIC DRAFT

basins back to 515. This required DWR to prioritize the 515 basins in two phases (referred to as SGMA 2019 Basin Prioritization Phases 1 and 2), which are described below.

Phase 1 of the SGMA 2019 Basin Prioritization effort was completed on January 4, 2019. It identified 56 high- and medium-priority basins in the state. Phase 2 was completed on December 18, 2019, and identified an additional 38 high- and medium-priority basins in the state. The combined results of Phases 1 and 2 of the 2019 Basin Prioritization effort identified a total of 94 high- and medium-priority basins in the state. As defined in Water Code Section 10720.7, only high- and medium-priority basins are required to be managed under a GSP or an Alternative.

As part of the SGMA 2019 Basin Prioritization effort, DWR estimated that the 94 high- and medium-priority basins, and the state's adjudicated areas, account for 98% of the groundwater extraction (20 million acre-feet), 83% of the population (25 million Californians), and 88% of all irrigated agricultural acres (6.7 million acres) in the in-basin parts of the state.

Groundwater Sustainability Plan Regulations

SGMA required DWR to draft and adopt emergency regulations for the evaluation of GSPs and alternatives to GSPs (Alternatives), the implementation of GSPs and Alternatives, and coordination agreements. The GSP Regulations (California Code of Regulations, Title 23, Division 2, Chapter 1.5, Subchapter 2, [CCR Title 23 Section 350 *et seq*. or GSP Regulations]) were developed following a comprehensive multi-phased public outreach and engagement process.

Throughout 2015 and into 2016, DWR met regularly with numerous SGMA advisory groups and conducted public meetings and webinars to gather perspectives from statewide interested parties, partners, and local agencies. The input received was considered in the Draft GSP Emergency Regulations. On May 18, 2016, the revised and proposed GSP Emergency Regulations were presented to the California Water Commission and were unanimously approved, as written. After approval, the final GSP Regulations and the Notice of Proposed Emergency Rulemaking were submitted to the Office of Administrative Law in accordance with the Administrative Procedure Act. There are nine Articles in the GSP Regulations as follows:

- Article 1. Introductory Provisions.
- Article 2. Definitions.

PUBLIC DRAFT

- Article 3. Technical and Reporting Standards.
- Article 4. Procedures.
- Article 5. Plan Contents.
- Article 6. Department Evaluation and Assessment.
- Article 7. Annual Reports and Periodic Evaluations by the Agency.
- Article 8. Interagency Agreements.
- Article 9. Alternatives.

Article 5, Plan Contents, describes the required contents of GSPs, including administrative information, a description of the basin setting, sustainable management criteria, description of the monitoring network, and projects and management actions. DWR published a *GSP Annotated Outline Guidance Document* and a *Preparation Checklist for GSP Submittal Guidance Document* in December 2016 to help GSAs with the development and future reporting of GSPs and to ensure that complete GSPs were submitted for review and assessment.

The first plans prepared in accordance with the GSP Regulations were the Alternatives, which were submitted to DWR to meet SGMA's statutory deadline of January 1, 2017. The GSPs from the state's critically overdrafted basins were required to be submitted by January 31, 2020. All other GSPs in the remaining high- and medium-priority basins were required to be submitted by January 31, 2022. A discussion of submitted GSPs and DWR's determination of GSPs as approved, incomplete, or inadequate is provided in the Regulatory Oversight section of this chapter.

Technical Assistance – Best Management Practices and Guidance Documents

Chapter 7 of SGMA in Water Code Section 10729(a) directs DWR to provide technical assistance to entities that extract or use groundwater to promote water conservation and protect groundwater resources. In response, DWR has developed and is implementing a variety of technical support services to help GSAs and local agencies make informed planning decisions, implement their GSPs and Alternatives, and fill data gaps.

The Water Available for Replenishment report and its assessment of groundwater recharge potential in California has been foundational to DWR's groundwater recharge assistance efforts and its technical programs to characterize and

PUBLIC DRAFT

prioritize groundwater recharge areas. Additional groundwater recharge planning will be conducted as part of the California Water Plan Update 2028, in accordance with SB 659 of 2023, to "provide actionable recommendations to develop additional groundwater recharge opportunities that increase the recharge of the state's groundwater basins without reducing the amount of water available for environmental purposes or any other purpose allowed under state law."

DWR also develops Best Management Practices (BMPs), and guidance documents as part of its technical assistance. These resources provided by DWR are intended to assist GSAs and local agencies in developing and implementing GSPs and Alternatives. All the finalized and draft BMPs and guidance documents are available on DWR's Best Management Practices and Guidance Documents website. Additional information about BMPs and guidance documents are provided below within the Technical Assistance section of this Chapter.

Basins Subject to Critical Conditions of Overdraft

Overdraft is the condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which the water supply conditions approximate average conditions. Overdraft can be characterized by groundwater levels that decline over a period of years and never fully recover, even in wet years. Moreover, groundwater overdraft can cause adverse effects including chronic decline of groundwater levels, loss of stored groundwater, intrusion of seawater into coastal basins, land subsidence, degradation of water quality, and stream flow depletion, as well as increased pumping costs.

In 1978, an amendment to the Water Code directed DWR to investigate the state's groundwater basins, define their boundaries, and identify basins "subject to critical conditions of overdraft" (Water Code Section 12924(a)). In 1980, DWR published *Ground Water Basins in California: A Report to the Legislature in Response to Water Code Section 12924* (Bulletin 118-80), which characterized 11 groundwater basins in California as subject to critical conditions of overdraft. As defined in Bulletin 118-80, a basin is subject to critical conditions of overdraft when continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts.

In 2015, DWR updated the list of basins subject to critical conditions of overdraft. As part of the reevaluation process, if one or more adverse effects of overdraft were documented in a portion of a basin during the hydrologic base period (Water

PUBLIC DRAFT

Years 1989 through 2009), that groundwater basin was identified as subject to critical conditions of overdraft. In January 2016, DWR released a list of 21 groundwater basins identified as subject to critical conditions of overdraft. A description of the evaluation process that defined overdraft is documented in *Bulletin 118 — CalGW Interim Update 2016*.

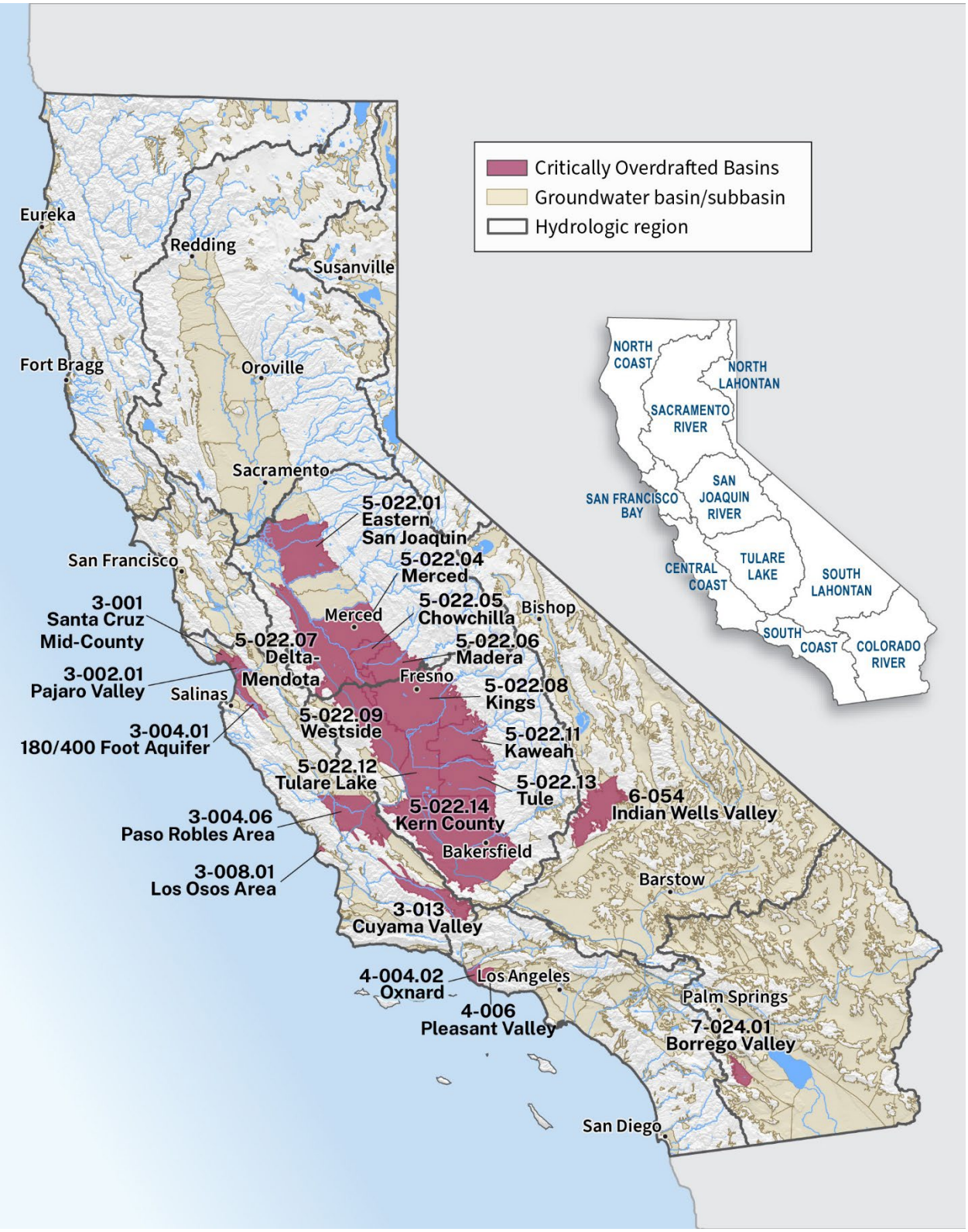
The 21 critically overdrafted groundwater basins are depicted in Figure 2-4 and listed in Table 2-6. The statutory deadline for a critically overdrafted basin to be managed under a GSP (or an Alternative) was January 31, 2020.

Table 2-6 Groundwater Basins Subject to Critical Conditions of Overdraft

Basin Number	Basin Name
3-001	Santa Cruz Mid-County
3-002.01	Pajaro Valley
3-004.01	180/400 Foot Aquifer
3-004.06	Paso Robles Area
3-008.01	Los Osos Area
3-013	Cuyama Valley
4-004.02	Oxnard
4-006	Pleasant Valley
5-022.01	Eastern San Joaquin
5-022.04	Merced
5-022.05	Chowchilla
5-022.06	Madera
5-022.07	Delta-Mendota
5-022.08	Kings
5-022.09	Westside
5-022.11	Kaweah
5-022.12	Tulare Lake
5-022.13	Tule
5-022.14	Kern County
6-054	Indian Wells Valley
7-024.01	Borrego Springs

PUBLIC DRAFT

Figure 2-4 Groundwater Basins Subject to Critical Conditions of Overdraft



2.4.2 Regulatory Oversight

Following the finalization of the Basin Boundary Regulations in 2015 and the GSP Regulations in 2016, DWR's first SGMA regulatory oversight phase began in 2017 with the evaluation and assessment of alternatives to GSPs (Alternatives), which are functionally equivalent GSPs. DWR completed the assessments of Alternatives in July 2019, and DWR's determinations of those Alternatives can be found on the SGMA Portal. The next regulatory oversight phase started with the basins subject to critical conditions of overdraft. For those basins that submitted GSPs in January 2020, DWR provided initial assessments within its two-year statutory deadline. On January 18, 2024, DWR completed the initial reviews for all other basins that were required to submit a GSP in January 2022. DWR's GSP determinations of adequacy can be found on the SGMA Portal.

DWR's regulatory oversight role is ongoing. Following the adoption of a GSP or an Alternative, GSAs and local agencies are required to submit an annual report by April 1 of each year with data and information pertaining to groundwater elevations; annual groundwater extraction amounts; surface water supply used, or available for use, for groundwater recharge; total water use; and change in groundwater storage. DWR is required to review the information provided in the annual report and determine if the plan is being followed. Additionally, at least every five years after the initial submission of a GSP or an Alternative, DWR is required to complete a periodic review and issue an assessment characterizing the basin's progress on implementing the plan and achieving the basin's sustainability goal.

Alternatives to Groundwater Sustainability Plans

SGMA allowed local agencies or GSAs with an existing basinwide groundwater management structure to submit an alternative to a GSP (Alternative). An Alternative, per Water Code Section 10733.6(b), may be based on any of the following, and must explain how the elements of an Alternative are functionally equivalent to a GSP described in the GSP Regulations:

- An existing groundwater management plan (see Water Code Section 10750 *et seq*.) or other law authorizing groundwater management.
- Groundwater management pursuant to an adjudication action.
- An analysis of basin conditions that demonstrates the basin has operated within its sustainable yield over a period of at least 10 years.

PUBLIC DRAFT

For basins designated as high- or medium-priority prior to January 31, 2015, the statutory deadline for submitting an Alternative was January 1, 2017. DWR received Alternatives from 15 basins by the statutory deadline and, of the submitted plans, only one basin, the Pajaro Valley Subbasin, was subject to critical conditions of overdraft.

Alternatives from nine basins, including the Pajaro Valley Subbasin, were approved by DWR on July 17, 2019, and plans from six basins were not approved. The six basins that did not receive an approval in July 2019 submitted their respective GSPs by the statutory deadline of January 31, 2022. As summarized in Table 2-7, the agencies from the nine approved basins resubmitted their Alternatives in late 2021 and early 2022 in accordance with the regulatory requirement to do so every five years, which initiated DWR's review of those plans. Following the statutory and regulatory (GSP Regulations Section 355.6) requirement to evaluate a plan and issue an assessment at least every five years, DWR approved all nine resubmitted Alternatives on June 27, 2024.

PUBLIC DRAFT

Table 2-7 Groundwater Basins Managed Under an Alternative to GSP

Basin ID	Basin Name	Alternative Based on	Date Periodic Evaluation Submitted	Date of DWR's Periodic Review Assessment	Current Alternative Status
2-009.01	Niles Cone	Existing Plan	December 29, 2022	June 27, 2024	Approved
2-009.02	Santa Clara	Existing Plan	December 17, 2022	June 27, 2024	Approved
3-002.01	Pajaro Valley	Existing Plan	December 24, 2022	June 27, 2024	Approved
3-003.01	Llagas Area	Existing Plan	December 17, 2022	June 27, 2024	Approved
6-005.01	Tahoe South	Existing Plan	April 28, 2022	June 27, 2024	Approved
7-021.01	Indio	Existing Plan	December 29, 2022	June 27, 2024	Approved
7-021.02	Mission Creek	Existing Plan	December 30, 2022	June 27, 2024	Approved
2-010	Livermore Valley	10-Year Analysis	December 21, 2022	June 27, 2024	Approved
8-001	Coastal Plain of Orange County	10-Year Analysis	December 28, 2022	June 27, 2024	Approved
7-024.01	Borrego Springs	New Adjudication Action	Stipulated Judgement Submitted June 25, 2021	February 25, 2025	Approved

Table 2-7 Notes: Nine Alternatives approved on June 27, 2024, were initially approved on July 17, 2019. The Alternative for the Borrego Springs Subbasin was submitted on June 25, 2021, and was approved on February 25, 2025.

PUBLIC DRAFT

For basins that were reprioritized as high- or medium-priority after January 31, 2015, as an option, a local agency had two years to either form a GSA and submit a GSP or submit an Alternative (Water Code Section 10722.4[d][1]). The only groundwater basin that submitted an Alternative after the initial planning deadline of January 2017 was the Borrego Springs Subbasin, which submitted an Alternative, based on management pursuant to an adjudication, on June 25, 2021. The Borrego Springs Subbasin Alternative was approved by DWR on February 25, 2025.

Comprehensive Groundwater Adjudications – Post SGMA

After SGMA was enacted, new legislation was passed adding provisions to the Water Code and the Code of Civil Procedure (SB 226, AB 779, and AB 1390) that established new processes for future adjudications. The methods and procedures for comprehensive adjudications are defined by the Code of Civil Procedure in Part 2, Title 10, Chapter 7, Section 830 *et seq*. — *Actions Related to Groundwater Rights* and in the Water Code in Division 6, Part 2.74, Chapter 12, Section 10737 *et seq*. — *Determination of Rights to Groundwater*.

DWR is required to post on its website information related to adjudication actions that are submitted by plaintiffs to those actions (see Code of Civil Procedure Section 836(m)). Since *CalGW Update 2020* was prepared, DWR has received and posted the following new or proposed adjudications. More information with hyperlinks to adjudication details is available on DWR's Adjudicated Areas website:

- Santa Barbara Channelkeeper v. State Water Resources Control Board (Adjudication filed on September 19, 2014).
    - This comprehensive adjudication is for the Ventura River Watershed and includes four groundwater basins, which are: Upper Ojai Valley Basin (4-001), Ojai Valley Basin (4-002), Upper Ventura River Subbasin (4-003.01), and Lower Ventura River Subbasin (4-003.02).
    - The GSP covering the Ojai Valley Basin was approved by DWR on October 26, 2023. The GSP covering the Upper Ventura River Subbasin was approved by DWR on April 27, 2023. The Upper Ojai Valley Basin and the Lower Ventura River Subbasin are prioritized as very low and are not required to have a GSP.
- Las Posas Valley Water Rights Coalition et al. v. Fox Canyon Groundwater Management Agency et al. (Adjudication filed on March 27, 2018, and finalized on July 10, 2023.)

PUBLIC DRAFT

    - This adjudication is for the Los Posas Valley Basin (4-008).
    - The GSP covering the Las Posas Valley Basin was approved by DWR on January 13, 2022.
- Borrego Water District v. All Persons Who Claim a Right to Extract Groundwater in the Borrego Valley Groundwater Subbasin, etc., et al. (Adjudication filed on January 30, 2020, and finalized on April 8, 2021.)
    - The Borrego Springs Watermaster submitted a new adjudication action for the Borrego Springs Subbasin (7-024.01) as a SGMA Alternative on January 31, 2020, and an updated Alternative on June 25, 2021. The Alternative, which is the physical solution of the adjudication, was approved by DWR on February 25, 2025.
- *OPV Coalition et al. v. Fox Canyon Groundwater Management Agency et al*. — Oxnard Groundwater Subbasin and Pleasant Valley Groundwater Basin. (Adjudication filed on June 15, 2021.)
    - The GSPs covering the Oxnard Subbasin (4-004.02) and the Pleasant Valley Basin (4-006) were both approved by DWR on November 18, 2021.
- Indian Wells Valley Water District v. All Persons Who Claim a Right to Extract Groundwater in the Indian Wells Valley Groundwater Basin, etc., et al. (Adjudication filed on June 16, 2021.)
    - The GSP covering the Indian Wells Valley Basin (6-054) was approved by DWR on January 13, 2022.
- Bolthouse Land Company, LLC et al. v. All Persons Claiming a Right to Extract or Store Groundwater in the Cuyama Valley Groundwater Basin. (Adjudication filed on August 17, 2021.)
    - The GSP covering the Cuyama Valley Basin was approved by DWR on May 25, 2023.

Groundwater Sustainability Plans

SGMA described the contents of a GSP in Water Code Section 10727 *et seq*. and presented general coordination and public noticing requirements, as well as mandates to consider the beneficial uses and users of groundwater within a basin when establishing sustainable management criteria. A GSP can be either:

1. A single plan covering an entire basin developed and implemented by one GSA.

PUBLIC DRAFT

2. A single plan covering the basin developed and implemented by multiple GSAs.
3. Multiple plans implemented by multiple GSAs and coordinated pursuant to a coordination agreement that covers the entire basin.

A GSP, or an Alternative as previously described in this chapter, is required in 93 of California's 94 high- and medium-priority basins. The Carmel Valley Basin is a medium priority basin but is managed under the State Water Board's subterranean stream designation rather than a GSP. A plan or multiple plans (either an Alternative or a GSP) were prepared and adopted in 102 of California's 515 basins, because some low and very-low priority basins voluntarily submitted a plan. Figure 2-5 is a statewide map illustrating the geographic distribution of the number of GSPs and Alternatives developed in each basin, and highlights where multiple plans were prepared within a single basin.

PUBLIC DRAFT

Figure 2-5 Number of GSPs and Alternatives in Each Groundwater Basin (April 2025)

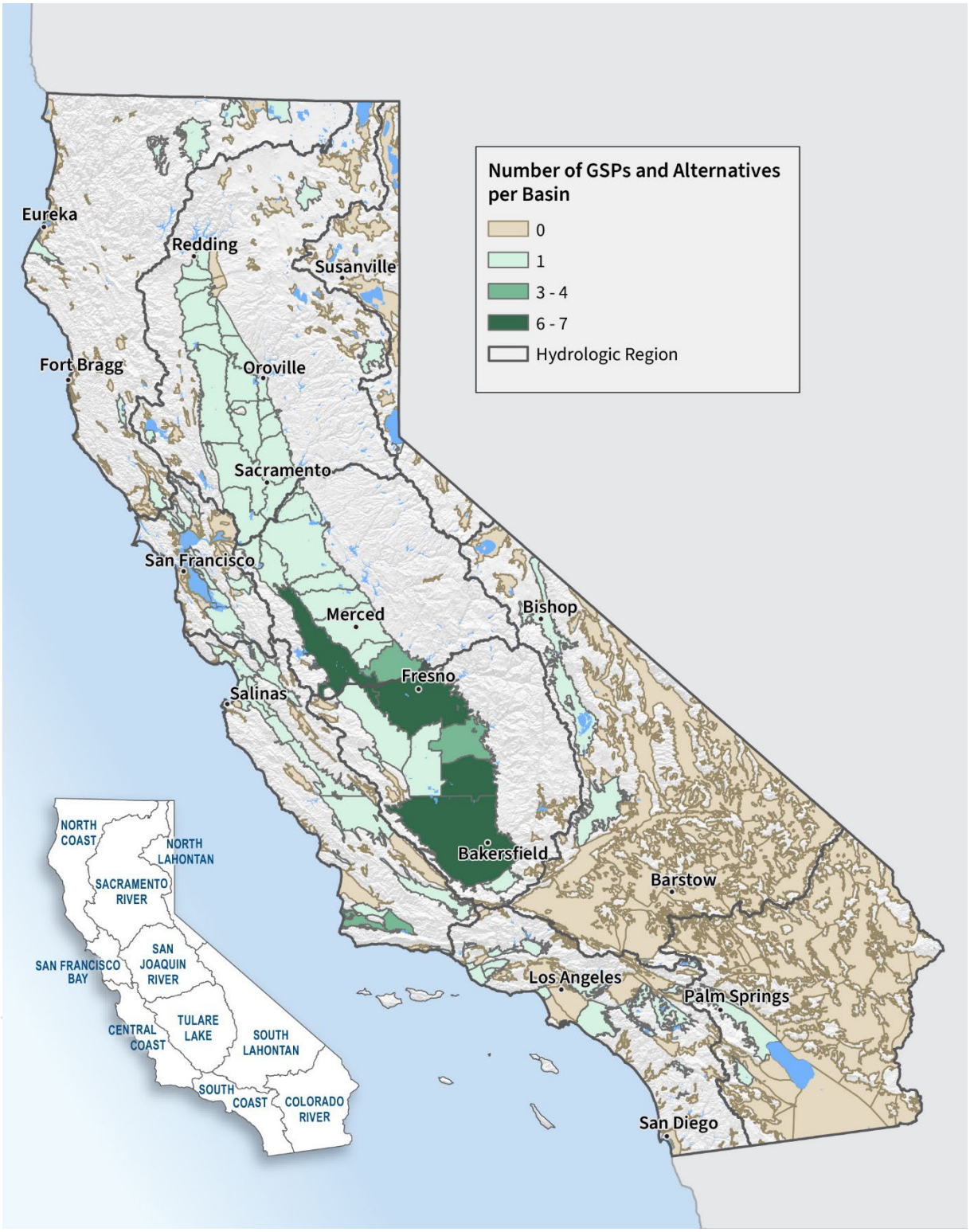


Figure 2-5 Note: Numbers not included in the legend indicate that there are no basins with that number of GSPs or Alternatives.

The GSP deadline for the 21 basins subject to critical conditions of overdraft was January 31, 2020, and the GSP deadline for all other high- and medium-priority basins was January 31, 2022. Two basins, the Montecito Basin and the Carpinteria Basin, were reprioritized as medium priority and high priority, respectively, in December 2019 and were assigned a GSP deadline of December 2024 per Water Code Section 10722.4(d).

DWR is required to issue a written assessment, and indicate in that assessment whether the GSP was approved, incomplete, or inadequate (see GSP Regulations Section 355.2). GSP evaluations and assessments involve the application of DWR's professional and expert judgment. DWR applies a substantial compliance regulatory standard to make individualized, basin-specific determinations.

- An **approved** GSP is one that satisfies the requirements of SGMA and substantially complies with the GSP Regulations. DWR may recommend **corrective actions** to address discrepancies, including measures to improve management or implementation of approved plans to better ensure they achieve sustainable groundwater management within the planning and implementation horizon.
- An **incomplete** GSP has one or more deficiencies that preclude its approval but has the potential to be corrected in a timely manner, not to exceed 180 days. DWR may recommend **corrective actions** to address a deficiency in an incomplete plan.
- An **inadequate** GSP is one that does not comply with the GSP Regulations and has not corrected its deficiencies by the plan's statutory deadline or was initially determined to be incomplete but did not take sufficient actions to warrant an approval.

On February 27, 2025, DWR completed the final review for all basins that were required to submit GSPs. DWR's adequacy determinations can be viewed on the SGMA Portal. The status of GSPs and Alternatives across California's groundwater basins as of August 2025 is summarized in Table 2-8 and Figure 2-6. Additionally, Table 2-9 provides a complete list of GSP evaluation status by basin, while Table 2-7, earlier in this chapter, provides a complete list of the evaluation status for Alternatives. Additional details are provided in the sections below.

PUBLIC DRAFT

Table 2-8 Summary of GSP and Alternative Status as of August 2025

Type of Plan and Approval Status	Number of Basins	Basin Priority
GSP — Approved	81	76 High and Medium 5 Very Low
GSP — Inadequate[1]	7	High
GSP — Incomplete	4	Low and Very Low
Alternative — Approved	10	High and Medium
No GSP or Alternative Submitted[2]	413	1 Medium 412 Low and Very Low

Table 2-8 Notes:

1. *As of August 2025, the GSP covering the Chowchilla Subbasin has been returned to DWR following an inadequate determination and State Intervention, and the GSP is currently under DWR review.*
2. *The medium priority basin that did not submit a GSP is the Carmel Valley Basin, which is managed under the State Water Resources Control Board's subterranean stream designation and is not required to submit a GSP.*

PUBLIC DRAFT

Figure 2-6 Groundwater Management Under SGMA as of August 2025

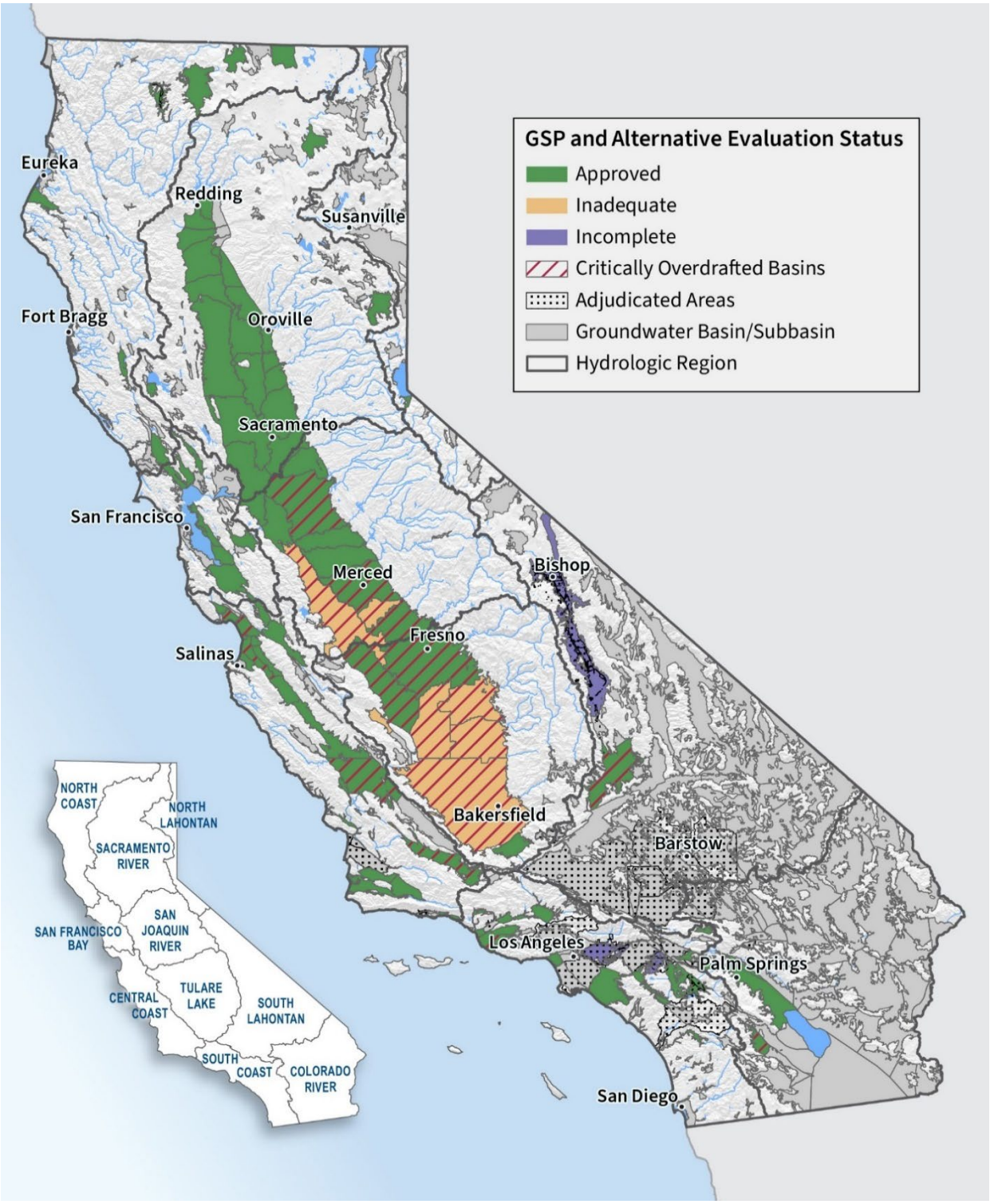


Figure 2-6 Notes: As of August 2025, the GSP covering the Chowchilla Subbasin has been returned to DWR following inadequate determination and State Intervention, and the GSP is currently under DWR review.

Table 2-9 Groundwater Basins with GSPs as of August 2025

Basin ID	Basin Name	Priority	GSP Status
1-002.01	Tulelake	Medium	Approved
1-003	Butte Valley	Medium	Approved
1-004	Shasta Valley	Medium	Approved
1-005	Scott River Valley	Medium	Approved
1-010	Eel River Valley	Medium	Approved
1-052	Ukiah Valley	Medium	Approved
1-055.01	Santa Rosa Plain	Medium	Approved
2-001	Petaluma Valley	Medium	Approved
2-002.01	Napa Valley	High	Approved
2-002.02	Sonoma Valley	High	Approved
2-009.04	East Bay Plain	Medium	Approved
3-001	Santa Cruz Mid-County	High	Approved
3-003.05	North San Benito	Medium	Approved
3-004.01	180/400 Foot Aquifer	High	Approved
3-004.02	East Side Aquifer	High	Approved
3-004.04	Forebay Aquifer	Medium	Approved
3-004.05	Upper Valley Aquifer	Medium	Approved
3-004.06	Paso Robles Area	High	Approved
3-004.09	Langley Area	High	Approved
3-004.10	Monterey	Medium	Approved
3-004.11	Atascadero Area	Very Low	Approved
3-009	San Luis Obispo Valley	High	Approved
3-013	Cuyama Valley	High	Approved
3-014	San Antonio Creek Valley	Medium	Approved
3-015	Santa Ynez River Valley	Medium	Approved
3-018	Carpinteria	High	Approved
3-027	Santa Margarita	Medium	Approved
3-049	Montecito	Medium	Approved
4-002	Ojai Valley	High	Approved
4-003.01	Upper Ventura River	Medium	Approved
4-004.02	Oxnard	High	Approved
4-004.03	Mound	High	Approved
4-004.05	Fillmore	High	Approved
4-004.06	Piru	High	Approved

PUBLIC DRAFT

Basin ID	Basin Name	Priority	GSP Status
4-004.07	Santa Clara River Valley East	High	Approved
4-006	Pleasant Valley	High	Approved
4-007	Arroyo Santa Rosa Valley	Very Low	Approved
4-008	Las Posas Valley	High	Approved
4-011.01	Santa Monica	Medium	Approved
4-013	San Gabriel Valley	Very Low	Incomplete
5-004	Big Valley	Medium	Approved
5-006.01	Bowman	Very Low	Approved
5-006.03	Anderson	Medium	Approved
5-006.04	Enterprise	Medium	Approved
5-012.01	Sierra Valley	Medium	Approved
5-015	Big Valley	Medium	Approved
5-021.50	Red Bluff	Medium	Approved
5-021.51	Corning	High	Approved
5-021.52	Colusa	High	Approved
5-021.54	Antelope	High	Approved
5-021.56	Los Molinos	Medium	Approved
5-021.57	Vina	High	Approved
5-021.60	North Yuba	Medium	Approved
5-021.61	South Yuba	High	Approved
5-021.62	Sutter	Medium	Approved
5-021.64	North American	High	Approved
5-021.65	South American	High	Approved
5-021.66	Solano	Medium	Approved
5-021.67	Yolo	High	Approved
5-021.69	Wyandotte Creek	Medium	Approved
5-021.70	Butte	Medium	Approved
5-022.01	Eastern San Joaquin	High	Approved
5-022.02	Modesto	High	Approved
5-022.03	Turlock	High	Approved
5-022.04	Merced	High	Approved
5-022.05	Chowchilla	High	Inadequate[1]
5-022.06	Madera	High	Approved
5-022.07	Delta-Mendota	High	Inadequate
5-022.08	Kings	High	Approved

PUBLIC DRAFT

Basin ID	Basin Name	Priority	GSP Status
5-022.09	Westside	High	Approved
5-022.10	Pleasant Valley	Medium	Inadequate
5-022.11	Kaweah	High	Inadequate
5-022.12	Tulare Lake	High	Inadequate
5-022.13	Tule	High	Inadequate
5-022.14	Kern County	High	Inadequate
5-022.15	Tracy	Medium	Approved
5-022.16	Cosumnes	Medium	Approved
5-022.18	White Wolf	Medium	Approved
5-022.19	East Contra Costa	Medium	Approved
5-029	Castac Lake Valley	Very Low	Incomplete
6-012.01	Owens Valley	Low	Incomplete
6-054	Indian Wells Valley	High	Approved
7-021.04	San Gorgonio Pass	Medium	Approved
8-002.03	Riverside-Arlington	Very Low	Incomplete
8-002.07	Yucaipa	High	Approved
8-002.09	Temescal	Medium	Approved
8-004.01	Elsinore Valley	Medium	Approved
8-004.02	Bedford-Coldwater	Very Low	Approved
8-005	San Jacinto	High	Approved
8-009	Bear Valley	Very Low	Approved
9-007.01	Upper San Luis Rey Valley	Medium	Approved
9-010	San Pasqual Valley	Medium	Approved

Table 2-9 Note: As of August 2025, the GSP covering the Chowchilla Subbasin has been returned to DWR following inadequate determination and State Intervention, and the GSP is currently under DWR review.

BASINS SUBJECT TO CRITICAL CONDITIONS OF OVERDRAFT – JANUARY 31, 2020, PLANNING DEADLINE

In January 2020, GSPs from 21 basins were submitted to DWR for review, which included 18 of California's 21 critically overdrafted basins. Three critically overdrafted basins did not submit a GSP to DWR: Borrego Springs Subbasin submitted an Alternative on June 25, 2021, based on a new adjudication action in January 2020; Pajaro Valley Subbasin was not required to submit a GSP because its Alternative covering that basin was approved by DWR in July 2019; and Los Osos Basin is an adjudicated area and is not required to prepare a GSP.

PUBLIC DRAFT

In addition to the plans from the critically overdrafted basins, GSPs from three other basins (Las Posas Valley Basin, North Yuba Subbasin, and South Yuba Subbasin) were submitted two years early.

Following the initial review of plans submitted in January 2020, GSPs from eight basins were approved and GSPs from 13 basins were determined incomplete. Of the 13 basins that initially had incomplete GSPs, plans from seven of those basins were ultimately approved after correcting deficiencies while plans from the remaining six basins were determined to be inadequate and were disapproved following consultation with the State Water Board. Of the six critically overdrafted basins that had inadequate GSPs, all but the Tulare Lake Subbasin were covered by multiple plans, which required a coordination agreement.

GSPS IN HIGH- AND MEDIUM-PRIORITY BASINS – JANUARY 31, 2022, PLANNING DEADLINE

GSAs from a total of 63 basins submitted GSPs to DWR for review to meet the January 31, 2022, planning deadline. DWR's evaluation and assessment of those plans were conducted in five "batches" to meet SGMA's statutory review deadline of two years. Of the 63 basins that submitted plans, GSPs from 50 basins were approved and GSPs from 13 basins were determined incomplete. Only one of the basins that submitted a GSP in January 2022 prepared multiple plans: the Santa Ynez River Valley Basin's plan consisted of three GSPs covering three management areas, and all were approved.

Of the 13 basins that were determined to be incomplete in January 2024, all but one were ultimately approved by DWR on February 27, 2025, after corrections. The Pleasant Valley Subbasin (Basin No. 5-022.10) was determined to be inadequate and was disapproved following consultation with the State Water Board.

Two basins, the Montecito Basin and the Carpinteria Basin, were reprioritized as medium priority and high priority, respectively, in December 2019 and were assigned a GSP deadline of December 2024 (the Montecito Basin submitted its GSP in June 2023 and the Carpinteria Basin submitted its GSP in February 2024). The GSPs from both of those two basins were approved on February 27, 2025.

GROUNDWATER MANAGEMENT IN LOW- AND VERY LOW-PRIORITY BASINS

As of August 2025, nine low- or very-low priority basins have submitted GSPs to DWR. Four of those GSPs are incomplete as of August 2025. For the remaining 412 low- and very low-priority basins, management under a GSP is encouraged

PUBLIC DRAFT

but is not required. Local agencies in low- and very-low priority basins remain eligible to prepare GWMPs, also known as AB 3030 plans (Water Code Sections 10750–10755.4).

Prior to SGMA, a groundwater basin, portions of a basin, and areas located outside of a basin could be locally managed under a GWMP prepared in accordance with the requirements of AB 3030. One of the primary reasons, other than responsible management, for developing and adopting a GWMP in a low- or very-low priority basin is funding eligibility. As stated in Water Code Section 10753.7, a local agency seeking State funds administered by DWR for groundwater projects or groundwater quality projects, including projects that are part of an integrated regional water management program or plan, must have a GWMP. Like a GSP, a GWMP has required technical and monitoring components, as well as recommended components. DWR maintains a website for Non-SGMA Groundwater Management efforts and provides a list of more than 125 GWMPs that were developed, implemented, and updated prior to SGMA.

Annual Reports

SGMA provides, in Water Code Section 10728, that on the April 1 following the adoption of a GSP or an Alternative, and annually thereafter, a GSA or a local agency shall submit a report to DWR containing the following information about the basin managed in the respective plan:

- Groundwater elevation data.
- Annual aggregated data identifying groundwater extraction for the preceding water year.
- Surface water supply used for or available for use for groundwater recharge or in-lieu use.
- Total water use.
- Change in groundwater storage.

The GSP Regulations, in Section 356.2, list the various additional components that must be submitted annually, including: general information, including an executive summary and numerous maps; detailed description and graphical representation of surface water supply and groundwater data; and a description of progress toward implementing the GSP. All the submitted annual reports from basins with either a GSP or an Alternative are available for review on DWR's SGMA Portal and datasets containing groundwater extraction, surface water supply, total water use,

PUBLIC DRAFT

and change in storage volumes for a given water year are available on CNRA Open Data.

In October 2023, DWR published A Guide to Annual Reports, Periodic Evaluations, and Plan Amendments to provide guidance to GSAs and local agencies and to describe DWR's ongoing oversight of a basin's groundwater sustainability program. DWR reviews the annual reports each year and, if it is determined that additional information is required, DWR provides a written response to the basin's plan manager. DWR also utilizes annual reports when conducting its periodic review of GSPs and Alternatives.

DWR's Periodic Review of an Approved Plan

The GSP Regulations require a GSA to evaluate its approved GSP at least every five years and whenever the plan is amended and provide a written assessment of that evaluation to DWR. DWR reviews those plans, or any plan available from the basin, at least every five years, but may evaluate the implementation of a GSP at any time to determine whether it is consistent with the objectives of SGMA and in substantial compliance with the GSP Regulations. A GSA's periodic evaluation requirement of its approved plan is provided in Section 356.4 of the GSP Regulations. For those basins with an approved Alternative, the GSP Regulations state in Section 358.2 that the plan must be submitted to DWR at least every five years, with the option of submitting a periodic evaluation.

DWR's assessment and review of a periodic plan evaluation focuses on implementation of the basin's groundwater sustainability program, with an emphasis on assessing progress in achieving the basin's sustainability goal(s). When determining whether a GSP or an Alternative remains consistent with SGMA and is in substantial compliance with the GSP Regulations, DWR considers the following factors, as specified in GSP Regulations Section 355.6(c):

- Whether the exceedances of any minimum thresholds or failure to meet any interim milestones are likely to affect the ability of the Agency to achieve the sustainability goal for the basin.
- Whether the Agency is implementing projects and management actions consistent with the Plan, or that the Agency has demonstrated that actions described in the Plan have been rendered unnecessary based on changing basin conditions or an improved understanding of basin conditions.
- Whether the Agency is addressing data gaps and reducing the levels of uncertainty identified in the Plan.

PUBLIC DRAFT

- Whether the Plan continues to satisfy the criteria described in Section 355.4.

DWR's periodic review assessments are required to include a plan status determination, which can either be approved, incomplete, or inadequate, as outlined in the GSP Regulations in Section 355.6(d). However, DWR may evaluate the implementation of a basin's plan at any time to determine whether the GSP or Alternative is consistent with the objectives of SGMA and is in substantial compliance with the GSP Regulations.

DWR completed its first periodic reviews of the nine approved Alternatives in June 2024. For those basins that submitted GSPs by the statutory deadline in January 2020, or submitted GSPs early, the five-year periodic evaluation submission deadline was in January 2025. DWR initiated its review of approved plans from 14 basins in March 2025 to meet its mandate to issue an assessment at least every five years.

2.4.3 Planning Assistance

DWR's roles and responsibilities under SGMA include providing planning assistance services for GSAs and local agencies. DWR provides communication and engagement assistance, facilitation support services, written translation services, and verbal interpretation services to agencies participating in sustainable groundwater management. DWR has developed many toolkits, templates, and informational websites to assist agencies developing and implementing GSPs, and has hosted GSA forums to create a platform for local agencies to come together to engage and exchange ideas on topics related to GSP implementation, highlight various GSA efforts, foster professional networks, and provide an opportunity for DWR staff to identify high-priority GSA needs. DWR also established a Tribal Advisory Group in 2015 to bring together California Native American Tribal governments and Tribal communities to collaborate on outreach and engagement efforts associated with the implementation of SGMA. For information on how to access or apply for the following services, see Appendix D, "Citations, Reference Materials, and Links."

Communication and Engagement Resources

Successful implementation of SGMA is built upon a foundation of mutual understanding and proactive communication and engagement activities. DWR's proactive efforts to support local agencies and their communities include supporting periodic informational events, preparing guidance and resource documents, and developing templates that assist GSAs and local agencies as they

PUBLIC DRAFT

work toward managing groundwater to achieve sustainable conditions. DWR's Statewide Groundwater Management website is, and will remain, the primary source for up-to-date and accurate information from DWR regarding SGMA and available resources. Other forms of statewide communications about SGMA include information provided through DWR's periodic email updates posted to the SGMP listserv, as well as frequently asked questions, white papers, and other guidance.

Facilitation Support Services

DWR's Facilitation Support Services program assists GSAs and local agencies as they work through challenging water management situations. Under SGMA, GSAs are required to encourage the active involvement of diverse social, cultural, and economic interests, and to consider all beneficial uses and users of groundwater when developing and implementing GSPs. DWR provides professional facilitators to help GSAs foster discussions among various water management interests and interested parties during the development and implementation of GSPs. Since SGMA was enacted, DWR has made $8 million available in facilitation services to support the formation of GSAs and the development of GSPs in 57 basins and subbasins (as of February 2024).

Written Translation Services

Under SGMA, GSAs are tasked with encouraging the active involvement of all beneficial uses and users of groundwater during planning and implementation efforts in their respective basins. DWR's Written Translation Services program was developed to promote engagement with community members who have limited English proficiency. DWR provides written translation services to assist GSAs with better engagement in communities, incorporating feedback, and capturing a wider range of perspectives from their basins, which can help lead to successful SGMA implementation. GSAs or other associated groups may submit written notices, letters, forms, presentations, fact sheets, pamphlets, leaflets, and brochures to DWR for translation into the following languages: Chinese, Hmong, Korean, Laotian, Punjabi, Spanish, Tagalog, and Vietnamese.

Verbal Interpretation Services

The Verbal Interpretation Services program offers GSAs and local agencies simultaneous interpretation services to make engagement at local SGMA events equally accessible to all community members. Like the Written Translation Services program, the Verbal Interpretive Services program helps GSAs better engage with communities, incorporate feedback, and capture more diverse views

PUBLIC DRAFT

from their basin. Currently, the Verbal Interpretation Services program provides services in one or more of the following nine languages: American Sign Language (ASL), Chinese, Hmong, Korean, Laotian, Punjabi, Spanish, Tagalog, and Vietnamese.

Tribal Advisory Group

DWR's Office of Tribal Affairs, in conjunction with DWR's Sustainable Groundwater Management Program, formed the SGMA Tribal Advisory Group (SGMA TAG) in 2015. This advisory group was established to bring DWR and California Native American Tribal governments and Tribal communities together to collaborate on outreach and engagement efforts associated with the implementation of SGMA. Members of the SGMA TAG have assisted DWR in developing guidance documents, planning outreach events, and providing local updates on SGMA implementation across the state. DWR's Sustainable Groundwater Management Program staff will continue to work closely with DWR's Office of Tribal Affairs on SGMA-related issues and in support of Tribes. DWR is committed to a robust, collaborative, and transparent Tribal engagement process that provides for meaningful government-to-government consultation, information sharing, and opportunities for input.

2.4.4 Technical Assistance

Chapter 7 of SGMA in Water Code Section 10729(a) tasked DWR with providing technical assistance to entities that extract or use groundwater to promote water conservation and protect groundwater resources. As discussed in this section, DWR has developed and is implementing a variety of technical support services to help GSAs and local agencies make informed planning decisions, implement their GSPs and Alternatives, and fill data gaps.

Best Management Practices and Guidance Documents

DWR has published best management practices (BMPs) and other guidance documents for sustainable groundwater management on its website. The information provided in these documents assists local agencies and GSAs in updating and implementing GSPs and Alternatives. BMPs and guidance documents do not substitute for GSP Regulations or the statutory provisions of SGMA. As new information or needs arise, DWR will continue to develop relevant BMPs and other guidance to assist GSAs in achieving sustainable groundwater management consistent with SGMA timeframes and requirements.

PUBLIC DRAFT

Currently available BMPs include:

- *Land Subsidence BMP* (DRAFT — July 2025).
- BMP 6 Sustainable Management Criteria (DRAFT — November 2017).
- BMP 1 Monitoring Protocols Standards and Sites (December 2016).
- BMP 2 Monitoring Networks and Identification of Data Gaps (December 2016).
- BMP 3 Hydrogeologic Conceptual Model (December 2016).
- BMP 4 Water Budget (December 2016).
- *BMP 5 Modeling* (December 2016).

Currently available guidance documents include:

- Guidance for Managing Interconnected Surface Water Depletion (Expected 2025).
- Technical Papers on Interconnected Surface Water (DRAFT).
    - Paper 1: Depletions of ISW: An Introduction (February 2024).
    - Paper 2: Techniques for Estimating ISW Depletion Caused by Groundwater Use (September 2024).
    - Paper 3: Examples for Estimating ISW Depletion Caused by Groundwater Use (September 2024).
- Funding SGMA Implementation (March 2024).
- A Guide to Annual Reports, Periodic Evaluation, and Plan Amendments (October 2023).
- Considerations for Identifying and Addressing Drinking Water Well Impacts (April 2023).
- Resource Guide for Climate Change Data and Guidance (August 2018).
- Guidance for Climate Change Data Use During Sustainability Plan Development (August 2018).
- Stakeholder Communication and Engagement (January 2018) and subsequent Engaging and Communicating with Underrepresented Groundwater Users.
- Engagement with Tribal Governments (January 2018).
- GSP Annotated Outline (December 2016).

PUBLIC DRAFT

- Preparation Checklist for GSP Submittal (December 2016).

Technical Support Services

In the fall of 2018, DWR began accepting and reviewing service request applications for Technical Support Services (TSS) to help local agencies and GSAs make informed decisions using the best available data. The services include exploratory drilling with geologic and geophysical logging, monitoring well construction, downhole video camera surveys, groundwater sampling and analysis, groundwater level monitoring training, and other groundwater-related field activities at both basin, regional, and statewide scales to build the capacity needed to achieve sustainability. As of March 2025, DWR has completed TSS projects in 32 subbasins, constructing 234 monitoring wells at 92 sites statewide. The locations of completed TSS wells are on the SGMA Data Viewer. The majority of these wells have been equipped with automated groundwater level loggers and telemetry to record and transmit real-time, continuous groundwater level data. Water quality sampling and analyses have been performed at nearly all the monitoring wells constructed under TSS, in addition to six other existing monitoring wells. Downhole video camera surveys have also been conducted at 19 existing wells to determine otherwise unknown well construction details.

Underrepresented Communities, California Tribes, and Small Farmers Groundwater Technical Assistance Program

The Underrepresented Communities, California Tribes, and Small Farmers Groundwater Technical Assistance (URCTA) Program was established in 2021 by DWR. Its purpose is to assist underserved communities, California Native Tribes, and small farmers in accessing clean and sustainable groundwater resources while addressing significant challenges such as dry wells, water shortages, and poor water quality.

The URCTA Program offers technical support to communities facing groundwater issues, particularly in areas regulated by SGMA. Eligibility is extended to communities located within SGMA-regulated groundwater basins. The program provides a comprehensive range of services, including:

- Engineering and water system design.
- Development and improvement of water infrastructure.
- Groundwater monitoring and quality testing to ensure safety and sustainability.

PUBLIC DRAFT

- Solutions to water shortages through practical identification and implementation of strategies.
- Development of sustainable groundwater strategies for long-term planning and reliable water resources.

The URCTA Program collaborates with non-profits, academic institutions, and others, to enhance its impact and reach. This holistic approach aims to enhance water management and ensure a sustainable supply for the future.

Basin Characterization and AEM

DWR has a long history of characterizing California's groundwater basins as a part of *California's Groundwater* and through its ongoing Basin Characterization Program efforts. In 2021, DWR's Basin Characterization Program data collection effort expanded to include the collection of advanced geophysical data through the launch of the Statewide Airborne Electromagnetic (AEM) Survey Project. The goal of the AEM Survey Project was to improve the understanding of large-scale aquifer structures across the state's groundwater basins to support the implementation of SGMA. The AEM Survey Project has collected and made available approximately 16,000 miles of high-quality airborne geophysical data across California's priority groundwater basins. This unique dataset provides the groundwater community with subsurface information that improves the development and implementation of management plans to achieve groundwater sustainability.

With completion of the AEM Survey Project, DWR is undertaking the next phase of basin characterization where the AEM data will be analyzed in combination with other datasets to identify aquifer structures and subsurface conditions more thoroughly than ever before. Under the Basin Characterization Program, new and existing geologic, hydrogeologic, and geophysical data will be compiled and analyzed together to create continuous State-stewarded maps and models.

To support this effort, new data analysis tools and guidance will be developed that can generate aquifer recharge potential maps, subsurface texture models, hydrostratigraphic models (defining extent of aquifers and aquitards, depth to basement, and base of freshwater), and aquifer flow and storage parameters.

Continued data collection and analysis will be conducted through a series of groundwater investigations, first on a local scale and then expanding to a regional and statewide scale. The resulting maps and models will be regularly updated as new data becomes available, ensuring that up-to-date information is accessible for

PUBLIC DRAFT

groundwater management activities. Data access and data access equity will continue to be provided through the development of new online visualization tools that will serve as a central hub for accessing and exploring groundwater-related data in California. Additional information can be found in Chapter 3, "California's Natural and Built Groundwater Infrastructure."

SGMA Portal and Monitoring Network Module

In 2015, DWR began the development of the SGMA Portal as its online reporting system for the electronic submission, viewing, and downloading of required SGMA information. The SGMA Portal is a collection of modules covering the various aspects of SGMA implementation. These modules collect information related to basin boundaries, GSAs, GSPs, Alternatives, Adjudicated Areas, Projects and Management Actions, and associated monitoring data.

The key modules are listed below:

- **Basin Boundary Modification Request System** — receives and stores basin boundary modification requests and basin boundary descriptions.
- **GSA Formation Module** — receives GSA formation notices and provides public access to the GSA formation notices and current statuses.
- **GSP Reporting System** — receives GSPs and annual reports and provides public access to the plans and reports and, if available, DWR's assessments of the plans and reports.
- **Alternative Reporting System** — receives Alternatives and annual reports and provides public access to the plans and reports and, if available, DWR's assessments of the plans and reports.
- **Adjudicated Basins Annual Reporting System** — receives Adjudicated Area annual reports.
- **Monitoring Network Module** — receives monitoring site and associated monitoring data from various monitoring site types associated with GSP, Alternative, and Adjudicated Area implementation.
- **Projects and Management Actions Module** — receives and stores information on projects and management actions, allowing agencies to track, document, and report progress toward GSP implementation. It provides a centralized space for submitting, editing, and viewing PMAs, supporting compliance with GSP regulations.

PUBLIC DRAFT

There are other aspects to the SGMA Portal related to the submission, viewing, and downloading of SGMA-related information. Additionally, the SGMA Portal is consistently being updated to align with evolving SGMA requirements and provide the public with additional access to that information.

Interactive Tools and Data Reporting

The State has developed a suite of digital tools and datasets, described below, designed to enhance data accessibility for local and State agencies and the public. These resources provide crucial information for making informed water management decisions and ensure transparency and efficiency in our water management practices.

CALIFORNIA NATURAL RESOURCES AGENCY OPEN DATA PORTAL

The California Natural Resources Agency (CNRA) Open Data is the primary website for posting, sharing, and managing CNRA datasets. Departments within the CNRA that post and manage data through the CNRA Open Data include: DWR, Department of Conservation, Department of Fish and Wildlife, Department of Forestry and Fire Protection, and others. The underlying datasets for many of the applications and tools provided by DWR are available on the CNRA Open Data website.

SGMA DATA VIEWER

DWR has developed the SGMA Data Viewer to provide access to groundwater-related datasets that are organized by the topics under SGMA and SGMA implementation: Current Conditions, Groundwater Levels, Groundwater Storage, Water Quality, Land Subsidence, Interconnected Surface Water, Water Budget, and Basin Characterization. The SGMA Data Viewer is a one-stop shop for many datasets and resources dealing with sustainable groundwater management.

CALIFORNIA'S GROUNDWATER LIVE

In conjunction with the publication of California's Groundwater Update 2020, DWR's Sustainable Groundwater Management Office created the California's Groundwater Live (CalGW Live) website. This website includes the latest groundwater information, live statistics, and interactive dashboards, with the intent of improving public access to live and most up-to-date groundwater data. The website features current groundwater conditions, groundwater levels, well infrastructure, and land subsidence data. As more data becomes available, additional sections and interactive content will be added.

PUBLIC DRAFT

DRY WELL REPORTING

DWR's Dry Well Reporting System collects voluntary information from individuals not served by a public water system, who are experiencing dry wells and other problems with their water supply, and from agencies receiving calls from those individuals. This information system is part of the State's drought emergency response efforts and is intended to inform State and local agencies about drought impacts on household water supplies.

INTERFEROMETRIC SYNTHETIC APERTURE RADAR SUBSIDENCE DATA

DWR stewards interferometric synthetic aperture radar (InSAR) subsidence data that is made publicly available on the CNRA Open Data website. The subsidence dataset represents measurements of vertical ground surface displacement in more than 200 of the high-use and populated groundwater basins across the state starting in June of 2015.

The InSAR subsidence dataset is required as part of DWR's SGMA technical assistance to provide subsidence-related data to GSAs and local agencies for GSP and Alternative development and implementation. The dataset is available to view on the SGMA Data Viewer and is formatted to support the production of maps and graphs that show the extent, cumulative total, and annual rate of land subsidence.

WELL COMPLETION REPORTS

Water Code Section 13751 requires that anyone who constructs, alters, or destroys a water well, cathodic protection well, groundwater monitoring well, or geothermal heat exchange well must file a report of completion with DWR within 60 days of the completion of the work. Well drillers submit their Well Completion Reports (WCRs) using the Online System of Well Completion Reports (OSWCR) which is a geospatial database and index of well completion reports in California.

Well completion reports provide information about a well's location, construction, and the lithology observed during drilling. Lithologic descriptions, commonly cataloged by a driller, can be interpreted for geologic texture and used to understand the distribution of coarse-grained and fine-grained geologic materials underlying a well's location. Well completion reports are an important resource for characterizing groundwater basin conditions and developing geologic texture models.

OSWCR AND WCR MAP APPLICATION

Water Code Section 13752 allows for the release of copies of well completion reports to governmental agencies and to the public. DWR's Well Completion Report

PUBLIC DRAFT

Map Application is an interactive web-based mapping tool that spatially displays well statistics and general locations. Map application users can search for reports by location using an address or geographic coordinates.

CALIFORNIA STATEWIDE GROUNDWATER ELEVATION MONITORING PROGRAM

Since 2009, the California Statewide Groundwater Elevation Monitoring (CASGEM) program has been tracking both seasonal and long-term groundwater elevation trends across the state's groundwater basins. Collecting and analyzing these data on a statewide level is crucial for improving the management of California's groundwater resources. The CASGEM Program builds on many existing local long-term groundwater monitoring and management efforts. DWR is responsible for coordinating the program, collaborating with local entities, and maintaining groundwater elevation data through the CASGEM Online System. Currently, CASGEM wells account for approximately 13% of groundwater level monitoring wells.

DWR is also focused on expanding and enhancing California's groundwater level monitoring network, including in non-basin areas, building on the foundation established by the CASGEM Program. Currently, voluntary wells represent approximately 22% of groundwater level monitoring wells, and DWR plans to expand voluntary groundwater monitoring through community-based groundwater elevation monitoring efforts.

WATER DATA LIBRARY

DWR provides access to monitoring stations through the interactive Water Data Library (WDL) Station Map. This interactive viewer not only presents the data found in other databases, such as CASGEM, but also provides site water quality data that has been collected by DWR and continuous groundwater level time-series data from automated recorders at sites operated by DWR.

The Water Data Library includes the following datasets:

- **Groundwater Level Data:** This dataset contains seasonal and long-term groundwater level measurements collected by DWR and cooperating agencies in groundwater basins statewide. Most measurements are collected manually from wells twice per year to capture the peak high and low groundwater elevations, but the dataset also includes measurements recorded more frequently.

PUBLIC DRAFT

- **Water Quality Data:** This dataset contains historical DWR-collected chemical and physical parameters found in drinking water, groundwater, and surface water statewide.
- **Continuous Data:** This dataset contains continuous time-series data from automated recorders at sites operated by DWR. Readings are taken at 15-minute to one-hour intervals. Data in this dataset was collected from around 1930 to present, with the majority of the data collected since 1980. These stations fall into three subcategories:
    - Surface water stations (and tidal) that measure stage and/or flow of surface water features such as streams.
    - Water quality stations that measure water quality parameters such as pH, salinity, and dissolved oxygen in surface water features.
    - Groundwater stations that measure groundwater elevation and related measurements typically in groundwater wells.

Most of the monitoring sites are visited once every month or two when readings are downloaded from data recorders, reviewed, and published. The published data are formatted and displayed as daily averages, but the raw data, taken at 15-minute to one-hour intervals, can be made available on request.

GROUNDWATER AMBIENT MONITORING AND ASSESSMENT PROGRAM

The Groundwater Ambient Monitoring and Assessment (GAMA) Program presents online tools created by the State Water Board and the U.S. Geological Survey (USGS) to help users understand groundwater quality in California. The GAMA online mapping tools display information on water quality, public water system wells, and groundwater age. Most of these datasets can only be viewed within the GAMA Program's tools and cannot be downloaded.

One such tool featured in the GAMA online tools is the Groundwater Information System tool that allows for information downloads related to water quality data and public water system wells. The system integrates and displays groundwater quality data from several different sources on an interactive map interface. This system provides access to groundwater sampling results from more than 300,000 wells in California. Analytical tools and reporting features help users assess groundwater quality and identify potential groundwater quality problems in California.

PUBLIC DRAFT

LAND USE VIEWER

The CADWR Land Use Viewer allows individuals to easily view and download both statewide and existing county land use datasets. The application also enables the viewing of crop specific information and the visualization of land use change over time. The Land Use Viewer features statewide crop information for 2014, 2016, 2018–2021, and provisional statewide crop information for 2022 and 2023. Regional crop information for the Sacramento-San Joaquin Delta is available for 2015 and 2017.

AIRBORNE ELECTROMAGNETIC 3D VIEWER

Data access equity is a priority for the State and DWR. For the Statewide Airborne Electromagnetic (AEM) Survey Project, this meant ensuring technical, geophysical datasets could be visualized without access to expensive data visualization software. To support data access equity, DWR developed the AEM 3D Viewer, a novel, online, GIS-based viewer that allows the public to view and examine the AEM data in a three-dimensional space. The AEM 3D Viewer provides the public with an innovative way to visualize and understand the data collected in their groundwater basins.

GEOLOGIC MAPS - CALIFORNIA GEOLOGICAL SURVEY (CGS)

Geologic maps display the distribution of materials that are present at the surface of the Earth. Materials are typically grouped by material type, level of consolidation, and geologic age. Geologic maps provide information about surface conditions that can be useful in understanding generalized groundwater recharge conditions.

The California Geological Survey's Geologic Map of California presents an overview of the geology and structure of the state. It represents the geological features that could be found on a visit to any locality in the state. The restraints of scale limit the detail that can be shown, but the most important geologic features are depicted. The distribution of the major rock and unconsolidated sediment types and the major structural elements are shown with sufficient detail to be useful for many purposes.

OIL AND GAS WELL INFORMATION

The California Geologic Energy Management Division's (CalGEM) online mapping application, Well Finder, presents California's oil and gas and geothermal industry information from the geographic perspective. The application allows the user to locate oil, gas, and geothermal wells and other types of related facilities throughout the state. Information provided for each well includes drilling records

PUBLIC DRAFT

(typically geophysical logs); well site transfers; notices to work or re-work on wells; permits; oil and gas and geothermal operations; use type, such as oil and gas and geothermal producers versus injectors; and maintenance and safety logging information.

Well Standards – DWR Bulletin 74

California Well Standards, also known as DWR's Bulletin 74, sets the recommended minimum standards for construction, maintenance, and destruction of water supply, cathodic protection, monitoring, and geothermal heat exchange wells, for the purpose of protecting California's groundwater. *California Well Standards* are designed to reduce the chance of wells acting as conduits for contaminant movement into groundwater. Proper well construction and destruction helps prevent the introduction and spread of contaminants into the groundwater system.

In California, regulatory authority over well construction, alteration, and destruction activities is given to local jurisdictions (cities, counties, or water agencies) who have the authority to adopt a local well ordinance that meets or exceeds the model well ordinance adopted by the State Board based on the recommended well standards developed by DWR. Permitting and enforcement are carried out by the local enforcing agency, such as cities and counties, and when authorized by GSAs.

Historically, California Well Standards have included minimum separation distances, or setbacks, from potential sources of pollution to reduce the risk of groundwater contamination. Spacing wells to prevent groundwater or surface water depletion, as described in SGMA, is outside the scope of the California Well Standards. SGMA requires GSAs to consider well interference (well spacing in relation to other wells) and stream depletion (well proximity to streams), which are also outside of the scope of the California Well Standards.

DWR is developing an update to the 1991 California Well Standards to reflect the changes in standards of practice. The revised California Well Standards will reflect the current state of knowledge and be based on current standards of practice to further protect groundwater resources. The updated California Well Standards will also formally incorporate geothermal heat exchange well standards. To achieve these goals, an interdisciplinary team of DWR staff is coordinating with members of the public, industry experts, and other State and local agencies to review and

PUBLIC DRAFT

provide input for proposed changes. The revised *California Well Standards* are expected to be published in Spring 2026.

Modeling Tools

State-supported tools are essential for water accounting, providing standardized methodologies, modeling platforms, and analytical frameworks to help water managers track and manage water supply, use, and sustainability. An overview of these resources is provided in Chapter 4, "Groundwater Use, Extraction, and Water Budgets."

2.4.5 Financial Assistance

Through its Sustainable Groundwater Management (SGM) Grant Program, DWR provides funding for groundwater management planning and GSP implementation projects using a competitive grant solicitation process. The program is supported by State funding from California voter-approved statewide propositions and general funds. Eligible projects include developing and implementing GSPs; enhancing groundwater recharge using surface water, stormwater, or recycled water; and preventing and remedying groundwater contamination. The funding solicitations related to sustainable groundwater management, beginning in 2015 when SGMA went into effect, are described below.

California Groundwater Projects Tool

The California Groundwater Projects Tool, developed by the SGM Grant Program in collaboration with its consultants, is a web-based interactive map that provides a geospatial view of groundwater management projects across the state. Accessible through the SGM Grant Program's website, the tool includes information on thousands of completed, ongoing, and proposed projects that support the objectives of the Sustainable Groundwater Management Act (SGMA).

The tool presents both qualitative and quantitative data on project goals, locations, and outcomes. It is designed to serve water agencies, local interested parties and partners, and the public by improving access to groundwater project information, enhancing transparency, and supporting data-driven decision-making. By offering a centralized view of groundwater efforts statewide, the tool helps identify regional trends, funding needs, and implementation gaps.

Data collected through the tool have also informed the development of standardized monitoring methods, which are now used to assess post-construction

PUBLIC DRAFT

project performance. These methods track key groundwater indicators and help evaluate the long-term effectiveness of investments made through the SGM Grant Program. The tool is continually updated to incorporate additional groundwater-related grant data, expanding its value as a statewide planning and evaluation resource.

Sustainable Groundwater Management Grant Funding Sources

The SGM Grant Program is funded by Proposition 1, Proposition 68, and general funds from the State Budget Act of 2021 and the Budget Act of 2022.

- **Proposition 1** (The Water Quality, Supply, and Infrastructure Improvement Act of 2014): authorized general obligation bonds to fund ecosystem and watershed protection and restoration; water supply infrastructure projects, including surface and groundwater storage; and drinking water protection
- **Proposition 68** (The California Drought, Water, Parks, Climate, Coastal Protection, and Outdoor Access for All Act of 2018): authorized general obligation bonds pursuant to the Public Resources Code relating to drought, water, parks, climate, coastal protection, and outdoor access for all programs.
- **Budget Act of 2021** (Senate Bill 170): allocated $180 million in general funds and set aside an additional $60 million for Fiscal Year (FY) 2023 and another $60 million for FY 2024 for SGMA implementation projects, including program administration.
- **Budget Act of 2022** (Assembly Bill 179 and Assembly Bill 211): provided $60 million and $56 million for SGMA implementation projects, including program administration costs, with some of that funding allocated for small farmer technical assistance and temporary water rights permit processing.

Sustainable Groundwater Management Grant Awards

To date, following SGMA's enactment, the SGM Grant Program has awarded over $500 million in grants to support local agencies, including $139.3 million in three rounds of planning grants for development of GSPs, updates and revisions to approved Alternatives and implementation of related projects, and $363.8 million in three rounds of implementation grants, as summarized in Table 2-10.

PUBLIC DRAFT

Table 2-10 Funding Awarded under the SGM Grant Program by Round

SGM Grant Program Solicitation	Local Funding Awarded (in millions)
Planning Rounds	
Proposition 1, Round 1, Counties with Stressed Basins	$6.69
Proposition 1, Round 2	$85.25
Propositions 1 and 68	$47.33
Total (SGM Planning Rounds)	$139.27
Implementation Rounds	
Proposition 68, Round 1	$26.00
SGMA Implementation, Round 1	$150.52
SGMA Implementation, Round 2	$187.29
Total (SGM Implementation Round)	$363.80
Total	$503.07

PROPOSITION 1, ROUND 1, COUNTIES WITH STRESSED BASINS GRANTS

In 2015, DWR received 23 applications requesting $7 million in grant funding under Proposition 1 (SGM Planning — Round 1). The projects under this first round of funding were directed to counties with stressed basins, including ones subject to critical conditions of overdraft, and the funds were primarily used to support GSP development. They consisted of five categories of activities: (1) ordinance development; (2) GSA formation efforts; (3) data collection; (4) groundwater modeling; and (5) monitoring well installation. The final grant awards list was released in March 2016, awarding 21 grants totaling $6.7 million in grant funding.

PROPOSITION 1, ROUND 2, SUSTAINABLE GROUNDWATER MANAGEMENT PLANNING GRANTS

In 2017, DWR opened the proposal solicitation (SGM Planning — Round 2) under Proposition 1 to award funding on a competitive basis in basins designated as high- or medium-priority for two categories of projects: Category 1 projects that directly benefit Severely Disadvantage Communities (SDACs) and Category 2 projects for the development of GSPs. DWR received 78 applications requesting approximately $86.4 million in cost-share arrangement, with total project costs of approximately $150 million. The final grant awards list, released on April 14, 2018, awarded 78 grants totaling $85.3 million. The grants included $16.2 million for Category 1 projects and $69.6 million for Category 2 projects.

PUBLIC DRAFT

PROPOSITIONS 1 AND 68, ROUND 3, SUSTAINABLE GROUNDWATER MANAGEMENT PLANNING GRANTS

In 2019, DWR opened the proposal solicitation (SGM Planning — Round 3) under Propositions 1 and 68 to award funding on a competitive basis to high- and medium-priority basins, including basins subject to critical conditions of overdraft, for tasks and activities that help develop and implement GSPs or provide updates to approved Alternative GSPs. Projects were required to support groundwater sustainability planning and management within high- and medium-priority basins and assist in developing and implementing a GSP or provide updates to approved Alternative GSPs. DWR received 54 applications requesting $52.6 million in grant funding. The final grant awards list was released on March 13, 2020, awarding $47.3 million in grant funding ($46.3 million from Proposition 68 funds and $1.1 million from Proposition 1 funds).

PROPOSITION 68, ROUND 1, SUSTAINABLE GROUNDWATER MANAGEMENT IMPLEMENTATION GRANTS

In 2020, DWR opened the proposal solicitation (Prop 68 Implementation — Round 1) under Proposition 68 to award funding for tasks and activities that help develop and implement a GSP or provide updates to approved Alternatives. DWR received 15 applications requesting $70.3 million in grant funding. The final grant awards list was released on April 16, 2021, awarding six grants totaling $26 million in grant funding. Of the $26 million, $5 million is dedicated toward projects within, and that solely benefit underrepresented communities.

SGMA IMPLEMENTATION, ROUND 1, SUSTAINABLE GROUNDWATER MANAGEMENT IMPLEMENTATION GRANTS

In 2021, DWR opened the proposal solicitation (SGMA Implementation — Round 1) under the Budget Act of 2021 to award funding to local agencies responsible for managing critically overdrafted groundwater basins throughout the state. Additional funds were available for projects identified within the San Joaquin Valley. In 2021, DWR received 20 applications requesting $276 million in grant funding. The final grant awards list was released on April 22, 2022, awarding 20 grants totaling $150.5 million in general funds through the Budget Act of 2021.DWR also entered into an agreement with the Water Foundation for $2 million to fund a drinking water well mitigation template and a groundwater dependent ecosystem study.

SGMA IMPLEMENTATION, ROUND 2, SUSTAINABLE GROUNDWATER MANAGEMENT IMPLEMENTATION GRANTS

In 2022, DWR opened the proposal solicitation (SGMA Implementation — Round 2) under the Budget Act of 2021, Budget Act of 2022, and Proposition 68 for tasks

PUBLIC DRAFT

and activities that help develop and implement a GSP or provide updates to approved Alternatives, for projects within high- and medium-priority basins, including critically overdrafted basins. DWR received 82 applications requesting $877.1 million in grant funding. The final grant awards list was released on September 12, 2023, awarding 31 grants totaling $187.3 million in grant funds. Of this total, $179.2 million was set aside for awards that partially or solely benefit SDACs or other underrepresented communities. Additionally, $9.5 million was put into two contracts to expand the URCTA Program for assistance to small farmers. This assistance includes irrigation efficiency, legal services, and engineer/hydrology/geologic professional services.

GSP Implementation Funding Needs

GSPs provide a glimpse into the needed funding projected by GSAs to help bring their groundwater basins into sustainable conditions. The "Projects and Management Actions" sections of the GSPs include those projects and actions designed to increase supply or reduce demand, among other things, and achieve sustainability within SGMA's planning and implementation horizon. The GSAs in a basin must identify funding mechanisms to implement their proposed projects and actions, which are likely some combination of generating the revenue internally and seeking available grant funding.

In recent years, the Department of Water Resources (DWR) has held listening sessions with Groundwater Sustainability Agencies (GSAs) to better understand their financial needs for managing groundwater basins. During these sessions, GSAs emphasized the significant costs involved in meeting the requirements of the Sustainable Groundwater Management Act (SGMA).

Based on input from participating GSAs, the estimated costs per subbasin are as follows:

- Administrative costs for activities such as annual reporting and day-to-day GSA operations typically range from $500,000 to $1.5 million.
- Five-year updates to Groundwater Sustainability Plans (GSPs) are more resource-intensive, with estimated costs between $1.5 million and $5 million.
- Project implementation costs — including the design and construction of projects identified in GSPs — can range from $3 million to more than $10 million, depending on the size and complexity of the project.

PUBLIC DRAFT

These discussions have underscored the ongoing and substantial financial challenges GSAs face in implementing and sustaining long-term groundwater management.

Other Financial Assistance Programs Related to Groundwater Management

Groundwater planning and implementation projects are also eligible for financial assistance through other DWR-administered programs, including the Watershed Resilience and drought-related funding programs. DWR's Integrated Regional Water Management (IRWM) Program has also previously funded groundwater projects.

Additionally, many other State and federal programs offer funding for these projects. For example, the California Department of Conservation's Multibenefit Land Repurposing Program is a grant initiative that supports the repurposing of agricultural land to reduce groundwater reliance and promote sustainable water management. In 2021, the program provided $25 million in funding, which is available to local agencies, irrigation districts, water agencies, and other eligible organizations to implement projects that benefit groundwater sustainability and other environmental goals. A comprehensive list of other funding sources was provided in CalGW Update 2020 on Table
4-12, but programs are ever-evolving. Each funding opportunity may only be used for specific purposes, and each program should be contacted to verify applicant eligibility, program funding deadlines, available funds, and requirements.

INTEGRATED REGIONAL WATER MANAGEMENT PROGRAM

DWR's IRWM Program has previously provided significant funding for groundwater projects focused on improving water management and resilience. Through a collaborative, multi-interested party approach, the IRWM Program helped fund projects that addressed overextraction, contamination, and climate-induced changes in groundwater resources, contributing to the overall goals of SGMA.

WATERSHED RESILIENCE PROGRAM

DWR's Watershed Resilience Program supports projects that enhance watershed climate resilience, including groundwater initiatives. As part of California's Proposition 4, approved by voters in November 2024, $100 million has been allocated for projects related to integrated regional water management projects that enhance climate resilience on a watershed scale. This funding further advances DWR's Watershed Resilience Program, supporting the objectives of SGMA and helping communities build resilience to the growing impacts of climate change on their water resource.

PUBLIC DRAFT

DROUGHT FUNDING

In response to more recent drought conditions, the California Legislature authorized over a billion dollars in funding to DWR for drought relief in 2021 and 2022. This funding aims to ensure a reliable water supply and enhance resiliency to drought conditions across the state. DWR offers several funding opportunities to support local communities in addressing the impacts of the drought, including:

- DWR's Small Community Drought Relief Program supports small water suppliers and rural communities in addressing immediate and near-term water supply needs by providing financial and technical assistance to survive drought conditions. Eligible projects include providing hauled and bottled water, new wells and rehabilitation of existing wells, and construction or installation of permanent infrastructure. These projects help secure water access for communities not served by urban water suppliers.
- DWR's 2021 Urban and Multibenefit Drought Relief Program aims to address drought impacts by supporting projects that provide multiple benefits, including enhancing groundwater recharge and groundwater quality. Eligible applicants, including local governments and water agencies, can use funding for initiatives like groundwater recharge and ecosystem restoration, which benefit both urban areas and the environment.
- DWR's 2022 Urban Community Drought Relief Program focuses on immediate drought relief for urban communities. It supports projects like turf replacement, water conservation, and well installation and rehabilitation to enhance water supply reliability. Local governments, water agencies, and eligible organizations can apply for these funds.

LANDFLEX GRANT PROGRAM

DWR developed the LandFlex Grant Program (Land*Flex*) to provide immediate drought relief for areas with drinking water wells in drought-stricken communities by limiting unsustainable groundwater pumping in critically overdrafted basins. Limiting groundwater pumping and reducing overdraft means more water can be left in the ground and be available for drinking water wells in California's most vulnerable communities. Land*Flex* provides approximately $25 million in grants to GSAs that can provide grant funds to growers who limit agricultural water use. Land*Flex* was authorized by the Legislature pursuant to the Budget Act of 2021 and its trailer bill (Water Code Section 13198 *et seq*.).

For growers to enroll in LandFlex, GSAs work directly with growers to identify land that would reduce pumping impacts on nearby drinking water wells. Land*Flex* provides financial incentives to growers for each enrolled acre. To reach vulnerable

PUBLIC DRAFT

communities in need and provide growers the necessary resources, DWR partnered with Community Alliance with Family Farmers, Self-Help Enterprises, Western United Dairies Foundation, and the Almond Alliance to assist GSAs with providing outreach and engagement to growers.

The LandFlex grant program has successfully provided immediate and long-term benefits to local communities while protecting wells and critical infrastructure. As of May 2025, the program success metrics include:

- Total Acres Enrolled — 4,474 acres.
- Protected Domestic Wells — 16,512 wells.
- Immediate + Long-Term Water Savings = 102,000 acre-feet.
- Critical Infrastructure Protection (California Aqueduct).

TECHNICAL ASSISTANCE FOR EQUITY AND INCLUSION

DWR is committed to advancing equity and inclusion in groundwater management through a range of technical assistance services. DWR's Technical Assistance Program has supported 12 communities, including four California Tribes, with $2.5 million in funding, and an additional $18 million has been committed to support Tribes, underrepresented communities, and small farmers. To help local agencies navigate complex groundwater challenges, DWR provides professional facilitators who foster collaboration and dialogue among diverse interested parties and partners. Language accessibility is supported through Written Translation and Verbal Interpretation Services, which ensure that public materials and meetings are available in up to eight languages. In addition, DWR offers community engagement tools and guidance to help Groundwater Sustainability Agencies (GSAs) meaningfully include all water users, especially those who have historically been excluded from water planning processes.

Future SGMA Funding Sources

The passage of Proposition 4 in November 2024 — a $10 billion natural resources bond — will fund projects that address climate change and strengthen California's long-term resilience. Some of this funding will extend support for GSP implementation and build on the progress of SGMA's first decade. DWR will administer multiple grant programs under Proposition 4, including the Sustainable Groundwater Management Program and the Watershed Resilience Program.

PUBLIC DRAFT

2.4.6 Groundwater Recharge Assistance

DWR has provided groundwater recharge assistance to help local agencies and GSAs make informed decisions about their projects and management actions. Groundwater recharge is a key strategy throughout California to manage water under climate-driven weather extremes, including prolonged drought and periodic intense storm events, as identified in the Newsom Administration's California's Water Supply Strategy.

During drier years, when there is less snowpack and precipitation, groundwater accounts for up to 60% of the state's total water supply. During wet years, groundwater recharge — where water moves down (infiltrates) from the ground surface or the bottom of a waterway into an underlying aquifer — helps balance and replenish groundwater basins for use during future dry and drought years. California's groundwater basins can hold a massive amount of water, estimated at more than 1,000 million acre-feet. Comparatively, all the major above-ground reservoirs in California can hold up to 44 million acre-feet. Enhancing groundwater recharge is critical to leveraging available storage in groundwater basins. Additional groundwater recharge information is available in Chapters 3 and 4 as well as on DWR's Statewide Groundwater Management website.

Shallow Recharge Map from Statewide AEM Surveys

As a part of DWR's Statewide AEM Survey Project, AEM data were collected in all high- and medium-priority groundwater basins where data collection was feasible. AEM data can provide information about a groundwater basin's structure to depths of up to 1,000 feet. The AEM information improves the understanding of aquifer structures, the development or refinement of hydrogeologic conceptual models, and can help identify areas for recharging groundwater.

As a part of the Statewide AEM Survey Project, AEM data were interpreted for material texture in units of percent coarse-grained material, ranging from 0 to 100 percent. Coarse-grained materials (sands and gravels) are typically the areas within an aquifer where groundwater is stored and can more easily flow, both horizontally (e.g., water flowing into a pumping well) and vertically (e.g., water that is percolating downward during groundwater recharge). Fine-grained materials (silts and clays) are typically the areas within an aquifer where groundwater is stored but flows are inhibited or slowed.

DWR integrated the Statewide AEM Survey texture data from the upper 50 feet of basins to develop an AEM-defined shallow recharge map (see Chapter 3,

PUBLIC DRAFT

"California's Natural and Built Groundwater Infrastructure"). This map helps identify potential recharge pathways in the shallow portion of an aquifer, where the upper 50 feet is often dominated by coarse-grained materials. The AEM-defined shallow recharge map is discussed in additional detail in Chapter 3.

Flood-Managed Aquifer Recharge Resource Management Strategy

Flood-MAR is an integrated and voluntary resource management strategy that uses floodwater resulting from, or in anticipation of, rainfall or snow melt for managed aquifer recharge on agricultural lands, working landscapes, and managed natural lands, including but not limited to wildlife refuges, floodplains, and flood bypasses. Flood-MAR can be implemented at multiple scales, from individual landowners diverting floodwater with existing turnouts onto agricultural lands, to water management districts using extensive detention/recharge areas, to watershed-scale modernization of flood management infrastructure/operations. Flood-MAR concepts present an opportunity to both reduce the hazards created by high flows and increase the potential benefits, especially with climate change-induced increases in flood flows or high surface water flows and the oscillation between wet and dry conditions. Flood-MAR projects can be formulated and designed to provide broad benefits for Californians and the state's ecosystems, including water supply reliability, flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, subsidence mitigation, water quality improvement, working landscape preservation and stewardship, climate change adaptation, and recreation.

Since the release of California's Groundwater Update 2020, Flood-MAR has evolved from being a concept practiced by a few enterprising landowners and water districts, to large-scale implementation resulting in recharge of a significant volume of water in Water Year 2023. Flood-MAR was the organizing principle of the Governor's Executive Order N-4-23. Flood-MAR practitioners attribute the pace at which the practice of Flood-MAR has advanced in California to the power of collaborative action, and to the ways innovation and opportunity can drive transformation. Collaborative action is evident in the formation of the 500-member Flood-MAR Network and in the efforts of numerous organizations working on the ground to implement and study innovative multi-benefit Flood-MAR projects.

DWR's Flood-MAR Program includes the following activities:

- Flood-MAR Planning and Project Formulation
    - **San Joaquin Watershed Studies.** DWR, in coordination with local, State, and federal agencies; private researchers; and non-

PUBLIC DRAFT

governmental organizations, has been conducting ongoing evaluations of Flood-MAR opportunities in five San Joaquin Valley watersheds since 2019. These watershed studies assess climate change vulnerability and explore the effectiveness of Flood-MAR to concurrently reduce flood risk, improve water supply, and enhance ecosystems.

    - **Multi-benefit floodplain restoration opportunities.** DWR has been working with local partners since 2021 to develop a systematic approach to identify floodplain restoration and expansion opportunities that provide high-quality salmonid habitat and enhance naturally occurring floodplain recharge. The Ecological Floodplain Inundation Potential (EcoFIP) toolkit facilitates the identification, analysis, and prioritization of multiple floodplain restoration opportunities at the reach or project scale; helps partners visualize and compare conceptual restoration designs for potential habitat and recharge benefits; and quantifies potential benefits and implementation costs. For more information, see the StoryMaps about multiple benefit floodplain restoration work on DWR's Flood-MAR website.
    - **Case Studies and Guidance documents.** Working with NGOs and landowners, DWR has documented case studies of grower experiences with on-farm recharge. DWR also supported the documentation of district-scale recharge programs and incentives to guide other districts in developing these programs that included:

- Recharge methods and case studies.
- Recharge incentives and strategies.
- Recharge program guidance.
    - **Internal and external integrated planning and partnerships.** Internally, the Flood-MAR Program integrates and aligns its efforts with other DWR programs, such as the *Central Valley Flood Protection Plan* (CVFPP) and the CVFPP Conservation Strategy and the State Water Project. Externally, DWR also coordinates and aligns with many local and federal efforts, such as FIRO (Forecast-Informed Reservoir Operations), Pajaro Regional Flood Risk Management Project, and the U.S. Army Corps of Engineers' Engineering with Nature Program.
- Technical and Regulatory Assistance
    - **Temporary water rights applications support.** DWR has been providing technical assistance to local agencies working on temporary permit applications for pilot groundwater recharge projects. Since

PUBLIC DRAFT

2022, DWR provided support for 13 submitted permit applications and consulted with numerous other local agencies.

- **Flood-MAR Dashboard.** DWR has developed a Flood-MAR Dashboard for the San Joaquin and Sacramento valleys. The dashboard provides access to information on hydrologic and hydraulic conditions to support local public agencies in planning for and determining flood conditions that could indicate water may be available for diversion for recharge under a new water right, California Water Code Section 1242.1, or other directives, such as an executive order.
- **Partnerships to support on-farm demonstration sites.** DWR has supported NGOs to work directly with growers to implement on-farm recharge on their lands.
- **Recommendations for maximizing recharge during flood events.** During Water Year 2023, DWR worked with many local agencies and landowners to provide recommendations for dealing with flood flows during large precipitation events. Support included resources for identifying and forecasting flood flows (e.g., the California-Nevada River Forecast Center) and supporting local agencies implementing the flood diversion Executive Order.

- Flood-MAR Engagement
  - **Flood-MAR Network.** DWR supports the 500-member Flood-MAR network and sponsors activities such as monthly "Lunch-MAR" webinars and biannual Flood-MAR Forums. Forums were held in 2019, 2021, and 2023, and recordings can be accessed through the Flood-MAR Hub.

Water Rights Permitting Assistance

Following the release of California's Water Supply Strategy in August 2022, State agencies increased assistance to local public agencies interested in submitting permit applications for recharge projects that used high surface water flows. This assistance was particularly focused on 180-day temporary permit applications for local agencies to temporarily divert high flows for recharge under new pilot project efforts. The assistance included webinars that provided guidance on temporary permit pathways and using floodwaters for recharge, and direct assistance on the development of permit applications.

PUBLIC DRAFT

In August 2022, DWR started offering technical assistance to local agencies working on temporary permit applications that included:

- Completion of technical analyses for water availability and downstream impact analyses required for permit applications.
- Compilation and development of temporary permit application packages.
- Payment of permit fees.
- Additional support for complying with potential permit terms and conditions, such as biological and cultural assessments, reporting, and Lake and Streambed Alteration Agreements.

DWR provided this technical and financial support on two applications for Water Year 2023, seven applications for Water Year 2024, and four applications for Water Year 2025 — all were 180-day temporary permit applications. DWR also consulted numerous other local agencies on recharge projects and recharge study opportunities, as well as feasibility for potential permit applications. The State Water Board and California Department of Fish and Wildlife expedited and streamlined permitting processes and decisions for recharge projects using high flows, especially in Water Year 2023 when high flows were happening in real time. For Water Year 2023, nearly 700,000 acre-feet of diversions to underground storage were permitted by the State Water Board using temporary permit pathways.

Flood Diversion and Recharge Enhancement Initiative

In response to the winter 2023 Tulare Lake flooding emergency, the 2023 Temporary Flood Diversion and Recharge Enhancement Emergency Effort (2023 Emergency Effort) was created from limited one-time emergency funding to assist local agencies in the Tulare Lake region with additional flood diversions from local waterways. Seven emergency contracts were established to assist with the rental of 30 temporary pumps and one siphon, resulting in over 11,000 acre-feet of water diverted, as well as land clearing activities (a.k.a. "Rip & Chip") for 291 acres. These activities helped to reduce flood risk, enhance recharge, and prepare lands to receive future recharge and high flows.

Based on the success and positive feedback from this 2023 Emergency Effort, additional one-time emergency funding was secured and the Flood Diversion and Recharge Enhancement (FDRE) Initiative launched in December 2023, providing similar and expanded assistance to local agencies for continued flood diversion and recharge activities. Increased funding allowed DWR to support more local agencies

PUBLIC DRAFT

throughout the Central Valley and included more types of activities and assistance over multiple winter seasons. Fourteen contracts were executed by June 2024 to provide recharge-related assistance through 2026 for the rental and/or purchase of temporary flood diversion equipment (pumps, siphons, and protective screens), temporary flood basin development, temporary conveyance improvements, and land clearing. These activities not only support flood management by reducing flood risk, but also the mitigation of drought impacts by using the high flows to recharge local aquifers thereby increasing groundwater levels and storage. Please see the FDRE Brochure for additional information.

2.4.7 Land Subsidence Guidance

Land subsidence — the sinking of the land surface — has long been a challenge in California and poses serious risks to water supply reliability, public safety, and infrastructure. In many regions, subsidence is primarily driven by excessive groundwater pumping, which depletes and compacts aquifer systems. Over time, this process can permanently reduce groundwater storage capacity and damage critical infrastructure such as aqueducts, pipelines, levees, roads, and bridges. In areas of the San Joaquin Valley, for example, land has sunk by several feet within just a few years in addition to decades of subsidence prior to this, resulting in costly repairs and operational challenges to water conveyance and flood infrastructure. Addressing subsidence is therefore central to the SGMA, which requires local agencies to avoid or minimize subsidence, including avoiding other undesirable results, as they work toward groundwater sustainability.

To support local efforts, the DWR released the Draft Land Subsidence Best Management Practices (Subsidence BMP) document in July 2025 for public review and comment. The Draft Subsidence BMP provides guidance for GSAs on how to monitor, assess, and manage subsidence within the SGMA framework to avoid or minimize. It outlines scientific causal principles, monitoring approaches, and management strategies to help agencies both minimize existing subsidence and avoid new areas of land sinking. The Subsidence BMP is anticipated to be finalized in late 2025.

Complementing this guidance, CalGW Update 2025 includes an updated analysis of land subsidence conditions across California in Appendix I, "Update on Land Subsidence in California," developed for DWR as an update to *Land Subsidence from Groundwater Use in California* (Borchers and Carpenter 2014), originally prepared for the California Water Foundation. This appendix provides an inventory

PUBLIC DRAFT

of major subsiding areas statewide and presents sites throughout the Central Valley modeled for future subsidence risk.

Together, the Land Subsidence BMP and Appendix I, "Update on Land Subsidence in California," provide both the scientific foundation and practical tools necessary for agencies to understand where subsidence is occurring, anticipate where it may occur in the future, and implement management strategies to reduce risks.

2.4.8 Water Shortage Vulnerability

DWR developed the Water Shortage Vulnerability Scoring and Tool in response to Senate Bill 552 (SB 552) to improve drought preparedness for small water suppliers and rural communities, including frontline populations. The tool evaluates two dimensions of risk: physical vulnerability, which considers factors such as infrastructure reliability and climate change exposure, and social vulnerability, which reflects demographic and socioeconomic conditions that affect a community's ability to respond to shortages. Together, these measures identify where water shortage risks are highest and where proactive planning is most critical.

Because many small systems and rural communities depend almost entirely on groundwater, the tool also directly supports sustainable groundwater management. By pinpointing areas where overdraft, declining groundwater quality, or infrastructure constraints may intensify drought impacts, the tool provides valuable insights for GSAs as they develop and refine their GSPs. This integration allows GSAs to prioritize projects such as well protection, recharge, and emergency supply programs in the places that need them most.

The tool also incorporates climate change scenarios to highlight how hotter, drier conditions may worsen future groundwater stress. Aligning shortage vulnerability analysis with SGMA planning helps agencies and communities adapt to these changes while working toward long-term water reliability. In this way, the tool advances the intent of both SB 552 and SGMA by linking drought preparedness with sustainable groundwater management and by ensuring that groundwater planning considers both technical and human dimensions of resilience. Additional information on SB 552 and the broader context for this effort is available in Chapter 1, "Vision and Context for Sustainable Groundwater Management."

PUBLIC DRAFT

2.5 Groundwater Management by Other State and Local Agencies

Several State agencies play major roles in supporting California's local agencies and GSAs as they develop and implement groundwater management programs and projects. Roles of these agencies in supporting groundwater management may not be self-evident or immediately recognized. A list of key State agencies involved in supporting sustainable groundwater management is provided below. For more information on the roles of the various State agencies in protecting groundwater resources, see CalGW Update 2020, Chapter 4 (Page 4–10).

- State Water Resources Control Board.
- Regional Water Quality Control Boards.
- California Department of Conservation.
- California Department of Fish and Wildlife.
- California Department of Food and Agriculture.
- California Department of Pesticide Regulation.
- California Department of Toxic Substances Control.

Several federal agencies supply studies, data, and funding to local agencies and GSAs in developing and implementing groundwater management programs and projects. A list of key federal agencies involved in supporting sustainable groundwater management is provided below. For more information on the roles of the various federal agencies in protecting groundwater resources, see CalGW Update 2020, Chapter 4 (Page 4–14).

- Bureau of Land Management.
- National Oceanic and Atmospheric Administration.
- U.S. Bureau of Reclamation.
- U.S. Environmental Protection Agency.
- U.S. Fish and Wildlife Service.
- U.S. Forest Service.
- U.S. Geological Survey.

PUBLIC DRAFT

2.6 Local Implementation of SGMA

When SGMA went into effect in January 2015, Part 2.74 (Sustainable Groundwater Management) was added to the Water Code, but Part 2.75 (Groundwater Management) had been foundational to California's voluntary groundwater management efforts since AB 3030 went into effect in 1992. Many of the local agencies that developed and adopted GWMPs following Part 2.75 eventually prepared and adopted GSPs or Alternative GSPs for the basins that they overlie. Many of California's groundwater basins have been implementing successful groundwater management for decades.

SGMA provided GSAs with new regulatory authority to implement plans and sustainably manage groundwater basins, including the authority to implement a GSP. Chapter 5 of SGMA lists the powers and authorities a GSA receives once it adopts and submits either a GSP or an Alternative to DWR, and states that a GSA may use those powers and authorities to provide the maximum degree of local control and flexibility consistent with SGMA's sustainability goals. However, among other limitations outlined in Chapter 5, Water Code Section 10726.8 states that, "Nothing in [Part 2.74] shall be construed as authorizing a local agency to make a binding determination of the water rights of any person or entity, or to impose fees or regulatory requirements on activities outside the boundaries of the local agency." Additionally, that section states, "Nothing in [Chapter 5] or a [GSP] shall be interpreted as superseding the land use authority of cities and counties, including the city or county general plan, within the overlying basin." Some of the powers and authorities granted to GSAs by SGMA in Chapter 5 include, but are not limited to, the following:

- Authority to conduct investigations to determine the need for groundwater management, propose and update fees, monitor compliance and enforcement, and inspect properties or facilities to determine compliance.
- Register groundwater extraction facilities.
- Require the installation of water measuring devices.
- Require the reporting of surface water diversions to underground storage.
- Acquire and hold real and personal property to implement a GSP.
- Appropriate and acquire surface water or groundwater, and surface water and groundwater rights.
- Provide for a program of voluntary fallowing of agricultural lands.

PUBLIC DRAFT

- Impose spacing requirements on new groundwater well construction to minimize well interference and impose operating regulations on existing wells.
- Authorize temporary and permanent transfers of groundwater extraction allocations and establish accounting rules.

Chapter 8 of SGMA describes the financial authority given to a GSA to fund the costs of a groundwater sustainability program, and states that the powers granted to a GSA are in addition to the powers already granted to it as a local agency. Chapter 9 explains the enforcement powers granted to a GSA, which includes issuing civil penalties if a rule, regulation, ordinance, or resolution adopted pursuant to Section 10725.2 is violated. The powers granted to a GSA by SGMA are discretionary and are focused on local control.

To assist GSAs in their GSP implementation efforts, DWR published a Funding SGMA Implementation guidance document in March 2024. The purpose of this high-level resource guide is to provide GSAs with information that will support the selection and development of self-funding streams for funding SGMA implementation. The document outlines common funding mechanisms available to GSAs and provides a general approach that agencies can consider when developing a funding mechanism.

The powers and authorities provided to a GSA by SGMA, in addition to the powers and authorities that the local agencies may already have, are intended to help implement a basin's groundwater sustainability program and achieve sustainability goal. Water Code section 10721 defines "sustainability goal" as "the existence and implementation of one or more groundwater sustainability plans that achieve sustainable groundwater management by identifying and causing the implementation of measures targeted to ensure that the applicable basin is operated within its sustainable yield." Sustainable groundwater management is defined by the basin's sustainable management criteria and is achieved by a variety of projects and management actions, as discussed in the sections that follow.

2.6.1 Role of Sustainable Management Criteria and Corrective Actions in SGMA

Sustainable management criteria (also referred to as SMCs) establish measurable goals for six sustainability indicators, while corrective actions guide GSAs in addressing planning deficiencies within a GSP. Together, these elements form a

PUBLIC DRAFT

feedback loop that supports adaptive management, ensuring basins stay on track to achieve or maintain sustainable conditions.

Sustainable management criteria are fundamental to defining and achieving sustainability under SGMA. By setting clear quantifiable thresholds for the sustainability indicators applicable to a basin, sustainable management criteria provide a framework for assessing progress and ensuring that groundwater resources are managed responsibly. These criteria are more than technical benchmarks — they reflect local decision-making, priorities, and approaches to addressing the unique challenges and conditions of each basin. The development of sustainable management criteria demonstrates how communities balance the needs of beneficial uses and users of groundwater while protecting that resource for future generations.

Corrective actions play a crucial role in the evolution and refinement of sustainable management criteria, as well as other aspects of a GSP. By identifying areas where GSPs lack clarity, rigor, or sufficient justification, corrective actions provide a mechanism for continuous improvement, ensuring that GSPs remain robust and adaptive to changing basin conditions. Together, sustainable management criteria and corrective actions create a dynamic system where local groundwater management is continually evaluated, strengthened, and aligned with State and regional goals, fostering a collaborative approach to achieve long-term groundwater sustainability across California.

Sustainable Management Criteria

One of the fundamental components of SGMA is the requirement for local agencies and GSAs to set quantitative thresholds that define sustainable conditions within a basin. These quantitative thresholds must be set for each applicable sustainability indicator and are referred to as *sustainable management criteria*. This section will explore what sustainable management criteria are, share examples of how some GSAs developed sustainable management criteria, and provide recommendations for how sustainable management criteria may be refined during plan implementation to improve transparency and the understanding of what constitutes an undesirable result in a basin.

The GSP Regulations guide the development of GSPs and the management of the basin through locally defined, quantitative sustainable management criteria. These

PUBLIC DRAFT

criteria are the quantitative standards by which a GSA defines conditions that constitute sustainable groundwater management in the basin. These include:

- **Undesirable results** — conditions the GSA defines as significant and unreasonable.
- **Minimum thresholds** — thresholds that if exceeded constitute significant and unreasonable conditions.
- **Measurable objectives** — thresholds which constitute sustainable conditions.
- **Interim milestones** — metrics the GSA may aim to achieve during the 20-year implementation period for each applicable sustainability indicator.

Demonstrating the absence of undesirable results indicates the basin is achieving its **sustainability goal**. Unlike sustainable management criteria, the sustainability goal is qualitative and is supported by locally defined minimum thresholds and definitions of undesirable results.

The GSP Regulations also require GSAs to sufficiently evaluate and document how sustainable management criteria may affect the interests of the beneficial uses and users of groundwater within a basin and the ability of an adjacent basin to achieve its sustainability goal. In addition, a GSA must demonstrate that the proposed thresholds for one sustainability indicator will not lead to undesirable results for another sustainability indicator. Each of the term mentioned above are discussed in detail below.

Undesirable Results

As defined in SGMA, "sustainable groundwater management" is the "management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results." Undesirable results must be avoided or eliminated through the implementation of projects and management actions, and progress must be demonstrated with empirical data (e.g., measurements of groundwater levels or rates of subsidence). The avoidance of undesirable results is thus critical to the success of a GSP.

SGMA defines undesirable results as one or more of the following effects caused by groundwater conditions occurring throughout the basin:

- Chronic lowering of **groundwater levels** indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not

PUBLIC DRAFT

sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

- Significant and unreasonable reduction of **groundwater storage**.
- Significant and unreasonable **seawater intrusion**.
- Significant and unreasonable **degraded water quality**, including the migration of contaminant plumes that impair water supplies.
- Significant and unreasonable **land subsidence** that substantially interferes with surface land uses.
- **Depletions of interconnected surface water** that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

Sustainability indicators are defined in the GSP Regulations as "any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results." A GSA is required to establish criteria for all six undesirable results unless the GSA is able to demonstrate that undesirable results related to one or more sustainability indicators are not present and are not likely to occur in the basin.

It is up to the GSA to define the significant and unreasonable conditions that result in undesirable results. However, the GSP Regulations require that this definition include potential effects on the beneficial uses and users of groundwater, including property interests and land uses. SGMA lists the beneficial uses and users of groundwater in Water Code Section 10723.2 —they include, but are not limited to, all of the following:

- Holders of overlying groundwater rights, including agricultural users (farmers, ranchers, and dairy professionals).
- Domestic well owners.
- Municipal well operators.
- Public water systems.
- Local land use planning agencies.
- Environmental users of groundwater.
- Surface water users, if there is a hydrologic connection between surface and groundwater bodies.

PUBLIC DRAFT

- The federal government, including, but not limited to, the military and managers of federal lands.
- California Native American Tribes.
- Disadvantaged communities, including, but not limited to, those served by private domestic wells or small community water systems.
- Entities listed in [Water Code] Section 10927 that are monitoring and reporting groundwater elevations in all or a part of a groundwater basin managed by the GSA.

GSAs used a variety of strategies to define undesirable results in their GSPs. Many GSAs included a series of qualitative descriptions of specific conditions the GSA is managing the basin to avoid. Using the best available data, GSAs should conduct thorough analyses and disclose results in sufficient detail, including information such as the number and location of affected domestic wells, volume of depleted interconnected surface water, and areas of land subsidence, to name a few. Undesirable results are also defined quantitatively by minimum threshold exceedances at a single representative monitoring site, multiple monitoring sites, a portion of a basin, a management area, or an entire basin.

Minimum Thresholds, Measurable Objectives, and Interim Milestones

Minimum thresholds represent groundwater conditions that, if exceeded, could cause undesirable results. One groundwater management responsibility of a GSA is to set minimum thresholds at representative monitoring sites for each applicable sustainability indicator after considering the interests of the beneficial uses and users of groundwater, how the land is used, and property interests in the basin. Minimum thresholds should also be set at levels that do not impede adjacent basins from meeting their minimum thresholds or achieving their defined sustainability goals. Exceeding a minimum threshold at a single monitoring site is not necessarily an undesirable result, but it may indicate the need to modify one or more management actions or implement a project to address the issue before it becomes more widespread across the basin.

On the other end of the groundwater management spectrum from minimum thresholds are measurable objectives. Measurable objectives represent the maintenance or improvement of groundwater conditions needed to achieve the sustainability goal for the basin. They are quantitative targets that reflect the basin's desired groundwater conditions and are set for each applicable

PUBLIC DRAFT

sustainability indicator at each representative monitoring site, in the same manner as minimum thresholds.

Interim milestones are developed to track a path from current conditions to measurable objectives and must be defined in five-year increments at each representative monitoring site. These measurable metrics are used by GSAs and DWR to track a basin's progress toward meeting its sustainability goal. Interim milestones should be coordinated with projects and management actions proposed by the GSA to achieve the sustainability goal. The schedule for implementing projects and management actions will influence how rapidly the interim milestones move toward the measurable objectives (i.e., the path to sustainable groundwater management).

Avoidance of defined undesirable results in a basin must be achieved within 20 years of GSP implementation. Some basins may experience undesirable results within the 20-year period, particularly if the basin had pre-existing undesirable results as of January 1, 2015. The occurrence of one or more undesirable results within the initial 20-year period does not, by itself, necessarily indicate that a basin is being managed unsustainably, or that it will not achieve sustainability within the 20-year period. However, some potential impacts of undesirable results, even if they occur early in plan implementation, may not be reversible or may have longlasting, permanent impacts within the basin and, therefore, may indicate a basin is being managed unsustainably. However, GSPs must clearly define a planned pathway to reach sustainability in the form of interim milestones and show actual progress in annual reporting. Quantitative sustainable management criteria are essential, as they offer the GSA a clear framework to demonstrate sustainability, thereby enabling the public and DWR to effectively assess progress towards sustainability.

Setting sustainable management criteria will likely be an iterative process. Initial criteria may need to be adjusted to address the interests of beneficial uses and users of groundwater. The GSA should evaluate whether the sustainable management criteria adequately characterize how and when significant and unreasonable conditions occur and define a path toward sustainable groundwater management in the basin.

PUBLIC DRAFT

Sustainability Goal

The sustainability goal should succinctly state the GSA's objectives and desired conditions of the groundwater basin, describe how the basin will reach that desired condition, and explain why the measures planned will lead to success.

Unlike the other sustainable management criteria, the sustainability goal is not quantitative. Rather, it is supported by locally defined minimum thresholds and undesirable results. Demonstration of the absence of undesirable results supports a determination that the basin is operating within its sustainable yield and, thus, that the sustainability goal is being achieved.

The sustainability goal may only be finalized after minimum thresholds and undesirable results have been defined, projects and management actions have been identified, and the projected impact of those projects and management actions on groundwater conditions has been evaluated.

Sustainable Management Criteria by Sustainability Indicator

Sustainable management criteria are foundational elements of SGMA that define how groundwater sustainability is measured and maintained over time. Sustainable management criteria provide a structured framework for identifying and avoiding significant impacts on groundwater basins, ensuring long-term resource availability. Minimum thresholds serve as a cornerstone for local groundwater management under SGMA, providing clear and measurable benchmarks for assessing the sustainability of groundwater conditions. By defining the lowest acceptable limits for groundwater levels, storage, quality, and other critical indicators of sustainability, minimum thresholds offer a practical framework for balancing groundwater use with environmental protection, economic needs, and community priorities. These thresholds reflect local challenges and conditions, allowing GSAs to tailor their approaches to the specific needs of their basins while maintaining compliance with the GSP Regulations.

Setting minimum thresholds requires careful consideration of local conditions, such as hydrogeology, water use, and community priorities, as well as potential impacts on groundwater users, ecosystems, and infrastructure. GSAs have employed a variety of approaches to establish minimum thresholds, balancing scientific analysis with input from interested parties to create thresholds that are protective yet achievable. Monitoring minimum thresholds over time provides a feedback loop that helps GSAs proactively identify emerging issues, implement corrective actions, and adapt to changing conditions such as population growth, drought, or

PUBLIC DRAFT

shifts in water demand. As a result, minimum thresholds act as both a protective measure for groundwater resources and a performance indicator for the effectiveness of local management strategies. This section outlines the methodologies and criteria used by GSAs in defining minimum thresholds for each sustainability indicator, highlighting key considerations and challenges in their development. Analysis was conducted at the basin scale, and basins with multiple GSPs were consolidated to evaluate approaches across the entire basin. A total of 81 high- or medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.

CHRONIC LOWERING OF GROUNDWATER LEVELS

Groundwater levels are measured at specific locations, such as monitoring wells, and are often represented as either depth to groundwater or groundwater elevation relative to a reference elevation, such as mean sea level. Management of groundwater levels can be considered a prerequisite to achieving sustainable groundwater conditions in a basin. The minimum threshold for **chronic lowering of groundwater levels**, as stated in the GSP Regulations in Section 354.28(c)(1), is "the groundwater elevation indicating a depletion of supply at a given location that may lead to undesirable results." Minimum thresholds for chronic lowering of groundwater levels are supported by the rate of groundwater elevation decline based on historical trends, water year type, and projected water use in the basin, as well as the potential effects on other sustainability indicators.

GSAs across California have employed various approaches to define undesirable results and establish minimum thresholds for the chronic lowering of groundwater levels. Methods generally fall into distinct categories based on historical groundwater elevation data, known well construction, and groundwater trends, often tailored to the unique challenges and the needs of interested parties in the region. Figure 2-7 illustrates the different approaches taken by GSAs in setting minimum thresholds for groundwater levels. These approaches include:

- The most common approach, applied in 36 of 81 high- and medium-priority basins analyzed for this report, relies on the historical low groundwater level as the minimum threshold, referencing specific periods when groundwater conditions were considered acceptable, despite being stressed. In many instances, the depletion of supply experienced by beneficial uses or users due to these historical low groundwater levels has been mitigated and represents a basin condition that the GSA seeks to avoid repeating.

PUBLIC DRAFT

- Nine basins rely on groundwater levels from a defined period other than the historical period when groundwater lows were experienced.
- Nine basins use well depth as a guiding criterion, setting minimum thresholds to ensure groundwater remains accessible to active wells, thereby minimizing impacts on water users. Using this approach, GSAs can clearly define management criteria based on expected effects to beneficial uses and users by analyzing known well depths.
- Eleven basins combine well depth with historical low levels, offering flexibility to accommodate varying characteristics of wells or reliability of historical records.
- Thirteen basins employ a trend-based approach, focusing on stabilizing or reversing declining water level trends rather than targeting absolute levels.

These variations underscore the importance of local context and data availability in setting minimum thresholds that balance sustainability objectives with practical feasibility.

PUBLIC DRAFT

Figure 2-7 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Chronic Lowering of Groundwater Levels[3]

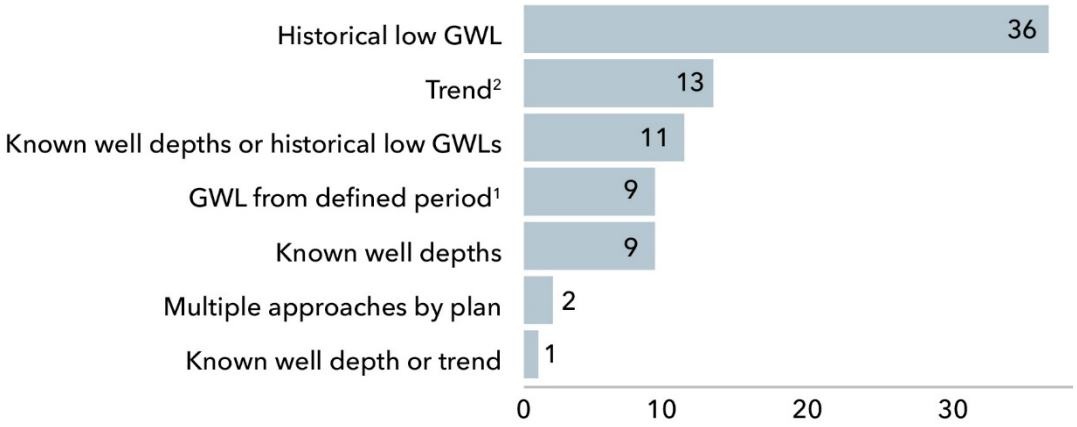


Figure 2-7 Notes:

1. *In some instances, the defined period was a period other than the historical low.*
2. *GSAs employed various modeling techniques to forecast future groundwater levels, including incorporating the benefit from planned projects and management actions.*
3. *GWL = Groundwater Level. A total of 81 high- and medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.*

REDUCTION OF GROUNDWATER STORAGE

The minimum threshold for **reduction of groundwater storage**, as stated in the GSP Regulations in Section 354.28(c)(2), is "a total volume of groundwater that can be withdrawn from the basin without causing conditions that may lead to undesirable results." Minimum thresholds for reduction of groundwater storage are supported by the sustainable yield of the basin, calculated based on historical trends, water year type, and projected water use in the basin.

Figure 2-8 illustrates the different approaches taken by GSAs in defining undesirable results and setting minimum thresholds for change in groundwater storage. These approaches include:

- The most common method for establishing minimum thresholds for groundwater storage, used in 65 of 81 high- and medium-priority basins analyzed for this report, relies on groundwater levels as a proxy for changes in storage. These do not explicitly define a separate minimum threshold for

PUBLIC DRAFT

change in storage but rather rely on the same thresholds established for the chronic lowering of groundwater levels.

- Five basins set thresholds based on sustainable yield, focusing on maintaining a balance between groundwater extraction and natural or managed recharge to avoid long-term overdraft.
- Two basins use pumping volume as a direct measure to limit the total amount of water extracted.
- Four basins rely on the volume of water in storage, tracking absolute changes in the aquifer's capacity over time.

Figure 2-8 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Change in Groundwater Storage

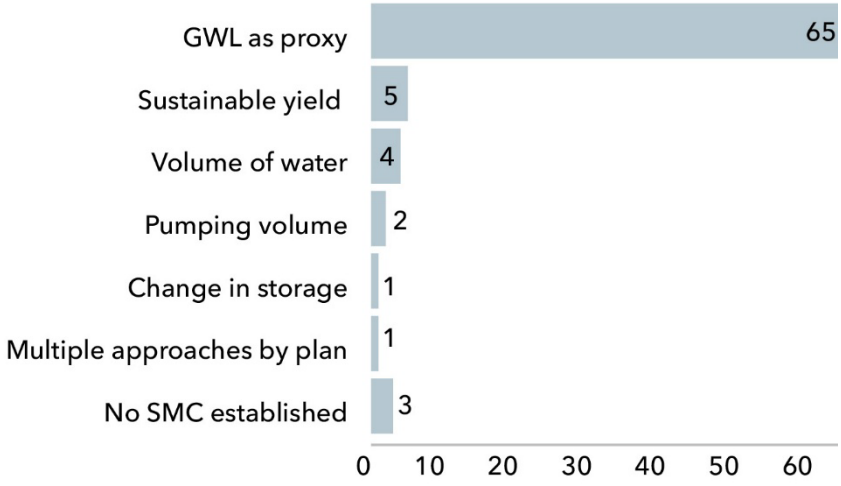


Figure 2-8 Notes: GWL = Groundwater Level. SMC = Sustainable Management Criteria. A total of 81 high- and medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.

SEAWATER INTRUSION

The minimum threshold for **seawater intrusion**, as stated in the GSP Regulations in Section 354.28(c)(3), is "defined by a chloride concentration isocontour for each principal aquifer where seawater intrusion may lead to undesirable results." Minimum thresholds for seawater intrusion are supported by maps and cross-sections of the chloride concentration isocontour that defines the minimum threshold and measurable objective for each principal aquifer, as well as a

PUBLIC DRAFT

description of how the seawater intrusion minimum threshold considers the effects of current and projected sea levels.

Seawater intrusion is a sustainability indicator primarily relevant to coastal basins, where the encroachment of seawater into freshwater aquifers poses a significant risk to water quality and availability. The majority (65) of 81 basins analyzed here do not need to track seawater intrusion as a sustainability indicator because it is not applicable to those inland locations. Figure 2-9 shows the different approaches taken by GSAs in setting their minimum thresholds for seawater intrusion. These approaches include:

- For the coastal basins where seawater intrusion is a concern, the most common approach (applied in 11 of 81 high- and medium-priority basins analyzed for this report) uses a chloride isocontour, a line delineating chloride concentration in groundwater, to define minimum thresholds. This method sets a boundary for acceptable salinity levels, tracking when and where seawater potentially advances into critical freshwater zones.
- Two basins incorporate groundwater levels as a proxy to manage seawater intrusion indirectly, assuming that maintaining water levels above a certain threshold will prevent the inland migration of saline water.
- One basin combines chloride isocontours with groundwater level proxies, using both metrics to enhance monitoring and management.
- Less common approaches include basins that use water quality regulatory standards (one basin), or a combination of regulatory standards and groundwater levels as proxies (one basin), to define minimum thresholds. These methods align with broader water quality management objectives while addressing the specific risks of seawater intrusion.

PUBLIC DRAFT

Figure 2-9 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Seawater Intrusion

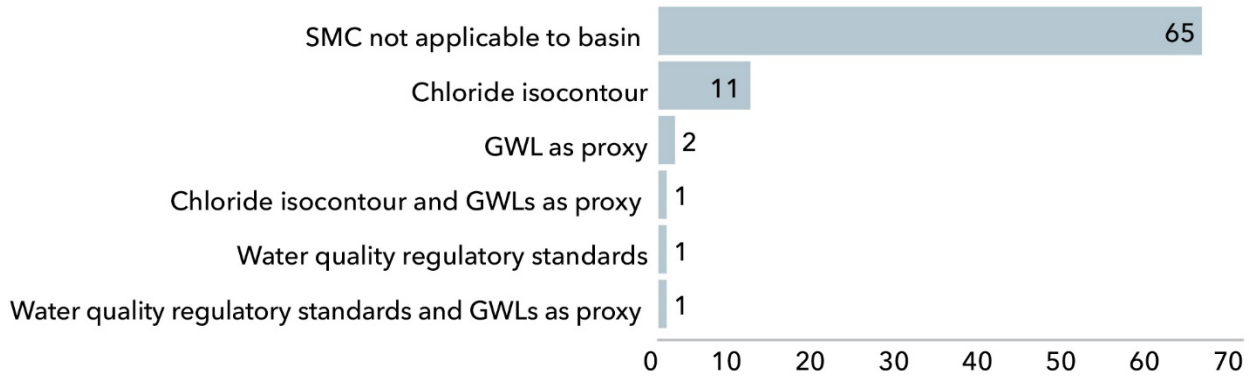


Figure 2-9 Notes: GWL = Groundwater Level. SMC = Sustainable Management Criteria. A total of 81 high- and medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.

DEGRADED GROUNDWATER QUALITY

The minimum threshold for **degraded groundwater quality**, as stated in the GSP Regulations in Section 354.28(c)(4), is "the degradation of water quality, including the migration of contaminant plumes that impair water supplies or other indicator of water quality as determined by the Agency that may lead to undesirable results." Minimum thresholds for degraded water quality are based on the number of supply wells, a volume of water, or a location of an isocontour that exceeds concentrations of constituents determined to be of concern for the basin. In setting minimum thresholds for degraded water quality, local, State, and federal water quality standards applicable to the basin must be considered.

Constituents monitored for water quality vary by basin and minimum thresholds for groundwater quality reflect regional differences in contamination risks, regulatory frameworks, and interested party priorities. These thresholds aim to prevent significant and unreasonable impacts on water quality that could harm beneficial uses such as drinking water, agriculture, and ecosystems.

Figure 2-10 illustrates the different approaches applied by GSAs in setting minimum thresholds for degraded groundwater quality. These approaches include:

- The majority of basins (47 of 81 high- and medium-priority basins analyzed for this report) rely on regulatory standards, such as maximum contaminant levels (MCLs) set under State or federal guidelines, as their minimum

PUBLIC DRAFT

thresholds. This approach directly aligns water quality management with established public health and environmental protection benchmarks. Other basins use varying approaches as described below.

- Nine basins use regulatory standards or a defined concentration as the benchmark, combining regulatory compliance with locally relevant water quality goals.
- Eight basins define minimum thresholds as the number of additional exceedances above regulatory standards, allowing for limited flexibility while still prioritizing water quality protection.
- A smaller subset of basins utilizes more specific metrics, such as a defined concentration threshold (one basin) or percentage of wells exceeding the threshold (two basins), to tailor thresholds to local conditions.
- Three basins use groundwater levels as a proxy for water quality, recognizing the link between water level declines and potential contamination risks.
- Similarly, three basins use a trend or equation-based approach, focusing on preventing worsening water quality trends.

DRAFT

Figure 2-10 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Degraded Groundwater Quality

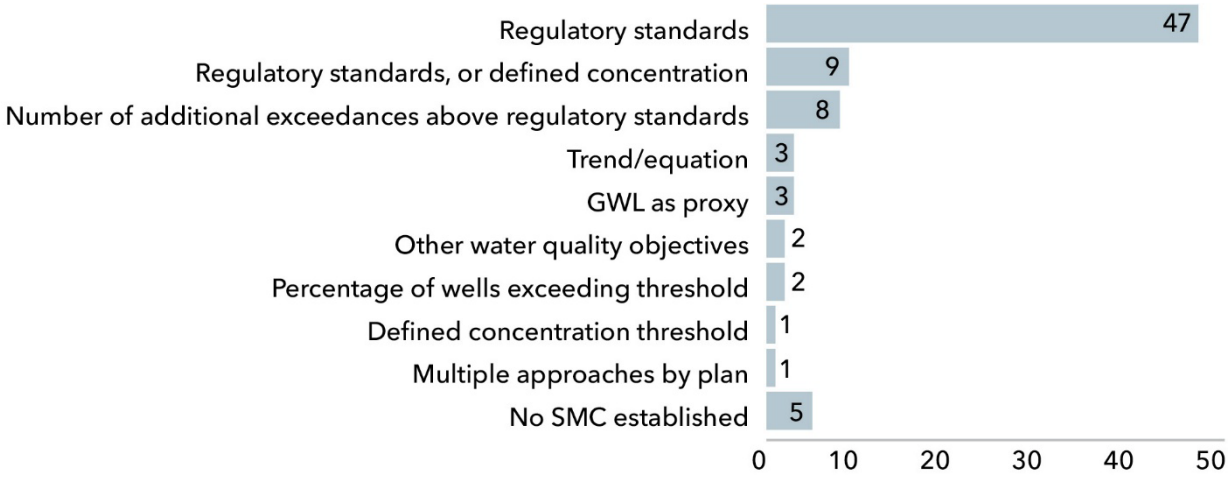


Figure 2-10 Notes: GWL = Groundwater Level. SMC = Sustainable Management Criteria. A total of 81 high- and medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.

LAND SUBSIDENCE

The minimum threshold for **land subsidence**, as stated in the GSP Regulations in Section 354.28(c)(5), is "the rate and extent of subsidence that substantially interferes with surface land uses and may lead to undesirable results." Minimum thresholds for land subsidence are based on identification of land uses and property interests that have been affected, or are likely to be affected, by land subsidence in the basin. The minimum threshold discussion must include an explanation of how the GSA determined and considered those uses and interests, and the GSA's rationale for establishing minimum thresholds considering those effects. The minimum thresholds and measurable objectives for subsidence must be supported by maps and graphs showing the rate and extent of land subsidence in the basin.

Minimum thresholds for land subsidence vary across basins, reflecting the varying degrees of subsidence risk and monitoring capabilities across basins. These approaches are designed to mitigate the risk of land subsidence while maintaining sustainable groundwater management practices. Figure 2-11 shows the different approaches taken by GSAs in setting their minimum thresholds for land subsidence.

- The most common approach, used in 20 of 81 high- and medium-priority basins analyzed for this report, consists of setting thresholds based on a subsidence rate that avoids undesirable results, prioritizing limits on land surface lowering that could negatively impact infrastructure or harm ecosystems.
- Similarly, 19 basins aim to maintain the current land surface elevation, using this as a benchmark to prevent any measurable subsidence from occurring.
- 18 basins rely on groundwater levels as a proxy, using declines in groundwater levels as an indicator to indirectly manage subsidence risks.
- Nine basins set minimum thresholds based on the recent subsidence rate, focusing on preventing rates from worsening compared to recent trends.
- Two basins combine subsidence rates with groundwater level proxies, integrating these measures for a more comprehensive monitoring framework.
- Conversely, one basin established a threshold tied to a subsidence rate exceeding historical averages, allowing for a limited amount of subsidence consistent with past conditions.

PUBLIC DRAFT

- Another basin linked minimum thresholds to groundwater levels that maintain aquifer saturation percentage, aiming to minimize the compaction of aquifer materials.
- Notably, nine basins did not establish sustainable management criteria for subsidence, primarily due to a lack of observed subsidence impacts in the basin.

Figure 2-11 Number of GSPs Employing Approaches for Setting Sustainable Management Criteria for Land Subsidence

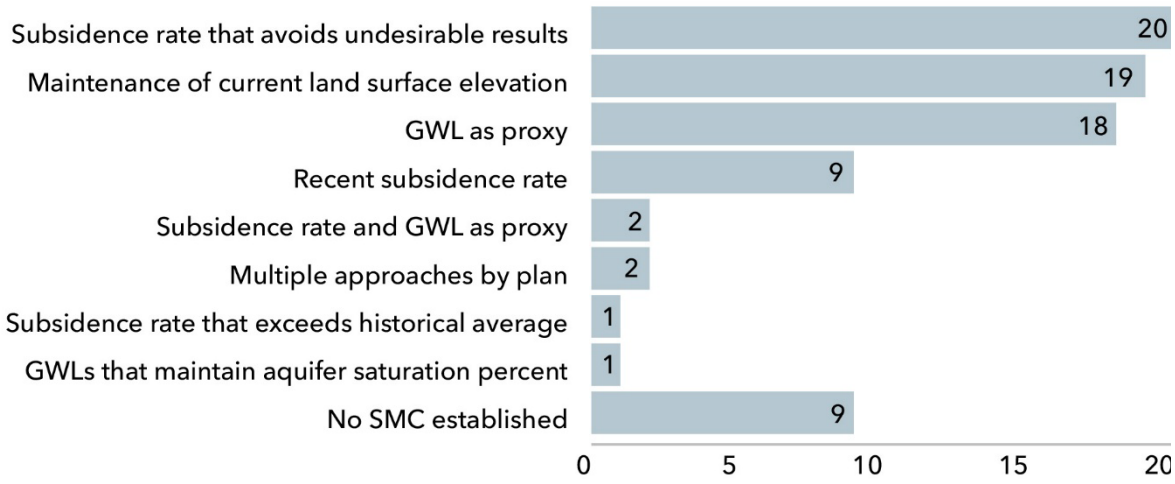


Figure 2-11 Notes: GWL = Groundwater Level. SMC = Sustainable Management Criteria. A total of 81 high- and medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.

DEPLETIONS OF INTERCONNECTED SURFACE WATER

The minimum threshold for **depletions of interconnected surface water**, as stated in the GSP Regulations in Section 354.28(c)(6), is the rate or volume of surface water depletions caused by groundwater use that has adverse impacts on beneficial uses of the surface water and may lead to undesirable results. The minimum threshold established for depletions of interconnected surface water are supported by the following: (a) The location, quantity, and timing of depletions of interconnected surface water; and (b) A description of the groundwater and surface water model used to quantify surface water depletion. If a numerical groundwater and surface water model is not used to quantify surface water depletion, the GSP is required to identify and describe an equally effective method, tool, or analytical model that accomplishes the requirements of the GSP Regulations.

PUBLIC DRAFT

Minimum thresholds for the depletions of interconnected surface water are designed to define conditions beyond which significant and unreasonable adverse impacts on beneficial uses of the surface water would occur. Figure 2-12 shows the different approaches taken by GSAs in setting their minimum thresholds for the depletion of interconnected surface waters sustainability indicator. These approaches include:

- The majority of basins (55 of 81 high- and medium-priority basins analyzed for this report) use groundwater levels as a proxy for monitoring stream depletion, assuming that maintaining groundwater levels above certain thresholds will minimize adverse impacts on interconnected surface water. This approach simplifies monitoring by relying on data already collected for other sustainability indicators.
- A smaller number of basins (four) directly model stream depletion, using models to estimate and set limits on the amount of groundwater pumping that affects surface water flows.
- Similarly, one basin combines stream depletion estimates with groundwater level proxies, integrating these metrics for a more nuanced understanding of interconnected impacts.
- Three basins use baseflow — the portion of streamflow sustained by groundwater discharge — as a direct metric for setting minimum thresholds, aiming to preserve consistent flow rates in critical reaches of streams.
- Another basin defines minimum thresholds based on the percentage of time the stream remains connected to the aquifer, emphasizing the importance of maintaining hydrologic connectivity.
- One basin considers surface water deliveries as a factor in managing interconnected surface water, linking thresholds to the availability of alternative supplies.
- Noticeably, 16 basins have not established sustainable management criteria for stream depletion, citing data limitations or uncertainty about the relationship between groundwater use and surface water impacts. This highlights the need for continued technical and financial assistance to effectively measure undesirable results.

The varied approaches that have been applied in GSPs highlight the challenges and importance of tailoring sustainable management criteria for interconnected surface water to local hydrologic conditions, ensuring that both groundwater and surface water systems can be managed sustainably under SGMA.

PUBLIC DRAFT

In February and September of 2024, DWR released a series of three papers and an informational webinar, which provided a general overview of the technical aspects of interconnected surface water. These resources discuss the quantification of depletions of interconnected surface water due to groundwater pumping. Using the technical basis provided in these three papers, DWR is developing guidance for GSAs to consider when managing depletions of interconnected surface water for their groundwater basins. An interconnected surface water guidance document is planned for 2025.

Figure 2-12 Number of GSPs Employing Approaches to Establish Sustainable Management Criteria for Depletions of Interconnected Surface Water

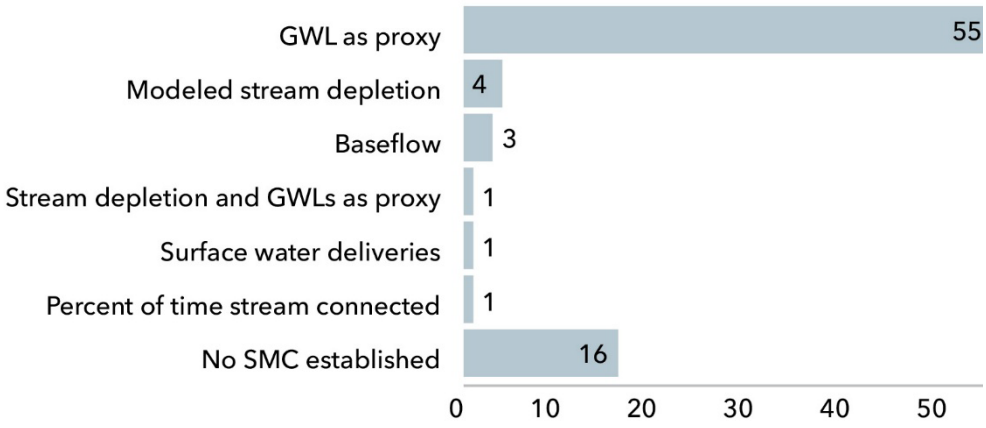


Figure 2-12 Notes: GWL = Groundwater Level. SMC = Sustainable Management Criteria. A total of 81 high- and medium-priority basins, corresponding to 109 approved, incomplete, or inadequate GSPs, were evaluated for their minimum threshold approaches. Alternatives, low/very low priority basins, as well as basins with GSPs still under initial review by DWR as of December 2024, were excluded from the analysis.

Corrective Actions

SGMA directed DWR to evaluate a GSP within two years of its submittal date and issue a written assessment of the plan. As allowed by Water Code Section 10733.4(d), the assessment may recommend corrective actions to address discrepancies or deficiencies identified by DWR or to further refine and improve plans to increase their likelihood of achieving sustainable groundwater management within SGMA timeframes. All GSPs and Alternatives approved by DWR received corrective actions — some of the corrective actions were recommended to address planning discrepancies or technical approaches that were determined not to materially affect the ability of the agencies in the basin to implement the GSP. Other corrective actions, however, were required to address

PUBLIC DRAFT

deficiencies that directly precluded the plan's approval. GSPs with required corrective actions were generally determined to be incomplete and were required to sufficiently address the deficiencies within 180 days or risk the plan being determined inadequate. The corrective actions in the approved GSPs generally addressed regulatory or planning shortcomings and often focused on refining methodologies, improving data accuracy, and enhancing interested party engagement. By addressing corrective actions, GSAs can strengthen their GSPs and align more closely with adjacent basins and the legislative intent of SGMA.

Most of the recommended corrective actions applied to a basin's GSP need to be addressed by the plan's next periodic evaluation and represent the continual improvement process of sustainable groundwater management. Some recommended corrective actions were provided for minor deficiencies related to establishing and implementing sustainable management criteria. While the initially established criteria may not have precluded the approval of a GSP, DWR has expressed a need for the GSAs to iteratively improve, justify, monitor, and finalize sustainable management criteria. Sustainable management criteria are a critical component of a GSP and establishment of the criteria, with sufficient details and supporting analyses, is essential to meet the requirements of SGMA and substantially comply with the GSP Regulations.

Corrective actions related to sustainable management criteria were recommended for all six sustainability indicators, highlighting the centrality of sustainable management criteria in achieving sustainable conditions. Figure 2-13 depicts the number of basins that were issued corrective actions based on each sustainability indicator and sustainable management criteria component. Many corrective actions were tied to the definition of undesirable results and minimum thresholds across these indicators, reflecting the critical need for clarity and rigor in articulating what constitutes undesirable groundwater conditions, and the thresholds established to avoid those conditions.

DWR issued recommended corrective actions to most of the approved plans with respect to the potential effects of the defined undesirable result (GSP Regulations Section 354.26(b)(3)), indicating DWR expects improvements to the definition of undesirable results by the basin's next periodic evaluation deadline. Some definitions of undesirable results were too narrow and excluded many factors, which DWR identified as a deficiency that precluded approval and required correcting. Overall, DWR emphasized the importance of defining undesirable results in a manner that is clear, quantifiable, and that considers the beneficial uses and users of groundwater within the basin.

PUBLIC DRAFT

GSPs approved by DWR also received recommended corrected actions to further detail effects of proposed minimum thresholds on beneficial uses and users. These descriptions, required by the GSP Regulations in Section 354.28(b)(4), outline the specific conditions the GSA aims to avoid. For instance, GSPs that were approved often supported established minimum thresholds for groundwater levels with a well impact analysis that disclosed the number, location, and type of potentially dry wells. However, key details of local wells may be unknown, such as pump depth, screen intervals, precise location, or service status. In such cases, those approved GSPs analyzed the associated uncertainty and did not use the uncertainty to reduce the analysis scope. DWR staff assessed the thoroughness of the analyses by evaluating the information in the GSP, relevant publicly available data, and public comments. Groundwater levels, degraded water quality, subsidence, and depletions of interconnected surface water minimum thresholds received the most corrective actions.

The approved GSPs generally provided detailed descriptions of the potential effects on the basin from significant and unreasonable groundwater conditions, ensuring that interested parties can understand when undesirable results occur and how they may impact the basin's sustainability. Moving forward, it will be critical for GSAs to address identified deficiencies, such as narrow and vague definitions that exclude key factors or rely on insufficient detail.

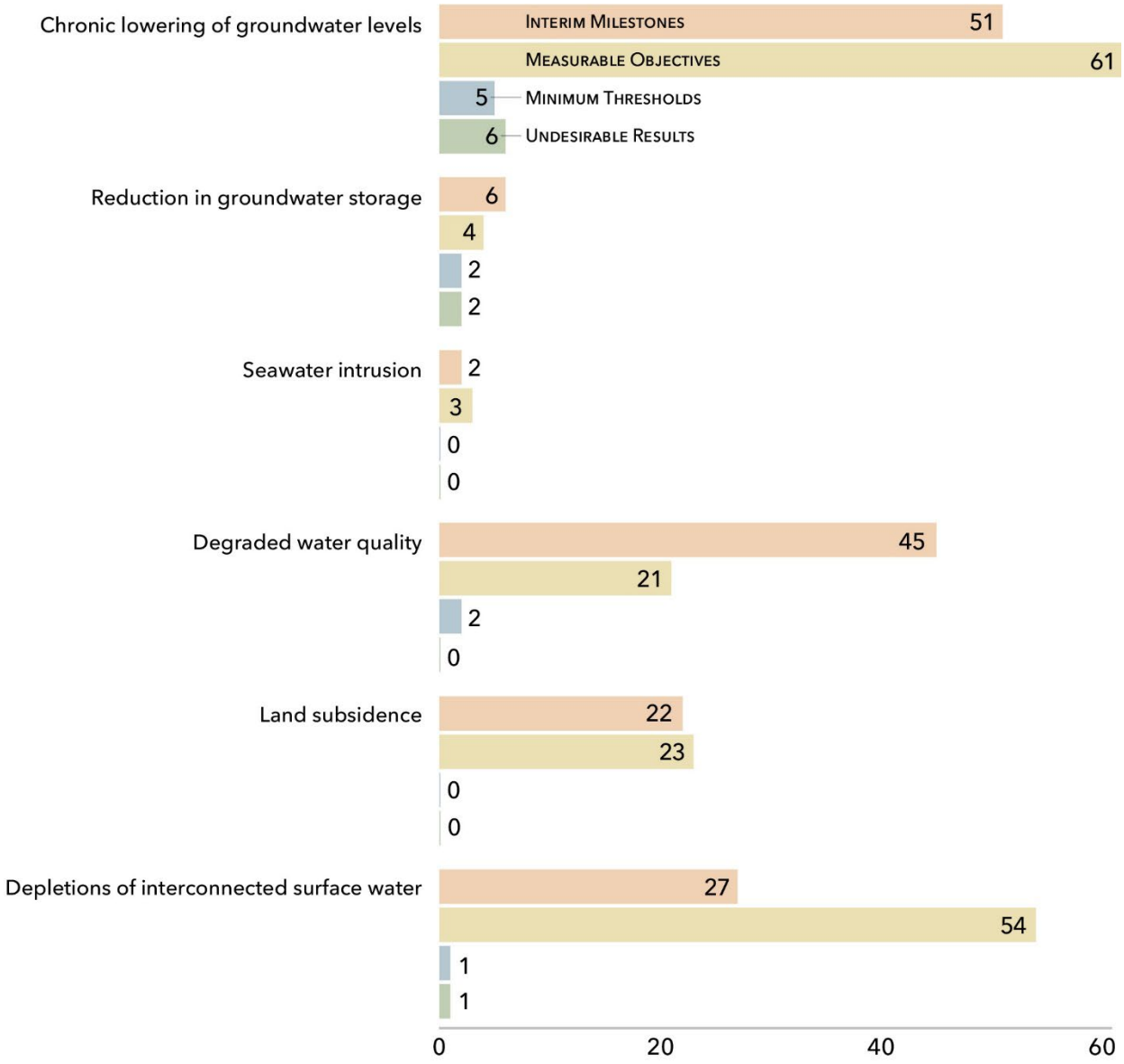
Apart from defining the effects, another area identified for improvement includes the quantitative criterion of a combination of minimum threshold exceedances across the basin (GSP Regulations Section 354.26(b)(2)). Many GSPs provided quantitative levels that constitute an undesirable result, but did not provide adequate information to support and justify the combination of minimum threshold exceedances that determined when and where those undesirable results were occurring. DWR rejected the GSAs' reliance on factors such as non-drought conditions, direct effects from GSA activities, or seasonal high measurements to constrain or otherwise obscure when the basin would experience undesirable results. In those instances, DWR recommended appropriate corrective actions to remove these restrictions.

In contrast, measurable objectives and interim milestones received fewer corrective actions, likely because they are frequently aligned with minimum thresholds, making their development less contentious or uncertain. While measurable objectives and interim milestones are essential for tracking progress and long-term planning, the primary focus of State oversight remains on the

PUBLIC DRAFT

establishment and justification of minimum thresholds and the prevention of undesirable results.

Figure 2-13 Corrective Actions Associated with Each Sustainability Indicator



In general, there were no correlations between the approach used to define undesirable results or establish minimum thresholds and whether corrective actions were issued by DWR. Corrective actions were generally not tied to the specific method chosen in establishing sustainable management criteria but rather to the adequacy of the justification, analysis, and level of detail provided to support the management criteria.

In many cases, the issuance of corrective actions reflected a need for greater transparency or rigor in explaining how undesirable results and minimum thresholds were established, rather than an issue with the chosen approach itself. For example, a GSA that used a robust method but failed to demonstrate how the minimum threshold avoided undesirable results or aligned with basin-wide sustainability goals was still likely to receive a recommended corrective action. Conversely, GSAs that provided comprehensive analysis and clear connections between their minimum thresholds and management objectives often avoided corrective actions, regardless of the approach used.

Overall, DWR emphasizes the importance of clear, well-supported sustainable management criteria that reflect a comprehensive understanding of basin conditions while considering the beneficial uses and users of groundwater in a basin. Comprehensive GSPs establish minimum thresholds by incorporating robust analyses, thorough supporting data, and a thoughtful approach to addressing uncertainties. Across all sustainability indicators, DWR's reviews highlight the need to clearly define undesirable results, quantify potential impacts at or below minimum threshold levels, identify affected interested parties or systems, and evaluate associated uncertainties to ensure the thresholds are both practical and protective.

In addition to addressing direct impacts, DWR expects GSAs to account for the broader implications of allowing conditions to approach minimum thresholds and the impact to other sustainability indicators, such as how declining groundwater levels might influence land subsidence, interconnected surface water, or groundwater quality. Narrowly defined thresholds that fail to consider the uses and users of groundwater, or exclude critical data, risk undermining the effectiveness of a GSP. Plans that meet expectations demonstrate a holistic approach, addressing the interconnections between indicators and ensuring that sustainable management criteria are appropriate, equitable, and grounded in a solid understanding of basin dynamics.

2.6.2 Projects and Management Actions

The legislative intent of SGMA is for local agencies and GSAs to take actions to sustainably manage groundwater basins in accordance with an approved GSP's groundwater sustainability program. The authorities granted by SGMA to California's GSAs, such as appropriating and acquiring surface water or groundwater, proposing fees, developing groundwater pumping allocations, and requiring the installation of water-measuring devices, allow for a broad degree of

PUBLIC DRAFT

local control and flexibility in how groundwater is managed. Utilizing the authorities granted by SGMA, as well as other existing authorities, powers, or programs, most GSAs will need to develop and implement a combination of projects and management actions (PMAs) to achieve a basin's sustainability goal.

DWR anticipates that demand management, water conservation and efficiency, and optimizing conjunctive use of water through in-lieu or direct recharge will be critical for many basins to reach their sustainability goals. However, these activities make up only a subset of a broad range of PMAs being developed by GSAs. Other types of PMAs include mitigation programs, monitoring and modeling to filling data gaps, obtaining new water supplies, expanding surface water storage, community engagement, coordination with other agencies, special investigations, and various other actions and activities related to SGMA implementation and groundwater management. Not all PMAs are easily categorized, and over a quarter of the submitted PMAs may serve multiple functions such as the installation of a monitoring well which will improve a basin's monitoring network but may also fill data gaps in the GSP or help to refine a GSA's numerical groundwater model. Many PMAs will also need to be implemented in conjunction with other actions for their intended benefits to be fully realized. For example, irrigation efficiency programs are sometimes characterized as demand management actions; however, those actions may not effectively reduce demand unless coupled with specific demand reduction policies.

GSAs, through their GSPs, are required to describe all PMAs that have been determined to help achieve a basin's sustainability goal, including PMAs that respond to changing hydrologic or climatic conditions over the planning and implementation horizon. This description must include elements such as public noticing, regulatory processes, and how benefits will be evaluated. GSAs are also required to describe the progress towards implementing PMAs through GSP annual reporting requirements. In addition, GSAs are also required to report on the status of PMAs in periodic evaluations of their plan and describe how the implementation of specific PMAs have affected groundwater conditions in the basin.

During the initial review of all submitted GSPs, DWR staff observed that, on average, each GSP includes nearly 20 PMAs. DWR found that the implementation "status" of these PMAs was highly variable, as many of them were slated for implementation through adaptive management strategies based on various factors, such as changing basin conditions, funding availability, and ongoing feasibility assessments. Therefore, while numerous PMAs are currently being implemented, or are scheduled for implementation within a few years, a significant

PUBLIC DRAFT

number of PMAs are either conceptual in nature or are only proposed for implementation pending specific triggers or conditions that would warrant their implementation. Similarly, the initiation year and completion year of many PMAs are not well-defined in the GSPs or are obscured by their dependency on these specific triggers and circumstances mentioned above. Only one third of the PMAs have an expected initiation and completion date. Recognizing the need for an effective method to track and report on the progress toward implementing PMAs, DWR recently developed the PMA Module within the SGMA Portal.

PMA Module

The PMA Module provides a space for GSAs, DWR, and interested parties to more easily review and understand specific PMA information and associated data. It also serves as a mechanism for GSAs to report on the current implementation status and progress of their PMAs, through an annual report update feature, which both assists the GSAs in meeting the annual reporting requirements and helps inform DWR in evaluating a basin's progress towards achieving sustainability. Additionally, the PMA Module promotes public transparency and serves to inform interested parties about the status of projects and management actions, consistent with SGMA's noticing and communication requirements. Data and information housed within the PMA Module — such as project types, implementing agencies, initiation and completion dates, costs, project water supply source, and any associated quantifiable benefits — will be publicly available for viewing or tabular export via the SGMA Portal.

While the PMA Module is primarily a regulatory assistance tool to help fulfil GSP implementation reporting requirements at a basin level, its dataset is also intended to provide DWR and the public with valuable insights on the successes, challenges, and ongoing needs associated with SGMA implementation. Some specific questions that the PMA Module may help to answer include, but are not limited to:

- How many PMAs are actively being implemented? What are the quantifiable benefits of these projects?
- If projects are not being actively implemented, when will they be? How many PMAs are "shovel ready" for implementation pending funding availability?
- What proportion of overdraft will be eliminated through supply augmentation? What proportion through demand management?

PUBLIC DRAFT

- How much water is being used for direct aquifer recharge and by what mechanisms is recharge occurring? Where is the water being used for recharge (or in-lieu use) coming from and how reliable are these sources?
- How much recycled or desalinated water is being utilized by GSAs and where is it being used?
- How are conjunctive use patterns changing across California? As demand for surface water increases due to pumping reductions, what effect is SGMA having on the State's groundwater and surface water systems when viewed more holistically?

DWR anticipates that the PMA Module will help streamline GSA reporting requirements and provide DWR staff and the public with transparent, qualitative, and quantitative data to better understand how basins are progressing towards sustainability. Given the complexity of achieving sustainable groundwater management and the implications of SGMA on water use patterns, tools and datasets like the PMA Module will be useful for water management planning, both at the basin and statewide scales in the future.

As of April 21, 2025, the PMA Module included information on 1524 different PMAs. Figure 14 and Table 11 show the distribution of the PMAs across 19 different categories. A more detailed breakdown of data from the PMA module is presented in Appendix J, "Projects and Management Actions."

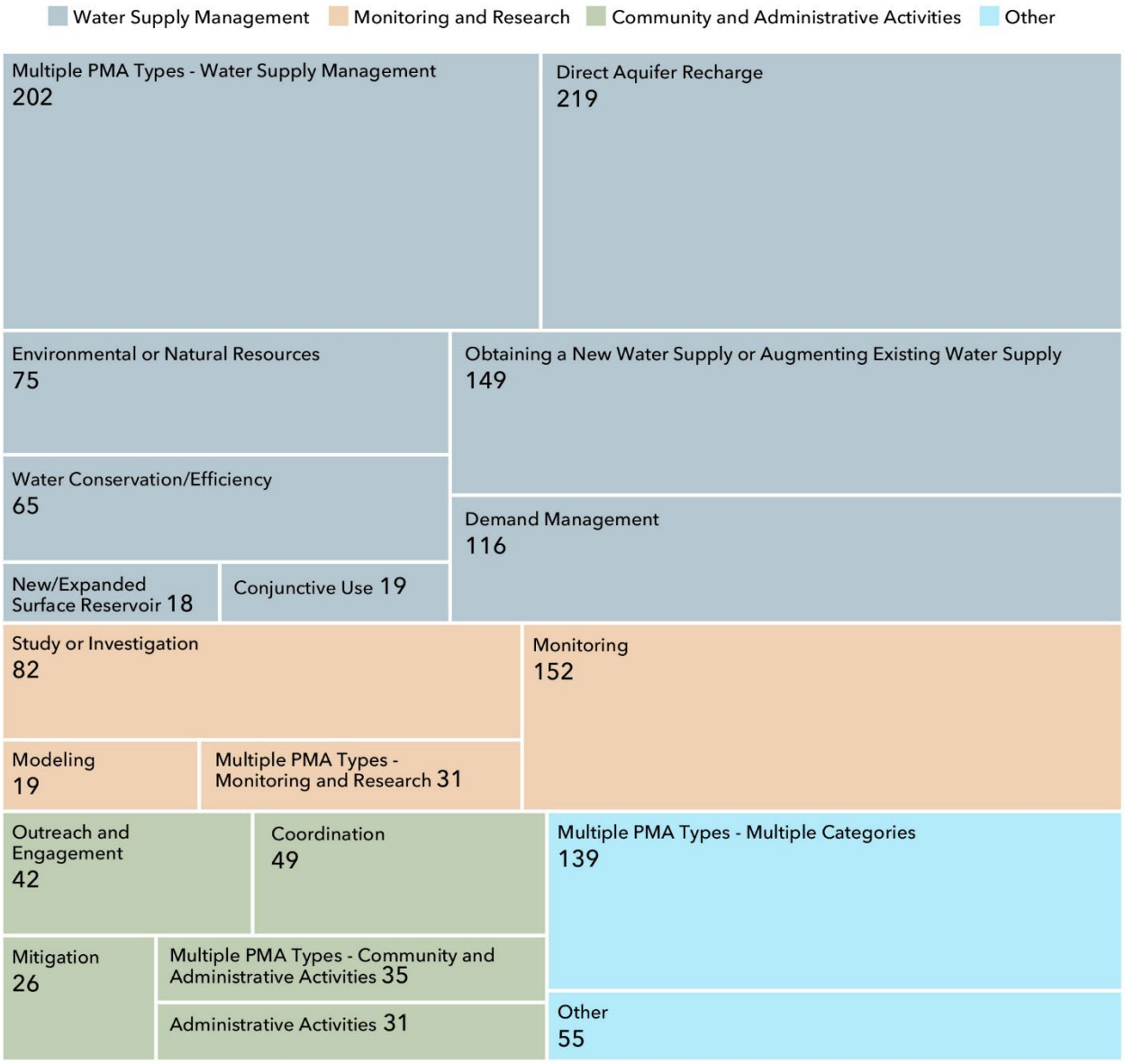
PUBLIC DRAFT

Table 2-11 PMAs Reported in the SGMA Portal PMA Module

PMA Types	Number of Projects
Direct Aquifer Recharge	219
Conjunctive Use	19
Water Conservation/Efficiency	65
Monitoring	152
Modeling	19
Outreach and Engagement	42
Coordination	49
Mitigation	26
Demand Management	116
Obtaining a New Water Supply or Augmenting Existing Water Supply	149
Environmental or Natural Resources	75
Study or Investigation	82
New or Expanded Surface Water Reservoir	18
Administrative Activities	31
Other	55
Multiple PMA Types — Water Supply Management	202
Multiple PMA Types — Monitoring and Research	31
Multiple PMA Types — Community and Administrative Activities	35
Multiple PMA Types — Multiple Categories	139
Total Projects:	**1524**

PUBLIC DRAFT

Figure 2-14 PMA Types Reported in the SGMA Portal PMA Module



2.6.3 PMA Spotlight: Groundwater Markets

Groundwater markets continue to evolve in California with the implementation of GSPs and associated management actions as GSAs explore creative ways to minimize economic impacts in the face of substantial reductions in groundwater pumping to achieve sustainability. Of the GSPs submitted to DWR, plans from 42 basins include groundwater market activities as a strategy or management action to achieve sustainability. The status of these activities ranges anywhere from conceptual frameworks to fully implemented water markets. Water markets can serve as cost-effective management strategies to move toward sustainable

management of limited groundwater resources, potentially in a more equitable way when specific market rules are in place.

A groundwater market can allow landowners with a groundwater allocation to decide whether to use or sell the allocation and alleviate potential financial losses if they determine that an allocation is insufficient to sustain a planned land use. Groundwater markets can improve flexibility and reduce total costs, but they should have controlling factors that prevent excessive, localized drawdown that can affect drinking water supplies, groundwater dependent ecosystems, or other users. Trading should also account for other potential external costs of groundwater trading and encourage fair and equitable market practices.

Several examples of established or emerging groundwater markets are described below to illustrate some of the challenges and strategies associated with establishing a market. The mechanics, structures, and oversight of groundwater markets can vary based on groundwater basin characteristics and associated governance. Each example generally includes the market location, the administering agency, guiding principles, and market framework, as applicable. A summary of example markets in California is provided in Table 2-12 with their locations shown in Figure 2-15. In addition to these examples, several other markets have been proposed in GSPs and are in the early planning and development stages.

Links to additional information on case studies presented below are included in Appendix D, "Citations, Reference Materials, and Links."

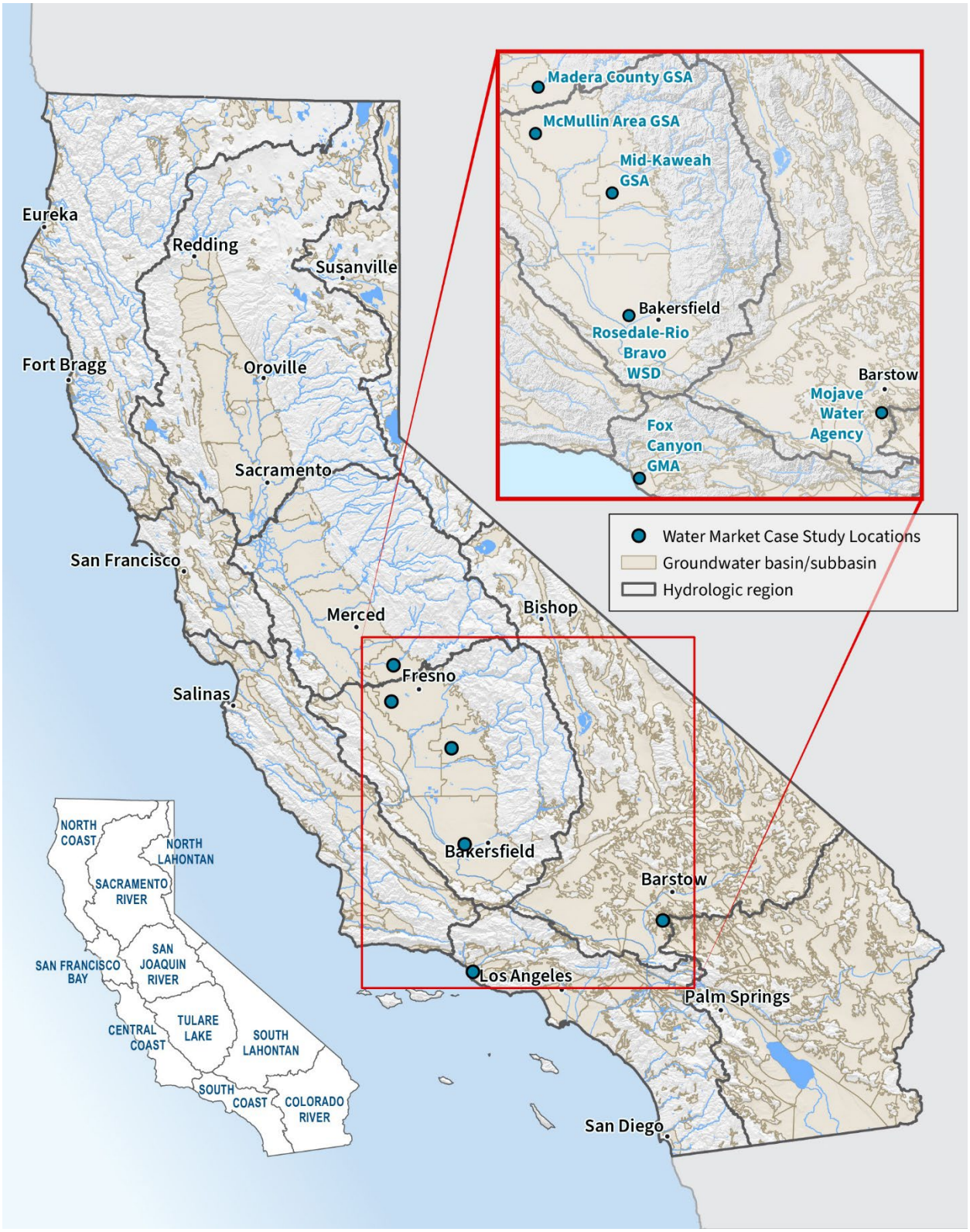
Table 2-12 Summary of Water Market Case Studies

GSA	Location	Status
Madera County	Madera County	Emerging
McMullin Area GSA*	Kings County	Emerging
Kaweah Subbasin	Tulare County	In-Development
Rosedale-Rio Bravo Water Storage District (Kern Groundwater Authority)*	Kern County	In-Development
Mojave Water Agency Management Area	San Bernardino County	Active
Fox Canyon Groundwater Management Agency*	Ventura County	Active

*Table 2-12 Note: * Groundwater market previously discussed in California's Groundwater Update 2020.*

PUBLIC DRAFT

Figure 2-15 Location of Water Market Case Studies



Groundwater Market Case Studies

MADERA COUNTY

In the Madera Subbasin, located within the San Joaquin River Hydrologic Region, the Madera County GSA included a water trading program as one of their management actions for demand management. According to the GSP, the Madera County groundwater market would establish a local groundwater credit system and allow trading of those credits among groundwater users. The program would establish an accounting of available groundwater supply, allocation of that water supply to local interested parties, and a record-keeping system that facilitates and documents all trades. The GSA has identified that additional conditions on location and timing of the use of traded credits may be needed and are likely to be required in many areas of the Subbasin (Corona 2021).

As the GSP was being developed in 2019, Madera County applied for and received a grant through the Bureau of Reclamation's WaterSMART Water Market Strategy Program to evaluate the feasibility for a water market that would allow certain irrigated parcels within the county to buy and sell groundwater pumping allocations. The Madera County GSA conducted a water market study in 2021 that included:

- Outreach with local interested parties to define opportunities, identify concerns, and obtain feedback on alternative groundwater market strategies.
- Assessing the feasibility of a groundwater market in Madera County, including potential environmental, economic, and social impacts and unintended consequences.
- Developing a market strategy framework, outlining the market structure, rules, and strategies for reducing adverse effects.
- Conducting a pilot groundwater market demonstration program.

The study identified that a key prerequisite in a viable groundwater market in the basin is the development of an allocation system and an accounting system to track these allocations. In June 2021, the Madera County GSA adopted an allocation strategy based on the Madera Subbasin's sustainable yield and transitional water, the latter being the amount of consumptive use that exceeds the sustainable yield until sustainability is achieved (by 2040). The allocation provides an annual per-acre allotment of sustainable yield and transitional water to eligible parcels, which is based on the average evapotranspiration (ET) of applied water within the GSA (Corona 2021).

PUBLIC DRAFT

The study also evaluated the need for monitoring and enforcement procedures to establish trust in market transactions and mitigate adverse impacts on the beneficial uses and users in the Madera Subbasin. Following the development of a market strategy and rules, the study simulated nine pilot rounds to evaluate multiple years of trading under varying hydrologic conditions, market structures, rules, and administrative processes (Corona 2021).

The general structure of the market simulated in the pilot study is as follows (Corona 2021):

- **Tradable Allocations:** The units of trade in the market were sustainable yield allocations, which were bought and sold on a volume basis (acre-feet).
- **Transitional Water Purchases:** Participants were offered the opportunity to buy transitional water (up to a set acre-feet/acre quantity). The quantity of transitional water available to participants decreased over the course of the pilot until no transition water was available in later pilot rounds.
- **Eligible Participants:** Eligible participants included agricultural growers and farmers who would be eligible to receive a sustainable yield allocation for their irrigated acreage (or previously irrigated acreage), consistent with the GSA's allocation approach.
- **Trading Locations**: All eligible participants within Madera County were allowed to participate in the pilot program.
- **Water Purchase Transfers:** Buyers of sustainable yield allocations will pump more water where they are located, while sellers will forego pumping and using the sustainable yield allocations they sell.
- **Matching Buyers and Sellers:** Market participants bought and sold groundwater allocations by submitting "bids" to the market administrator. Buyers and sellers were matched using a blind matching process to protect the anonymity and confidentiality of participants. Sellers were sorted on a spreadsheet according to their willingness to accept (WTA) when selling, and buyers according to their willingness to pay (WTP) when buying. First, the buyer with the highest WTP was matched with the seller with the lowest WTA.
- **Trading Period:** Trades were made once per month based on simulated information provided by the GSA, representing trading over a simulated year.

PUBLIC DRAFT

The pilot study received feedback from the participants related to uncertainty in water supply and eventual participation in the pilot, the benefits of land fallowing and selling allocations, and affordability of water prices for small farmers. The study concluded that the initial pilot studies indicate a groundwater market may be a useful tool for meeting SGMA requirements; however, challenges are also foreseen. The following recommendations were made based on findings from the simulated market study (Corona 2021):

- Hire a neutral third party to administer trading and enforce rules or assess penalties.
- Keep the matching process simple.
- Have financial transparency for funds generated from the market.
- Only implement rules when a rule needs to be put in place.
- Limit trade to farm unit zones.
- Incentivize strategies to reduce consumption and generate supply.

KAWEAH SUBBASIN

In the Tulare Lake Hydrologic Region, the GSAs in the Kaweah Subbasin are developing a water marketing strategy with financial assistance from the Bureau of Reclamation. Funding through a WaterSMART application was awarded to the Tulare Irrigation District to evaluate a framework for a water market. In 2021, a Strategy Committee was established with representatives from across the Kaweah Subbasin. The committee then selected a consultant to assist in developing a marketing strategy. In 2022, the consultant and Strategy Committee held multiple outreach and engagement meetings allowing interested parties to provide input on items to be included in the Subbasin's water market strategy. The strategy document was developed in 2023 with the Mid-Kaweah GSA approving a pilot of the program in early 2024.

The pilot program was established using the following guiding principles (Greater Kaweah GSA Board of Directors 2023):

- **Flexibility:** Provide water users with the flexibility to comply with new regulations and to respond to changing water availability.
- **Adaptability:** The Water Market Strategy should promote adjustments in practices, rules, and procedures as conditions change and as the experience of market participants grows and new information becomes available.
- **Transparency:** The process of developing the Water Market Strategy and conducting market activities should be visible and understandable to

PUBLIC DRAFT

interested parties. Transparency includes the availability of accurate and reliable water use data and the timely reporting of water market activity.

- **Do No Harm:** The Water Market Strategy should anticipate and avoid adverse impacts to water users and uses (Water Code Section 10721(x)).
- **Equity & Inclusion:** The Water Market Strategy should be developed with an open process that includes the full range of potential market participants and other interested parties. The implementation of the Water Market Strategy should be relatively simple and understandable to interested parties.
- **One Basin-wide Strategy:** The Water Market Strategy will develop a common framework available to all GSAs in the Kaweah Subbasin.

The pilot program also included a set of rules for the units traded, allowable trade types, eligible participants, and allowable trading zones (Greater Kaweah GSA Board of Directors 2023). These rules are described below:

- **Units Traded:** The trade units are classified as one acre-foot of allocation, which is measured as ET.
- **Allowable Trade Types:** Participants are allowed a one-time transfer of up to 10 inches per acre, measured as ET.
- **Eligible Participants:** Those eligible to participate in the pilot program are landowners within a GSA who hold allocations, are current with all GSA fees, and are in compliance with all applicable GSA ordinances, rules, and regulations.
- **Trading Zones:** Two zones were developed and designed to mitigate adverse impacts to groundwater conditions in the Kaweah Subbasin and in DACs. The pilot program established a minimum threshold trigger that when activated, would restrict that zone from further trading and additional GSA restrictions would apply. The trigger applicable to DACs is still in development, however, trading within these areas would also cease until impacts are mitigated.

The Mid-Kaweah GSA also secured a third-party administrator to oversee the pilot market and established an online automated marketing platform in conjunction with the existing Kaweah Subbasin Groundwater Dashboard. The dashboard has been used by growers to track their groundwater allocations and compare evapotranspiration against precipitation, groundwater, and surface water volumes within their properties.

PUBLIC DRAFT

MOJAVE WATER AGENCY MANAGEMENT AREA

The Mojave Water Agency was created in 1960 to manage water from the State Water Project for communities in the high desert. In the 1990s, water users in the western Mojave Desert began a court case to redefine groundwater rights and set up a system for trading those rights. This adjudication process led to a 2000 California Supreme Court decision that divided the Mojave River Basin into five subareas, each with distinct hydrologic characteristics.

Following the California Supreme Court decision, the Mojave groundwater market began operation as several smaller markets rather than a single unified one as seen in other basins in California. The purpose of smaller markets was to avoid potential impacts to other subareas. As described in Ayers (2021) "Certain regions, or subareas, in the adjudicated zone exhibit greater hydrologic connection within themselves than they do with other areas. A trade that moves pumping rights from one area into another would result in an increase in total pumping — and consumptive use — in the receiving subarea that could set it out of long-term hydrologic balance. Such transfers are prohibited outside of exceptional cases requiring watermaster approval, so five separate markets now exist." The adjudication ruling also established interconnected flow requirements between subareas because of their interconnected nature.

The groundwater rights that are traded within these subareas are based on the amount of water pumped during the pre-adjudication period from 1986–1990, also known as the Base Annual Production (BAP) rights. Each year, these rights generate Free Production Allowance (FPA), which gives holders the right to pump a certain volume of water. If a user exceeds their FPA, they must offset the excess by leasing FPA from another holder, buying replenishment water from the watermaster, or using carryover FPA from previous years.

Mojave Water Agency has used the market to help reduce overdraft in some areas, like buying BAP to conserve groundwater and bring the basin closer to balance. While the court set a requirement to reduce pumping over the first five years of adjudication, it became difficult to enact these cuts due to conditions established in the ruling. The Baja subarea was especially affected by the process established in the court ruling; thus, FPA reductions were not approved by the court in the Baja subarea, which resulted in continued overdraft conditions. However, the groundwater market system overall has been successful in encouraging groundwater users to reduce their pumping and mitigate further overdraft in other subareas throughout the Mojave River Basin. It also serves as a unique case study in groundwater markets being used outside of SGMA for a common purpose — to

PUBLIC DRAFT

achieve sustainable management in a way that lessens economic impacts to individual users.

Updates on California Groundwater Markets Described in California's Groundwater Update 2020

Three other emerging groundwater markets were described in California's Groundwater Update 2020. Brief descriptions and updates are provided below as examples of how markets continue to evolve as they are implemented to better suit local conditions and needs. These three markets continue to serve as examples of how groundwater markets can be leveraged to take steps toward achieving sustainable groundwater management in some basins.

FOX CANYON GROUNDWATER MANAGEMENT AGENCY

In the South Coast Hydrologic Region, the Oxnard Subbasin in western Ventura County is managed by the Fox Canyon Groundwater Management Agency. In response to GSP requirements for this basin, the Fox Canyon Groundwater Management Agency became the first GSA to formally test a groundwater market.

Setting groundwater allocations or tradable units is one of the most important and challenging initial steps toward establishing a groundwater market. The Fox Canyon Groundwater Management Agency GSA adopted an ordinance establishing an allocation system in October 2019, which was later amended in October 2020, March 2021, and again in March 2024. Pumpers can use their allocations to pump groundwater or sell any portion of their allocations to another pumper in the basin and forgo pumping themselves. The GSA intends to transition from a wellhead-based (metered pumping) to a land-based allocation system (based on land use and crop type), which is being developed utilizing fixed parcel-based water-use data (Fox Canyon Groundwater Management Agency 2021). The fixed allocation system would allocate the same amount of water per acre of irrigated land across the basin but would make proportionally larger cuts to higher water-use participants as allocations are ramped down to achieve the GSP goals and could result in larger economic impacts to those users than others in the basin.

The Fox Canyon Groundwater Management Agency GSA implemented water-market pilot program in two phases to assess the market's potential. The pilot program was implemented in the Oxnard Subbasin, with agricultural pumpers or mutual water companies delivering water solely for agricultural use eligible for participation. The Fox Canyon Groundwater Management Agency GSA established the following rules for the water market pilot programs (Fox Canyon Groundwater

PUBLIC DRAFT

Management Agency, Water Market Ordinance 2016, 2019, 2020; Heard et al. 2021):

- **Temporary (annual) trades only:** Annual trading was chosen because of concerns that permanent sales of agricultural allocations could encourage development projects and conversion of agricultural lands.
- **Restricted trading in two special management areas:** Restricted trading was enacted because of location-specific concerns regarding seawater intrusion and cones of depression caused by over-pumping. In the special management areas, trading is allowed within and outside the areas but pumping within the areas cannot exceed allocations; groundwater users within the special management areas cannot buy additional allocations from outside the area.

The Fox Canyon Groundwater Management Agency GSA also instituted measures to better and more equitably manage the market, including monitoring requirements for accurate data, third-party administration, anonymous trading, and algorithmic matching of trades to maximize efficiency and minimize strategic bidding.

As discussed in CalGW Update 2020, the Fox Canyon Groundwater Management Agency groundwater market had to overcome several challenges in development, in addition to the groundwater allocation process described above. The process was resource-intensive and required significant, dedicated staffing capacity. Funding for the initial planning efforts and pilot projects was assisted by grant support from the Natural Resource Conservation Service. The development process included efforts by various agencies, non-governmental organizations, and local growers. Early support from local growers was also critical for early buy-in by other market participants in the region.

After the water market pilot program concluded in 2021, the market ceased operations and remains inactive. No further developments or initiatives have been pursued to revive the program, as the current groundwater extraction reporting system makes the water market no longer viable.

MCMULLIN AREA GSA

The McMullin Area GSA in Fresno County developed a water marketing strategy with financial assistance from the Bureau of Reclamation in 2021. The McMullin Area GSA identified a groundwater market as a component of GSP implementation with the goal of voluntary exchange of groundwater pumping credits among

PUBLIC DRAFT

applicable users to provide flexibility and confidence in managing their individual water needs, while also helping the GSA achieve groundwater sustainability targets (Geosyntec 2021). The market's goals and objectives are based on six components:

- **Aligned:** A groundwater market should support the GSP. It should not conflict with GSP management objectives or create uncertainty around GSP implementation projects or programs.
- **Transparent:** The design of a market should be transparent to participants with respect to how trading rules and processes have been developed.
- **Equitable:** The market should be accessible to all interested parties and trading rules should not create inequities that could be exploited by participants.
- **Flexible:** The market should be capable of managing transactions across diverse agricultural water needs that include permanent crops, seasonal groups, fallowed lands, and rural residential water needs.
- **Adaptive:** The groundwater market should be able to function across the full spectrum of water year types and remain functional over a long period of time.
- **Compliant:** The groundwater market should comply with all applicable legal and regulatory requirements related to both water and land use.

The water market strategy identifies the need for an allocation framework for a successful groundwater market. The market would utilize allocations assigned by the McMullin Area GSA, which are based on groundwater extraction volumes linked to individual groundwater uses within the GSA; however, the allocation policy is still in development. They are considering the use of time-based, spatially based, or landowner-based allocation systems and considering potential water right issues that may arise while assigning allocations (Geosyntec 2021).

The McMullin Area GSA presents a framework of eight components for developing a groundwater market (Geosyntec 2021):

1. Develop conceptual basin model for trading.
2. Determine available water supply.
3. Define tradable units.
4. Establish a trading structure.
5. Establish market rules.

PUBLIC DRAFT

6. Define monitoring and enforcement criteria.
7. Develop a report system and administrative processes.
8. Select or develop a trading platform.

Two trading structure types are contemplated for the market: a decentralized market (trades are originated and executed anonymously and are largely independent of each other) or a centralized market (potential buyers and sellers can find each other and certain types of trading information are monitored, collected, and made available to all market participants). Following a workshop conducted by the McMullin Area GSA, feedback suggested approaches that provide some level of automation and anonymity were preferred. The GSA intends to continue outreach as it establishes its market structure.

The market rules are being established to prevent:

- Negative impacts to groundwater sustainability under SGMA, such as sustainable management criteria defined in the GSP.
- Negative impacts to individuals who do not participate in the market, such as beneficial uses and users of groundwater.
- Negative impacts to participants in the market.
- Negative impacts to the overall economy in the GSA's area.

While the definitive market rules are still being developed by the McMullin Area GSA, they are considering other components such as trading zones, timing of trades, and carryover allocations (Geosyntec 2021).

Preliminary monitoring and enforcement criteria include the monitoring of groundwater extractions, groundwater levels, water quality, land subsidence, surface water depletion, and groundwater pricing and volumes. The McMullin Area GSA would be the primary enforcer of the market, ensuring that groundwater extractions do not violate the allocation policy and are not negatively impacting groundwater conditions in the area.

While the GSA has developed a preliminary framework for a groundwater market in the McMullin Area, the strategy document outlines multiple steps needed prior to initiating the market. First, a groundwater allocation policy must be put in place. This is followed by the establishment of tradable water units, a trading system, monitoring network, and market rules. The GSA intends to develop the

PUBLIC DRAFT

allocation policy and evaluate further the market components in 2025, with a pilot program being initiated shortly thereafter.

ROSEDALE-RIO BRAVO WATER STORAGE DISTRICT

In the Tulare Lake Hydrologic Region, the Rosedale-Rio Bravo Water Storage District embarked on a joint pilot project in 2019 with the Environmental Defense Fund to build an online, open-source groundwater trading platform as a strategy for complying with SGMA in the Kern County Subbasin (Environmental Defense Fund 2019). The web-based platform was completed in 2020 and real-time evapotranspiration (ET) data incorporation commenced in 2021, allowing users to better track their water usage. Future uses of the platform may serve as an online exchange where buyers and sellers can connect and negotiate groundwater allocation transfers within the district service area. Transactions may begin anonymously, but as parties get close to an agreement the identities would be disclosed to finalize the trade and complete financial transactions outside of the platform.

In the initial pilot study, landowners and historic groundwater users were allocated an interim portion of the overall groundwater available within the management area. The interim allocations ranged from 0.15 to 0.3 acre-feet per year, measured as ET, per acre of land. The allocations were developed to include native yield, precipitation, and project water data to estimate a sustainable yield for the acreage. Sustainable yield was then subtracted from acreage demand to determine allowable imbalance, which was later adjusted to regain supply (Averett 2020). The final allocations of groundwater available for pumping are intended to be dependent on existing groundwater levels, final sustainability indicators and thresholds, and climate conditions, and will be set to maintain groundwater levels above minimum thresholds defined in the GSP. Allocations are tracked by the Rosedale-Rio Bravo Water Storage District and will be adjusted when trades are completed and reported by the relevant parties through the platform. The platform is the first online, open-source groundwater trading platform in the Tulare Lake Hydrologic Region.

Groundwater Markets Summary

Groundwater markets may not be appropriate in all basins, but in-basin trading provides flexibility to generate economic returns from groundwater allocations, even in the face of groundwater scarcity. Markets allow water users to cooperate rather than compete for this scarce resource. By facilitating responsible groundwater trading in an open and transparent marketplace, California can

PUBLIC DRAFT

mitigate many of the economic and environmental effects of water scarcity. The challenges for implementing successful groundwater markets are varied and can be broadly categorized into six groups: institutional foundations that consider safeguards for vulnerable uses and users of groundwater, economic efficiency, environmental sustainability, equity considerations, reliable and transparent data, and protection against market failures. Groundwater markets typically include some combination of groundwater allocations, restrictions, curtailments, and fees to create a tradeable unit and restrict pumping to within established limits. With careful consideration and an adaptive approach, groundwater markets can offer great opportunities as an effective management strategy for achieving sustainability.

State Efforts in Assisting with Groundwater Markets

There are several initiatives and programs at the State level intended to support the development of groundwater markets as a strategy for sustainably managing groundwater basins through policy directives and technical support. These efforts are driven, in part, by Governor Gavin Newsom's Administration's *Water Resilience Portfolio* and subsequent steps taken by State agencies to make progress toward specific actions in the Portfolio. State agencies have helped identify potential roles for the State and needs of local agencies for the successful implementation of groundwater markets over the past five years and will continue to assist with further technical and policy support moving forward.

WATER RESILIENCE PORTFOLIO AND EXECUTIVE ORDER

In April 2019, Governor Newsom issued an executive order on the development of the Water Resilience Portfolio (WRP) directing all State agencies to incorporate the following principles into water planning in California:

- Prioritize multi-benefit approaches that meet multiple needs at once.
- Utilize natural infrastructure such as forests and floodplains.
- Embrace innovation and new technologies.
- Encourage regional approaches among water users sharing watersheds.
- Incorporate successful approaches from other parts of the world.
- Integrate investments, policies, and programs across State government.
- Strengthen partnerships with local, federal, and Tribal governments, water agencies, irrigation districts, and other interested parties.

PUBLIC DRAFT

The incorporation of principles from the Water Resilience Portfolio into projects creates a supportive environment for creative solutions, such as groundwater markets or water scarcity. The Water Resilience Portfolio identified one specific action related to water groundwater markets:

> WRP Action 3.6: Create flexibility for groundwater sustainability agencies to trade water within basins by enabling and incentivizing transactional approaches, including groundwater markets, with rules that safeguard natural resources, small- and medium-size farms, and water supply and quality for disadvantaged communities.

CALIFORNIA WATER COMMISSION WHITE PAPER

In May 2022, the California Water Commission released the draft paper *A State Role in Supporting Groundwater Trading with Safeguards for Vulnerable Users: Findings and Next Steps*. The paper was developed in response to requests for the Commission to take some initial steps on the Water Resilience Portfolio's Action 3.6.

The aim of the paper and associated public forums was to better understand the concerns and opportunities around groundwater trading and to explore how the State can help support well-managed, locally designed, and locally led trading programs that provide safeguards for natural resources, small- and medium-sized farm operators, and disadvantaged communities.

The paper describes conversations and recommendations from various experts, interested parties, and the public and is intended to guide State agencies in their support of locally led groundwater trading programs. It may also serve to educate implementers and interested parties about how to proceed with well-managed groundwater trading that safeguards natural resources, small- and medium-sized farms, and disadvantaged communities.

Generally, the paper acknowledges that local entities, including community members and local water agencies, are, with the support of experienced advisors, best positioned to establish trading programs that work for their communities and local conditions. State agencies can play an important role in promoting groundwater trading with appropriate safeguards for vulnerable users, disseminating information about where groundwater trading is being considered or used in California, developing best management practices, providing technical and financial assistance, creating incentive programs, hosting forums to further

PUBLIC DRAFT

understanding, and engaging interested parties to better recognize their concerns and fill information gaps.

INTERAGENCY WORKPLAN FOR ENABLING AND INCENTIVIZING WELL-MANAGED GROUNDWATER TRADING WITH SAFEGUARDS FOR VULNERABLE USERS

In response to the California Water Commission's White Paper, in 2024, DWR led a collaborative interagency effort to develop a draft Interagency Workplan for Enabling and Incentivizing Well-Managed Groundwater Trading with Safeguards for Vulnerable Users. The interagency work team included staff from the State Water Board, California Department of Fish and Wildlife, California Department of Food and Agriculture, and DWR, and concluded that tracking and monitoring markets and engaging with practitioners, interested parties, and vulnerable users to assess needs is a practical next step for the State and will be critical for scoping and developing a future State action.

2.7 State-Supported Groundwater Accounting Platform

The Rosedale-Rio Bravo Water Storage District's groundwater accounting platform, described briefly in the Rosedale-Rio Bravo case study above, was further developed and scaled to create an open-source groundwater accounting platform that will be freely available to help GSAs across the state manage the transition to sustainable supplies. DWR, the State Water Board, the California Water Data Consortium, and the Environmental Defense Fund (EDF) collaborated on the effort, along with funding assistance from the U.S. Bureau of Reclamation. The innovative Groundwater Accounting Platform is a robust State-supported data tool that will enable GSAs across California to track water availability and use. DWR, the Consortium, and EDF are working to make the platform available to more local agencies, including collaborating with three new pilot project partners: Merced Irrigation-Urban GSA in Merced County, Pajaro Valley Water Management Agency in Santa Cruz County, and Yolo County Flood Control and Water Conservation District northwest of the Greater Sacramento region.

The platform will help GSAs assess and quantify the impacts and benefits of management actions such as groundwater recharge projects, water trading programs, and groundwater demand reductions. The new platform is also designed to be compatible with online electronic portals, such as DWR's SGMA Portal and the State Water Board's Groundwater Extraction Annual Reporting System that local agencies use to submit data to the State. GSAs will be able to use the platform as-is or further develop the software to better suit their local needs. This

PUBLIC DRAFT

makes the platform cost-effective because GSAs are not paying to build groundwater accounting software from scratch.

2.8 State Water Board Intervention

The State Water Resources Control Board (State Water Board) is the State agency that implements Chapter 11 of SGMA (see Water Code Section 10735 *et seq*.). Chapter 11 gives the State Water Board authority to protect groundwater resources through a process called "state intervention" when local agencies are unable or unwilling to sustainably manage their groundwater basins. If local agencies fail to form a GSA, fail to develop an adequate GSP, or fail to successfully implement a GSP in a groundwater basin, the State Water Board may designate the entire basin probationary after providing public notice and holding a public hearing. State intervention is in addition to local management and is intended to be temporary — lasting only until the GSAs demonstrate they are ready to manage their respective basins. The State Water Board's website provides additional information on SGMA and up-to-date details on its current intervention processes.

2.8.1 Consultation with DWR

As described in the preceding sections, DWR provides essential regulatory oversight by assessing and evaluating GSPs in accordance with the GSP Regulations. If, during the assessment and evaluation process, DWR determines that the GSP (or coordinated GSPs) covering a basin is inadequate, state intervention by the State Water Board is triggered. State intervention is a process that could result in the State Water Board temporarily managing and protecting a basin's groundwater resources until the basin's GSAs are able and willing to do so effectively. State intervention is triggered when DWR, in consultation with the State Water Board, determines a GSP is inadequate or is not being implemented in a manner likely to achieve its sustainability goal. State intervention includes the authority for the State Water Board to designate a high- or medium-priority basin subject to SGMA as probationary under certain conditions as summarized in Table 2-13 below.

If DWR finds that the GSP covering a basin has deficiencies and is incomplete during the plan's evaluation and assessment, DWR provides an additional 180 days for the GSA to resolve the deficiencies. DWR works with GSAs during this time to explain the issues that precluded the GSP from being approved. After the GSP is resubmitted, DWR then reviews the plan again and, if the deficiencies are

PUBLIC DRAFT

not sufficiently addressed, DWR could find the GSP to be inadequate and intervention by the State Water Board is triggered. The SGMA statute and GSP Regulations require consultation between DWR and the State Water Board before a GSP is disapproved and is recommended for potential probationary designation.

Table 2-13 Pathways to Designate a Basin Probationary

Effective Date	State Intervention Triggering Event
July 1, 2017	Entire basin is not covered by a GSA(s) or an Alternative — Water Code Section 10735.2(a)(1)
Jan 31, 2020	Basin is subject to critical conditions of overdraft and no GSP has been adopted, or DWR determines the GSP is inadequate or is not being implemented in a manner that will likely achieve the sustainability goal — Water Code Section 10735.2(a)(2) and (3)
Jan 31, 2022	No GSP has been adopted in a high- or medium-priority basin, or DWR determines the GSP is inadequate, or the GSP is not being implemented AND the basin is in long-term overdraft — Water Code Section 10735.2(a)(4)
Jan 31, 2025	DWR determines the GSP is inadequate or the GSP is not being implemented AND the basin has significant surface water depletions (if no long-term overdraft) — Water Code Section 10735.2(a)(5)

2.8.2 Potential Probationary Basin Designation

Following DWR's finding that the GSP covering a basin is inadequate, the state intervention process begins with the State Water Board. The first step of state intervention involves a determination by the State Water Board as to whether the basin should be placed on probation (designating a basin as probationary). A probationary designation will identify the issues (deficiencies) that led to state intervention and, in general, provide at least one year for the GSAs to remedy those deficiencies. During probation, certain groundwater extractors may be subject to annual groundwater extraction reporting requirements and associated fees.

As of August 2025, two basins — the Tulare Lake Subbasin and Tule Subbasin — have been placed in probationary status following the process established by SGMA. The GSP covering the Chowchilla Subbasin has been returned to DWR following inadequate determination and State Intervention, and the GSP is

PUBLIC DRAFT

currently under DWR review. An additional four basins are deemed potentially subject to state intervention: Delta-Mendota, Kaweah, Kern County, and Pleasant Valley (Fresno County). The State Water Board's SGMA website should be consulted to determine the status of intervention efforts.

2.8.3 Interim Plans

Interim plans are described in Chapter 11 of SGMA (see Water Code Section 10735 *et seq*.) and are prepared at the discretion of the State Water Board. As of June 2025, the State Water Board has not developed an interim plan for either of the two basins designated as probationary basins.

An interim plan, if developed, is intended to be a temporary measure to protect a basin's groundwater resources until effective local management is in place. If a basin has been designated probationary for at least one year and deficiencies have not been corrected, the State Water Board may adopt an interim plan for a probationary basin through a public hearing process. As described in Water Code Section 10735.8, an interim plan is required to include:

- Identification of the actions that are necessary to correct a condition of long-term overdraft or a condition where groundwater extractions result in significant depletions of interconnected surface waters, including recommendations for appropriate action by any person.
- A time schedule for the actions to be taken.
- A description of the monitoring to be undertaken to determine effectiveness of the plan.

At the State Water Board's discretion, an interim plan could also include one or more of the following:

- Restrictions on groundwater extraction.
- A physical solution.
- Principles and guidelines for the administration of rights to surface waters that are connected to the basin.

To end the State Water Board's management or potential management of a groundwater basin, GSAs in that basin need to demonstrate to the Board (in consultation with DWR) their ability and willingness to manage groundwater sustainably and address the issues that caused state intervention to occur. This may require significant amendments to the GSPs, revision of coordination

PUBLIC DRAFT

agreements for those basins submitting multiple plans, pumping restrictions, or other measures to provide assurances that ongoing local management will be consistent with SGMA.

PUBLIC DRAFT

PUBLIC DRAFT

3 . California's Natural and Built Groundwater Infrastructure

Chapter Summary

Chapter 3, "California's Natural and Built Groundwater Infrastructure," of *California's Groundwater: Bulletin 118 — Update 2025* (CalGW Update 2025) describes California's natural groundwater infrastructure and the location of groundwater resources, highlighting the role of natural and built infrastructure in maintaining the state's water security.

It begins with a detailed discussion on natural groundwater infrastructure, such as watersheds, rivers and floodplains, forests and meadows, and groundwater aquifers, and other natural features that support groundwater flow and recharge. The geographic delineation of groundwater basins and the distinction between basin and non-basin areas are also discussed. This is followed by a high-level discussion on the impacts of climate change on natural infrastructure, such as snowpack and precipitation shifts, as well as implications for watersheds and non-basin areas. This discussion highlights the importance and vulnerability of the natural infrastructure in the face of climate change.

The chapter next covers California's efforts to characterize basins through programs like the Department of Water Resources' (DWR) Basin Characterization Program, which leverages tools like geologic maps, the SGMA Data Viewer, and State-led airborne electromagnetic (AEM) surveys. It outlines key hydrogeologic concepts, including aquifers, recharge areas, subsidence, and seawater intrusion, offering insights into how these components influence water availability. It further discusses advanced texture models and storage estimates that aid in understanding basin capacity and behavior under various conditions, supported by data collection from pilot studies and other characterization efforts.

Building on that foundation, the chapter then addresses groundwater in non-basin areas, including the population in those areas, hydrogeologic provinces, and recharge dynamics. These areas present distinct challenges in data collection and policy development, particularly in understanding water quality, flow paths, and supply variations related to rock type as well as the recharge opportunities and challenges. With ongoing work by the USGS and other agencies to characterize

PUBLIC DRAFT

these regions, the chapter highlights existing data gaps and emerging management strategies.

The discussion then turns to California's built groundwater infrastructure, such groundwater extraction infrastructure (e.g., production wells), groundwater recharge infrastructure (e.g., recharge basins and ASR wells), conveyance infrastructure, and groundwater banks. These systems enhance California's capacity for groundwater capture, usage, and storage. This section also covers various recharge techniques, from stormwater capture and recycled water recharge to aquifer storage and recovery (ASR) systems and multi-benefit water banking projects. The section emphasizes the importance of enhancing recharge capacity, leveraging in-lieu recharge techniques, and integrating infrastructure utilization and implementation strategies as sustainable practices for groundwater management.

Collectively, this chapter provides a comprehensive view of California's natural and built groundwater infrastructure, underscoring their critical role in sustainable water resource management for all Californians.

Chapter 3, "California's Natural and Built Groundwater Infrastructure," strongly aligns with the themes of CalGW Update 2025, including Theme 1, "Maximizing Groundwater Infrastructure for Climate Adaptation and Resiliency," and Theme 4, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support," as it emphasizes California's natural and built groundwater infrastructure, from aquifers and recharge areas to production wells and water banks. Through detailed discussions on data collection, hydrogeologic models, and recharge strategies, the chapter underscores the value of leveraging California's natural systems alongside technological tools to build a sustainable and resilient groundwater framework.

3.1 Introduction

Groundwater is one of California's most critical water resources, providing a vital source of supply for millions of residents, businesses, and ecosystems. It supports agricultural, municipal, and domestic water needs while sustaining natural habitats. Additionally, it serves as a crucial buffer against drought.

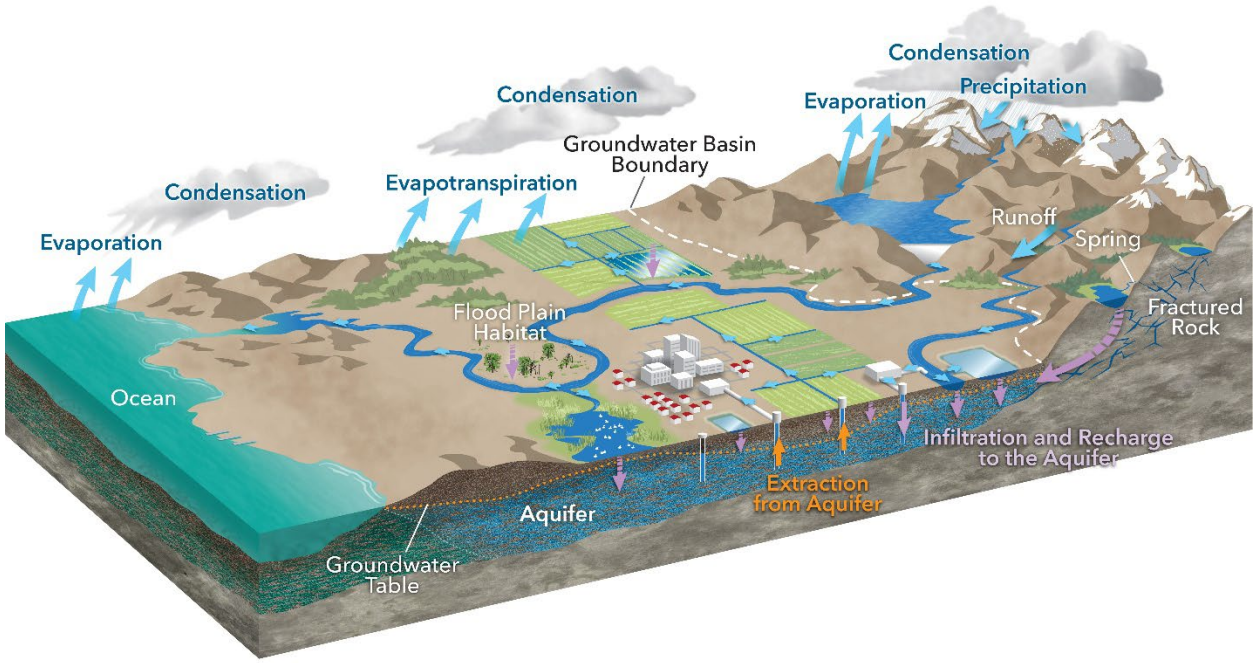
Groundwater is defined as the water beneath the Earth's surface in rocks or sediments that are saturated, meaning the pores or spaces within these materials are completely filled with water. Since all rocks contain some voids, groundwater can be found in varying amounts beneath almost any location in California. Its

PUBLIC DRAFT

availability and accessibility vary depending on local geology and hydrologic conditions. Aquifers, the underground formations that store and transmit groundwater, can be composed of porous materials such as alluvial deposits or fractured rock, which influence how groundwater moves and how it can be extracted.

Groundwater is a key component of the hydrologic cycle, in which water continuously moves from the atmosphere to the Earth's surface through precipitation, infiltrates into the ground, and eventually returns to the atmosphere through processes such as evaporation and transpiration (Figure 3-1). This natural movement of water plays a crucial role in replenishing aquifers and sustaining surface water bodies like rivers, lakes, and wetlands, which are often connected to groundwater systems.

Figure 3-1 The Hydrologic Cycle



California's relationship with groundwater is shaped by a unique combination of natural and built infrastructure that has evolved to meet the water needs of a large and diverse population. Natural groundwater infrastructure encompasses the natural features and processes that contribute to the storage and movement of groundwater within the environment. It includes alluvial groundwater basins, hard rock [non-basin] areas, rivers, springs, floodplains, wetlands, permeable geologic outcrops, mountain meadows, and other natural pathways that facilitate groundwater recharge, storage, and discharge.

In contrast, built groundwater infrastructure includes production wells, monitoring wells, recharge facilities, recycled water reuse facilities, aquifer storage and recovery (ASR) systems, stormwater capture systems, water banks, canals and other conveyance infrastructure, and surface water reservoirs. These built elements work synergistically with natural systems to bolster groundwater supplies, particularly during periods of drought and increased water demand. For instance, managed aquifer recharge projects enhance natural groundwater replenishment processes through the use of constructed channels or basins to divert stormwater, flood flows, or other water sources for recharge.

Integrating natural and built groundwater infrastructure is crucial for achieving groundwater sustainability. The interplay between the natural flow of water through watersheds and aquifers and engineered projects enables California to adapt to variations in water availability.

To provide a comprehensive understanding of California's groundwater system, the following sections of this chapter are organized around key topics that reflect the state's natural conditions, anthropogenic impacts, and groundwater infrastructure:

- **Natural Groundwater Infrastructure:** Describes the natural geological and hydrological features that contribute to, store, convey, recharge, and interact with groundwater, such as watersheds, river corridors, forests and meadows, and alluvial basins.
- **Impacts of Climate Change on Natural Infrastructure:** Examines how increasing temperatures and evapotranspiration, shifting snow and precipitation patterns, and prolonged droughts are altering the effectiveness and resilience of California's natural groundwater systems.
- **Groundwater Basin Characteristics:** Explores the geologic, hydrologic, and chemical properties that define the behavior and capacity of groundwater basins across the state.
- **Non-Basin Areas:** Addresses groundwater resources located in hard rock or fractured rock regions outside of designated groundwater basin boundaries and discusses their role in water supply, including climate change challenges.
- **Built Groundwater Infrastructure:** Reviews human-engineered systems, such as wells, recharge basins, ASR systems, and canals, that are designed to monitor, extract, convey, and augment groundwater supplies.

PUBLIC DRAFT

3.2 Natural Groundwater Infrastructure

Natural groundwater infrastructure encompasses connected groundwater and surface water systems within a watershed where water moves from one system to another as part of the hydrologic cycle. Under natural conditions, surface water bodies — such as streams, rivers, floodplains, lakes, wetlands, forests, and meadows — interact with groundwater, influencing its recharge, storage, discharge, and overall availability and access.

The relationship between groundwater and surface water within a watershed is influenced by various natural landscape features that govern the movement, storage, and availability of water. Watersheds serve as the primary organizing units of the hydrologic cycle, collecting precipitation and directing water through streams, rivers, meadows, alluvial aquifers, and groundwater found in non-basin areas, primarily hard-rock formations.

Understanding the role of these interconnected features of natural groundwater infrastructure is essential for effective water management and resilience. To that end, the following sections examine five key components of California's natural groundwater infrastructure, each contributing uniquely to groundwater recharge, storage, and availability:

- **Watersheds:** Natural drainage areas that collect precipitation and channel it through surface and subsurface pathways, influencing how and where groundwater is replenished.
- **Rivers and Floodplains:** Dynamic systems that convey surface water across the landscape and provide opportunities for groundwater recharge and discharge.
- **Forests and Meadows:** Upland ecosystems that regulate snowmelt, reduce runoff, and promote infiltration, playing a critical role in sustaining baseflow and groundwater recharge.
- **Groundwater Aquifers:** Subsurface formations, typically composed of permeable materials like sand and gravel, that store and transmit groundwater, forming the backbone of California's groundwater supply.
- **Other Natural Groundwater Infrastructure:** Includes mountain springs, seeps, wetlands, and permeable geologic outcrops that serve as localized recharge or discharge zones and contribute to the overall resilience of groundwater systems.

PUBLIC DRAFT

3.2.1 Watersheds

Watersheds consist of an area of land surface that drains water from higher elevations (e.g., mountains) to a common outlet at lower elevations (e.g., lakes or the ocean). Water falls on a watershed in the form of rain or snow and flows by gravity to lower elevations, moving through a network of small streams or tributaries into larger bodies of water such as lakes, rivers, reservoirs, and eventually reaching the ocean or collecting in terminal lakes or evaporative basins. The water in a watershed that flows above the surface of the earth is surface water, forming streams and rivers, while water that infiltrates into the ground becomes groundwater and fills aquifers and flows through the subsurface.

Similar to surface water, groundwater generally flows from higher to lower elevations. Once the water level in the aquifer is higher than the neighboring natural surface features, groundwater emerges into the surface and/or seeps into the streams and rivers within the watershed. When aquifers are adjacent to lakes or the ocean, groundwater can flow out of the aquifer and into these larger bodies of water. The converse is also true; when the water level in the aquifer is lower than neighboring surface features, water can flow into the aquifer.

Watershed sizes vary from small local watersheds covering just a few square miles to large regional watersheds encompassing major river systems. Small local watersheds combine to form increasingly larger watersheds, ultimately reaching the regional scale. This nested nature of watersheds is reflected in the USGS's watershed delineation system, which uses the Hydrologic Unit Code (HUC). The largest designation, HUC-2, employs a two-digit code to divide the United States into 22 major hydrologic regions, each covering hundreds of thousands of square miles. With each additional pair of digits, the system provides increasingly finer spatial resolution — progressing through HUC-4, HUC-6, and so forth — down to HUC-12, which identifies some of the smallest standardized subwatersheds. Each successive level in this hierarchy represents a more detailed subdivision of the land area encompassed by the level above it (United States Geological Survey 2022). Figure 3-2 shows California watersheds at the HUC 8 level, which is selected for use in the future water supply scenario analysis for the upcoming California Water Plan Update 2028.

PUBLIC DRAFT

Figure 3-2 Major California Watersheds (Hydrologic Unit Code 8 of the USGS National Watershed Boundary Dataset)



3.2.2 Rivers and Floodplains

Natural rivers and streams flow from higher elevations to lower elevations, draining precipitation in these watersheds in excess of what evaporates, supports plants, and recharges groundwater. Figure 3-3 shows the major rivers in California, many of which primarily originate from the higher elevations of the watersheds in the Sierra Nevada on the east and flow into the Central Valley, forming the two major rivers of California: the Sacramento and San Joaquin rivers. These two major rivers and most other rivers in California eventually flow into the Pacific Ocean. Exceptions are the Colorado River and its tributaries, which flow into the Gulf of California, and many arid-region rivers and streams which flow to salt flats or terminal lakes such as the Salton Sea, Mono Lake, or Owens Lake.

Floodplains, the low-lying areas adjacent to rivers, are also integral to groundwater systems. When rivers overflow during high-flow events, floodplains temporarily store water and spread it out across a broader area, reducing the velocity and erosive power of floodwaters. This slower movement allows more time for water to infiltrate into the ground, recharging underlying aquifers. This natural process not only reduces downstream flood risks but also sustains baseflows in rivers during drier periods, supports habitat for fish and wildlife, and replenishes local groundwater supplies that communities and ecosystems depend on.

PUBLIC DRAFT

Figure 3-3 Major California Rivers



3.2.3 Forests and Meadows

Forests and meadows are vital components of natural infrastructure, intricately linked with surface water and groundwater systems across California's diverse landscapes. Forests play a vital role in sustaining healthy watersheds by regulating surface and subsurface water flows, enhancing infiltration, and reducing erosion and sedimentation that can degrade downstream groundwater-dependent ecosystems. Healthy forest soils act as sponges, absorbing precipitation, storing water, and gradually releasing it into streams and underlying aquifers. In snow-dominated watersheds, forests also modulate snow accumulation and melt timing, affecting seasonal groundwater recharge patterns that sustain both human and ecological water needs throughout the dry season.

Forests also contribute organic matter to soils, promoting the development of porous, well-structured soil horizons that increase infiltration rates and groundwater recharge potential. Conversely, degraded or overly dense forests — often the result of historical fire suppression — can reduce infiltration, increase surface runoff, and exacerbate peak flows that cause channel incision and reduced groundwater recharge. Restoration efforts that include forest thinning, prescribed burns, and reforestation with native species can improve groundwater recharge capacity while reducing wildfire risk, supporting biodiversity, and enhancing overall watershed resilience.

Meadows are areas with shallow groundwater, including perched groundwater, that support open, vegetated fields or grassy areas and are part of natural groundwater infrastructure. They can be found in both low-lying areas and high elevation areas. The mapped meadow areas in California are shown in Figure 3-4. The figure also depicts non-basin areas where meadows play a critical role in maintaining groundwater recharge and storage. In these non-basin areas, meadows act as important natural reservoirs, helping to sustain groundwater levels and support surrounding ecosystems.

Understanding the characteristics of a meadow is essential for evaluating its ecological health and hydrologic function as part of the natural groundwater infrastructure. The distinction between healthy and unhealthy meadows is determined by the meadow's ability to support groundwater recharge, sustain biodiversity, and contribute to overall watershed resilience. A healthy meadow is characterized by phreatophytic grasses, riparian vegetation, and a meandering stream that has not incised too far into the meadow surface (Figure 3-5). These features contribute to groundwater recharge, regulating water flow, and provide

PUBLIC DRAFT

essential habitat for diverse plant and animal species. A healthy meadow serves as a key indicator of ecological health by maintaining water availability and supporting biodiversity.

However, numerous ecosystem and watershed studies have shown that many of the state's meadows are no longer functioning properly and considered unhealthy due to impairment from human activities. These activities can include cattle grazing, timber harvesting, and road construction (Crain 2007). One major indicator of an unhealthy meadow ecosystem is conifer encroachment, which leads to a drier landscape and reduced groundwater storage (Figure 3-6). Degraded meadows often exhibit compacted soils, diminished water storage, and a loss of native phreatophytic vegetation, making them more susceptible to erosion and further ecological decline. The removal of encroaching conifers is a critical component of meadow restoration projects, aimed at restoring the hydrologic function and ecological health of these vital landscapes.

PUBLIC DRAFT

Figure 3-4 Meadow Areas of California



Figure 3-5 Healthy Meadow

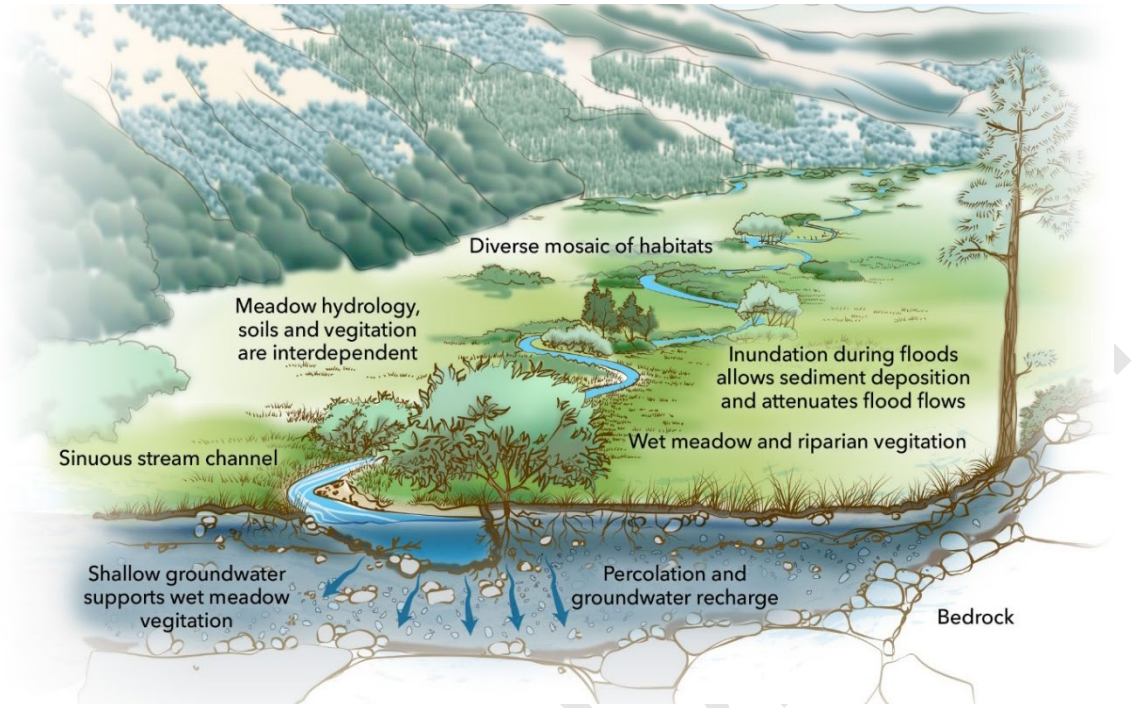
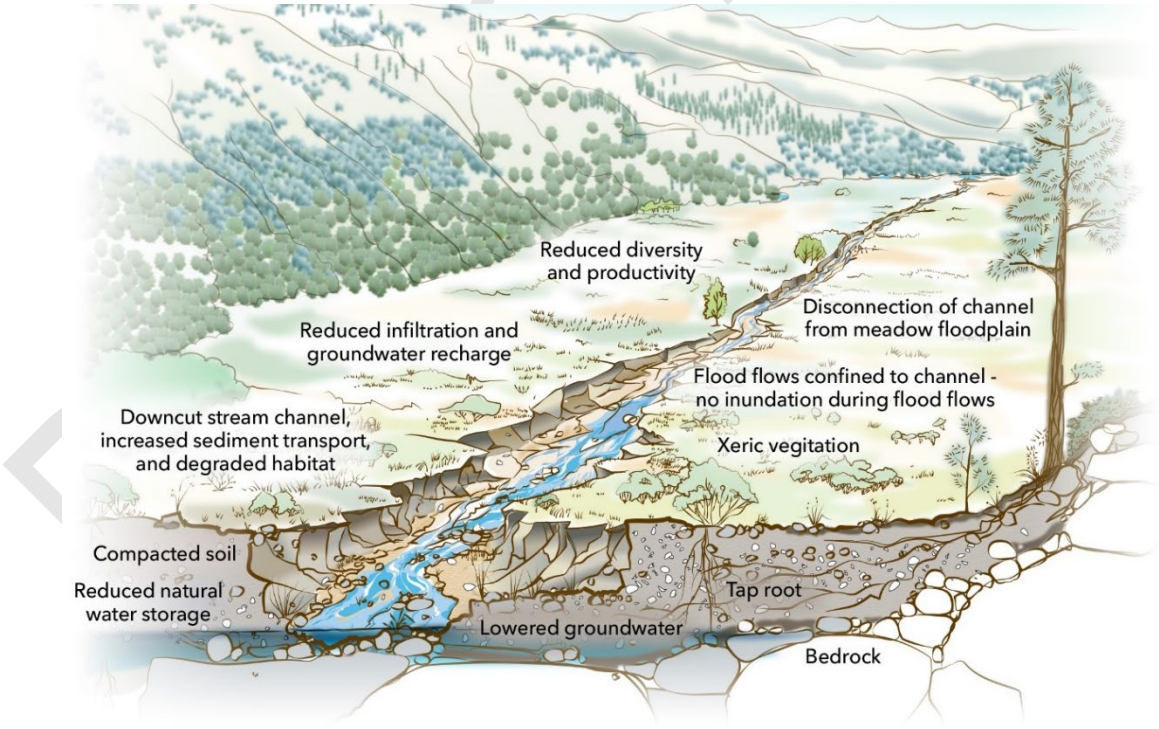


Figure 3-6 Unhealthy or Degraded Meadow



Figures 3-5 and 3-6 Source — American Rivers and Restoration Design Group.

3.2.4 Groundwater Aquifers

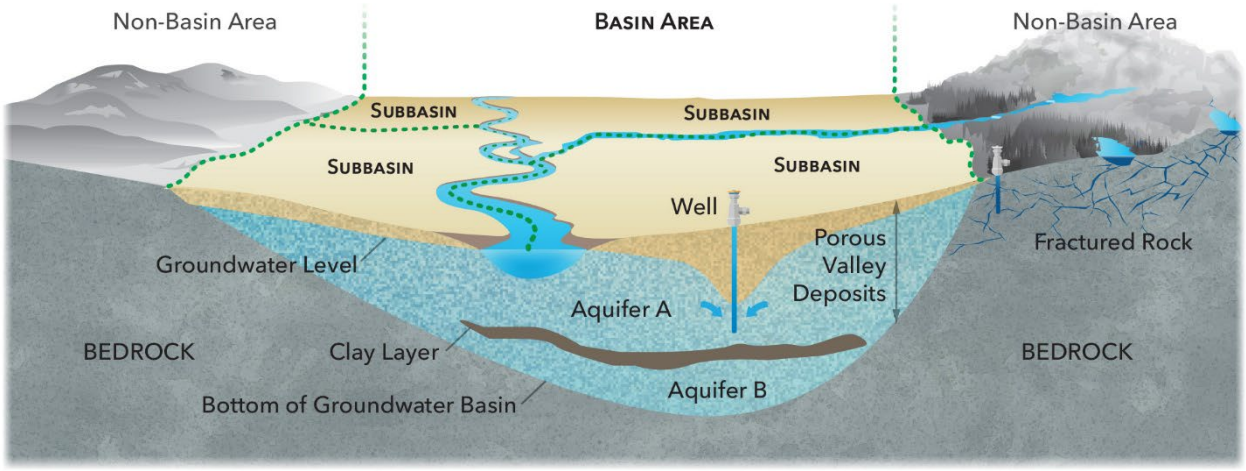
Groundwater aquifers are three-dimensional bodies of porous and permeable sediment or sedimentary rock that contain sufficient saturated material to yield significant quantities of groundwater to wells and springs, as defined in Title 23 California Code of Regulations Section 341[f], and can also be referred to as *alluvial aquifers*. These aquifers act as natural reservoirs that supply water to wells, springs, and surface water bodies. They are also important for maintaining water availability, especially during dry periods when surface water supplies are limited. Managed aquifer recharge projects enhance the function of these natural systems by directing available surface water into aquifers for storage enhancements and future use.

In addition to alluvial aquifers, the non-basin areas with their fractured bedrock formations and permeable volcanic deposits can also contribute to groundwater movement and storage. While these areas typically have lower water storage capacity than alluvial aquifers, they provide important, localized groundwater supplies that sustain rural communities and support springs, streams, wetlands, and other beneficial uses. Figure 3-7 shows the spatial relationship between aquifers, basins, subbasins, and non-basin areas.

To fully understand and manage California's groundwater resources, it is essential to examine how these features of groundwater aquifers are delineated, distributed, and function across the landscape. The following sections provide an overview of California's groundwater basins and non-basin areas and discuss the recent recognition of aquifers as natural infrastructure under California Senate Bill 122.

PUBLIC DRAFT

Figure 3-7 Spatial Relationships Among Aquifers, Basins, Subbasins, and Non-basin Areas



Groundwater Basins

The concept of a groundwater basin was first introduced around the turn of the 20th century as California's population and agricultural industry were rapidly expanding and becoming more reliant on groundwater. Over the next half-century, the understanding of, and reliance on, groundwater basins in California grew, which led to the first official list of groundwater basins in 1952 (California Department of Public Works 1952). Since then, DWR, working with other local, State, and federal agencies, has intermittently updated the definitions, boundaries, and locations of California's groundwater basins in various updates of California's Groundwater (CalGW, also known as Bulletin 118). The definition of a groundwater basin presented here was developed to support the objectives of the Sustainable Groundwater Management Act (SGMA). According to the Title 23 California Code of Regulations, Section 341 (g)(1), a groundwater basin is defined as:

> "An area specifically defined as a basin or 'groundwater basin' in Bulletin 118 [CalGW] and shall refer generally to an aquifer or stacked series of aquifers with reasonably well-defined boundaries in a lateral direction, based on features that significantly impede groundwater flow, and a definable bottom, as further defined or characterized in Bulletin 118."

Lateral boundaries of basins are features that significantly impede groundwater flow. Those features can include rock or sediments with relatively low hydraulic

PUBLIC DR

conductivity or a geologic structure, such as a fault. While lateral boundaries may be the most easily visualized or mapped boundary of a groundwater basin, the groundwater basin is three-dimensional and includes a bottom boundary, so that the basin includes all subsurface fresh-water-bearing material. The boundaries at depth are based on the spatial distribution of geologic materials or water quality in the subsurface (Figure 3-7). The definable bottom of a basin can be based on physical properties such as rock or sediment with very low hydraulic conductivity. Another approach is to use the geochemical properties of groundwater, which often utilizes total dissolved solids concentrations outlined by the U.S. Geological Survey (USGS), the U.S. Environmental Protection Agency (EPA), or the State Water Resources Control Board (State Water Board).

As of 2025, 424 groundwater basins are designated in California. Of these, 30 basins have been further divided into 121 subbasins. When the 394 undivided basins are combined with these 121 subbasins, the result is a total of 515 groundwater basins and subbasins in California as shown in Figure 3-8. A groundwater subbasin, as defined in Title 23 California Code of Regulations Section 341(g)(2), is:

> "An area specifically defined as a subbasin or 'groundwater subbasin' in Bulletin 118 [CalGW] and shall refer generally to any subdivision of a basin based on geologic and hydrologic barriers or institutional boundaries, as further described or defined in Bulletin 118."

Subbasin boundaries are established using physical geologic features such as faults or geologic contacts; hydrologic features such as rivers; geomorphic features such as topographic changes; or jurisdictional boundaries such as county, water district, or city boundaries. The largest group of subbasins is in the Central Valley, which is comprised of three groundwater basins: the Sacramento Valley, San Joaquin Valley, and Redding Area. The surficial expression of the three Central Valley groundwater basins has been divided, primarily along physical, hydrologic, or jurisdictional boundaries, into 40 subbasins.

California's groundwater basins and subbasins cover about 62,000 square miles, accounting for approximately 38% of the state's total area. Approximately 82% of the state's population live in areas underlain by groundwater basins, which also contain about 97% of the state's agricultural land (California Department of Water Resources 2019a, Unites States Census Bureau 2020).

PUBLIC DRAFT

Figure 3-8 California's 515 Groundwater Basin and Subbasin Boundaries and Hydrologic Regions



Non-Basin Areas

Any area outside of a defined groundwater basin is referred to as a non-basin area. Non-basin areas consist of impermeable granitic, metamorphic, volcanic, or sedimentary rocks, where groundwater is found in fractures or other voids (California Department of Water Resources 2013). Non-basin areas are adjacent to most of the state's 515 alluvial groundwater basins and subbasins (Figure 3-9) and in many locations non-basin area surround designated groundwater basins. Non-basin areas are an integral part of the natural groundwater infrastructure.

In contrast to alluvial basins, groundwater in non-basin areas is transmitted through connected fractures and in some cases, through openings formed by dissolution of the rock. Not all fractured-rock conduits are connected, which means groundwater flow can be limited or highly localized in these areas. Additional details on non-basin area hydrogeology are provided in Section 3.5.

PUBLIC DRAFT

Figure 3-9 **Statewide Map of Non-Basin Areas and River Systems**



Recognition as Natural Groundwater Infrastructure

California Senate Bill 122 (SB 122), enacted in July 2023, recognizes aquifers as "natural infrastructure," a designation that not only underscores their fundamental role in California's water management but also broadens the scope of environmental conservation and resource management within the state. By including aquifers in the definition of natural infrastructure, the legislation acknowledges their critical role in groundwater storage and movement, flood control, and ecosystem support. Aquifers regulate water availability, sustain rivers and wetlands through baseflow contributions, and help mitigate flood risks by absorbing excess surface water. The bill amends Section 71154 of the Public Resources Code to state:

> "Natural infrastructure includes the conservation, preservation, or sustainable management of any form of aquatic or vegetated terrestrial open space, including aquifers."

This approach aligns with California's broader commitment to sustainable water resource management, reinforcing the need for proactive policies and investments that protect and restore aquifers as a cornerstone of the state's water infrastructure. This expanded definition facilitates increased public funding for projects aimed at groundwater recharge, aquifer restoration, and sustainable groundwater management. Such initiatives are vital for enhancing California's water resilience, especially in the face of climate change and recurring droughts. By treating aquifers as natural infrastructure, SB 122 promotes integrated water management strategies that leverage natural systems to improve water supply reliability and environmental health.

3.2.5 Other Natural Groundwater Infrastructure

While watersheds, rivers and floodplains, forests and meadows, groundwater aquifers, and non-basin areas form the core of California's natural groundwater infrastructure, there are other natural features that also play vital supporting roles in facilitating groundwater replenishment and maintaining hydrologic balance. These include:

- Recharge Zones: Areas where surface water infiltrates into the ground and refills the aquifer. These zones often include forests, wetlands, and floodplains that facilitate the slow infiltration of rainwater or river water into aquifers.

PUBLIC DRAFT

- Riparian Zones: The interface between land and a river or stream, which plays a crucial role in groundwater recharge. These areas help maintain a balance between surface water and groundwater systems.
- Wetlands: Natural wetlands can act as recharge areas for aquifers while also filtering water and removing pollutants. They are an essential part of the water cycle and support biodiversity and can enhance groundwater quality.
- Permeable Soils and Rocks: Certain types of soil and rocks allow for the natural percolation of water into aquifers. These materials act as filters, cleaning the water as it moves downward.
- Karst Systems: Regions characterized by soluble rocks like limestone that have been eroded to form sinkholes, caves, and underground rivers. These systems create natural conduits for groundwater flow and storage.
- Springs: Points where groundwater naturally emerges at the earth's surface. Springs indicate the presence of a robust aquifer system and contribute to surface water flows in rivers and lakes.

These natural infrastructure components are essential for sustainable water management as they support water storage, enhance water quality, and provide ecological services vital to the health of various ecosystems. Recognizing and preserving these natural systems helps ensure long-term water availability and environmental resilience. However, the stability and function of these systems are increasingly threatened by climate change, making it critical to understand and address its impacts on natural groundwater infrastructure.

3.3 Impacts of Climate Change on Natural Groundwater Infrastructure

Climate change is profoundly affecting natural groundwater infrastructure by altering precipitation patterns, increasing the frequency of extreme weather events, and intensifying droughts. These changes disrupt groundwater recharge, reduce overall water availability, and exacerbate the depletion of aquifers. Understanding these impacts is essential for developing adaptive management strategies to protect and sustain California's groundwater resources in a changing climate. Cal-Adapt, an online platform developed to support *California's Fourth Climate Change Assessment* (spearheaded by the Scripps Institution of Oceanography), provides tools and datasets for evaluating climate change scenarios. It includes documentation of data sources and methodologies, which

PUBLIC DRAFT

are valuable for analyzing potential impacts on groundwater systems (Cal-Adapt 2024).

The following section examines several key ways climate change is affecting California's natural groundwater infrastructure. These impacts are interconnected and compound existing stresses on the state's water systems:

- **Temperature Increases:** Rising average temperatures lead to higher evaporation rates and earlier snowmelt, reducing the duration and volume of groundwater recharge.
- **Snowpack Shifts:** Warmer conditions cause more precipitation to fall as rain rather than snow, diminishing snowpack accumulation and altering the timing of spring runoff that traditionally recharges aquifers.
- **Precipitation Shifts and Atmospheric Rivers:** Changes in precipitation patterns, including more intense but less frequent storms and reliance on atmospheric rivers, increase flood risks while reducing consistent groundwater recharge.
- **Evapotranspiration Increases:** Elevated temperatures lengthen the growing season and increase plant water use, reducing the amount of water available for infiltration and recharge.
- **Impacts on Watersheds:** Altered hydrologic conditions within watersheds change flow regimes, degrade ecological functions, and disrupt natural recharge dynamics.
- **Impacts on Non-Basin Areas:** Climate-driven reductions in infiltration and spring flows in mountainous and hard-rock regions limit the contribution of these areas to regional groundwater systems.

3.3.1 Temperature Increases

California is projected to experience significant warming in the coming decades. According to Cal-Adapt climate tools, based on *California's Fourth Climate Change Assessment*, average annual maximum temperatures could increase by 4.4°F by mid-century and 5.8°F by century's end under a moderate emissions scenario (RCP 4.5), or by 5.8°F and 8.8°F, respectively, under a high-emissions scenario (RCP 8.5).

These rising temperatures alter groundwater recharge pathways — especially in snow-dominated watersheds. More precipitation falls as rain rather than snow, and snowpack melts earlier and faster. This reduces the slow, sustained meltwater

PUBLIC DRAFT

flows that historically supported aquifer recharge, particularly in mid-elevation areas. In both basin and non-basin settings, warmer conditions reduce natural storage and baseflow contributions, diminishing groundwater availability when it's most needed.

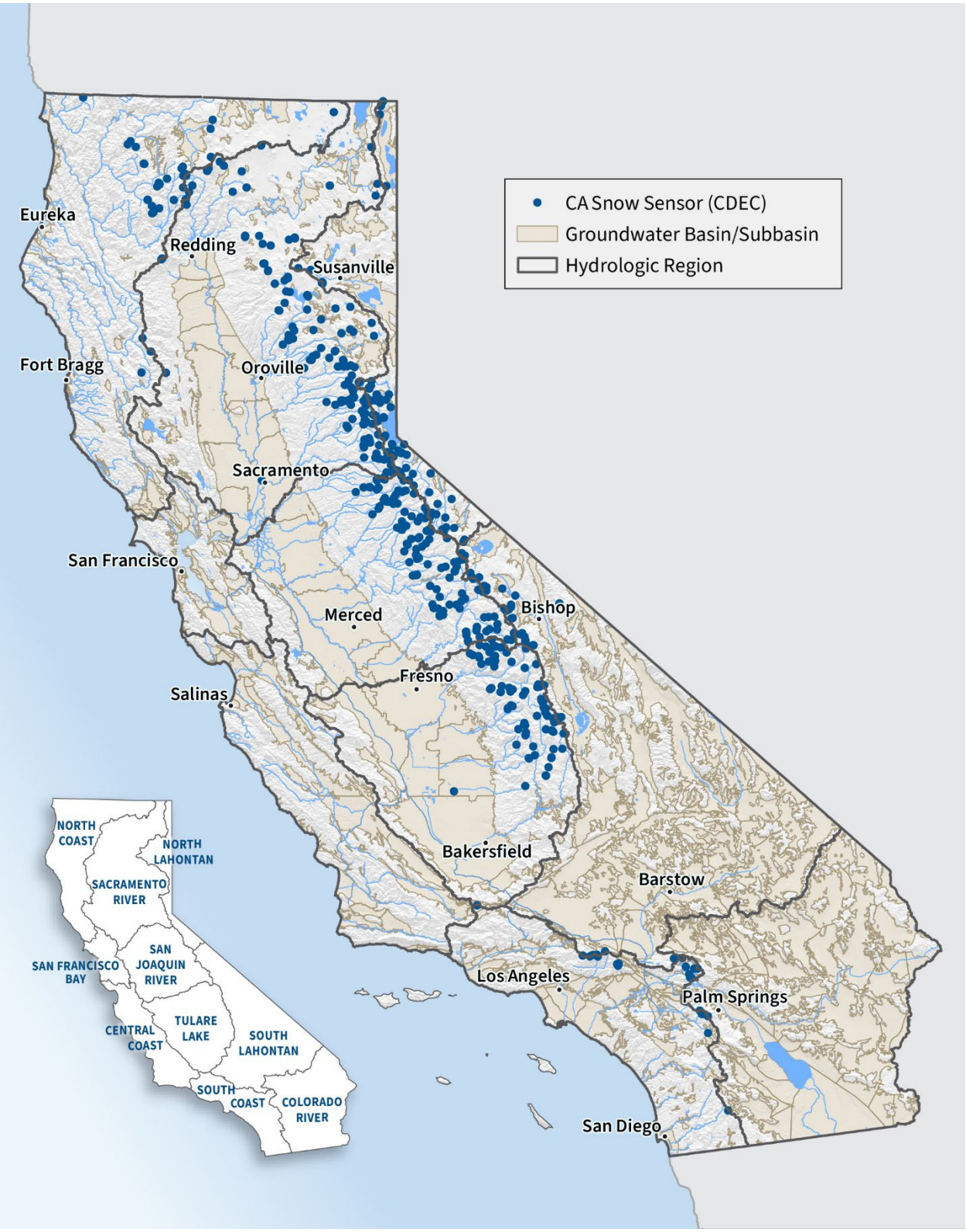
3.3.2 Snowpack Shifts

Historically, nearly a third of California's water supply has come from spring and summer snowmelt from the Sierra Nevada (Smith 2024). The California Cooperative Snow Surveys program, established in 1929, conducts snow surveys at more than 260 locations throughout the state (California Department of Water Resources 2024a). Most of California's snowpack measurement sites are located within non-basin areas, including the Sierra Nevada, the Cascades and Modoc Plateau, the Klamath Mountains, and the northern Coast Ranges (Figure 3-10). Newer technologies pioneered by NASA and Caltech's Jet Propulsion Laboratory through the Airborne Snow Observatory use aircraft-based LiDAR to measure the snow on the ground over entire watersheds, estimating the water equivalent. In recent years, NASA's technology has transferred to the commercial space and continues to be implemented across California to augment snow surveys.

During the period between 1982 and 2017, the annual snowpack cycle was observed to be narrowing, corresponding to a shorter winter season, primarily due to the onset of snowmelt occurring earlier in the water year (Evan 2019). Although a downward trend in average annual snow water equivalent has not yet been observed, changes in the shape of the snow water equivalent annual cycle have important implications for the timing of water availability in California. Rising temperatures associated with climate change are also causing more precipitation to fall as rain rather than snow, while increasing rates of evapotranspiration, sublimation, and snowmelt (Ortiz-Partida 2024). As a result, overall snowpack is reduced, leading to changes in runoff patterns and shorter winter seasons, which cause runoff to occur earlier in the spring. This reduces water availability during the summer months when demand is highest and raises flood risks, as rainfall generates immediate runoff rather than the gradual melting associated with snow (Masters 2023). For example, the State Water Project is predicted to decrease its delivery capacity by 23% within the next 20 years due to changing runoff patterns (California Department of Water Resources 2024b). Additionally, the narrower snowmelt patterns will lead to reduced groundwater recharge, as the shorter duration of snowmelt infiltration will limit the time available for water to seep into non-basin fractured-rock areas, where snowmelt infiltrates the subsurface more effectively than rainfall (Chao and Tasoff 2021).

PUBLIC DRAFT

Figure 3-10 **California Snowpack Measurement Sites**



Changes in the timing of snowmelt also impact reservoir management, as earlier melting of snow can cause reservoirs to fill sooner, increasing the risk of overflows (Martin 2018) and possibly forcing the operators to release water sooner. This change in snowmelt timing could result in less surface water for summer and fall use due to earlier releases and thus may require increased local groundwater pumping to make up for the surface water shortfalls. Ultimately, climate change may reduce California's ability to rely on mountain snowpack as a "natural water reservoir" that stores water in the winter and gradually releases it in the spring and summer (Scripps Institute of Oceanography 2024). Some studies caution that the water supply from snowpack is projected to decline to two-thirds of historical levels by 2050, and potentially one-third of historical levels by 2100 (Scripps Institute of Oceanography 2024).

3.3.3 Precipitation Shifts

Projections of annual average precipitation for California show no clear trend toward becoming consistently wetter or drier. However, climate change projections tend to agree on increased variability in year-to-year precipitation, which means there will be an increased occurrence of extremely dry and extremely wet years. California is likely to experience a sharpening of the seasonal precipitation regime, consisting of less frequent precipitation in the fall and spring, and larger storms in the winter months (California Natural Resources Agency 2019).

One of the key drivers of these projected extremes is the intensification of atmospheric rivers. Occurring usually between November and March, atmospheric rivers deliver the majority of California's water supply but also bring increased risk of flooding (Scripps Institute of Oceanography 2024). Higher temperatures result in increased evaporation and higher water vapor content in the atmosphere, which produce higher amounts of precipitation during storm events (Masters 2023). In this context, more intense atmospheric rivers in a hotter and more variable climate thus pose challenges for reservoir management and natural groundwater recharge in non-basin areas, where runoff storage in reservoirs and infiltration to fractured rock are optimal when snowpack melts slowly. Larger, warmer, more infrequent, and high-intensity storms will produce more direct runoff than accumulating snowpack, which is likely to reduce groundwater recharge in mid-range elevation areas because of their sensitivity to changes in the elevation of freezing temperatures.

PUBLIC DRAFT

3.3.4 Evapotranspiration Increases

Climate change is also intensifying evapotranspiration across California's landscapes, impacting groundwater-dependent ecosystems and the long-term sustainability of natural groundwater infrastructure. Rising temperatures lead to higher rates of evaporation from soils, rivers, and reservoirs, as well as increased transpiration from vegetation. Warmer conditions extend the growing season for many plants, increasing cumulative water use over the year. In groundwater-dependent areas, this increased water demand by vegetation can further lower groundwater levels, particularly during prolonged drought periods. Higher evapotranspiration rates also reduce the amount of water available to recharge aquifers, diminishing baseflows in rivers and streams and placing additional stress on already limited water supplies. As climate change continues, these shifts in evapotranspiration will challenge efforts to manage groundwater sustainably and underscore the need for integrated land and water management approaches that consider both ecosystem health and long-term water supply reliability.

3.3.5 Impacts on Watersheds

Significant variations in precipitation across California's watersheds have historically had a major impact on river flows and groundwater levels. Runoff from watersheds can range from minimal flow to large river flows that cause severe flooding. The historical and recent extremes of droughts, floods, and multi-year wet and dry periods illustrate the wide variations in precipitation in the form of rain and snow and the resulting fluctuations in watershed outflows, including river flows and groundwater recharge and discharge. The movement of variable water volumes through a watershed may alter its physical features, resulting in localized landslides to broader regional impacts such as changes to the courses of major rivers.

As part of the California Watershed Resilience Program, DWR conducted a comprehensive assessment of all watersheds to evaluate their vulnerability to climate change (California Department of Water Resources 2024c). The assessment examined multiple factors, including water supply, flood management, groundwater, water quality, ecosystems, hydropower, recreation, and wildlife. The impact on groundwater was estimated based on changes in precipitation, infiltration, and groundwater recharge.

As a part of the resilience assessment, average historical and future annual infiltration of precipitation was compared at the watershed scale. Figure 3-11 shows the historical annual infiltration (in millimeters) from 1981 to 2010 (left)

PUBLIC DRAFT

and changes from the historical annual infiltration (as a percentage) for the near future timeframe, from 2026 to 2055 (center), and the late future time frame, from 2056 to 2085.

Key results of the study indicate that projected changes in groundwater recharge are not uniform across the state but instead exhibit spatial variability — showing decreases in recharge in the Sierra Nevada, Southern California, and Northern California watersheds during the near future period, while projecting increases in recharge in coastal watersheds and parts of the valley floor. Groundwater infiltration is projected to further decrease during the late future period. The reduction in infiltration in Southern California is driven by decrease in precipitation and runoff, while the increase in evapotranspiration causes decreases in infiltration in Northern California.

Figure 3-11 Changes in Annual Groundwater Infiltration by Watershed: Historic (1981–2010), Near Future (2026–2055), and Late Future (2056–2085)

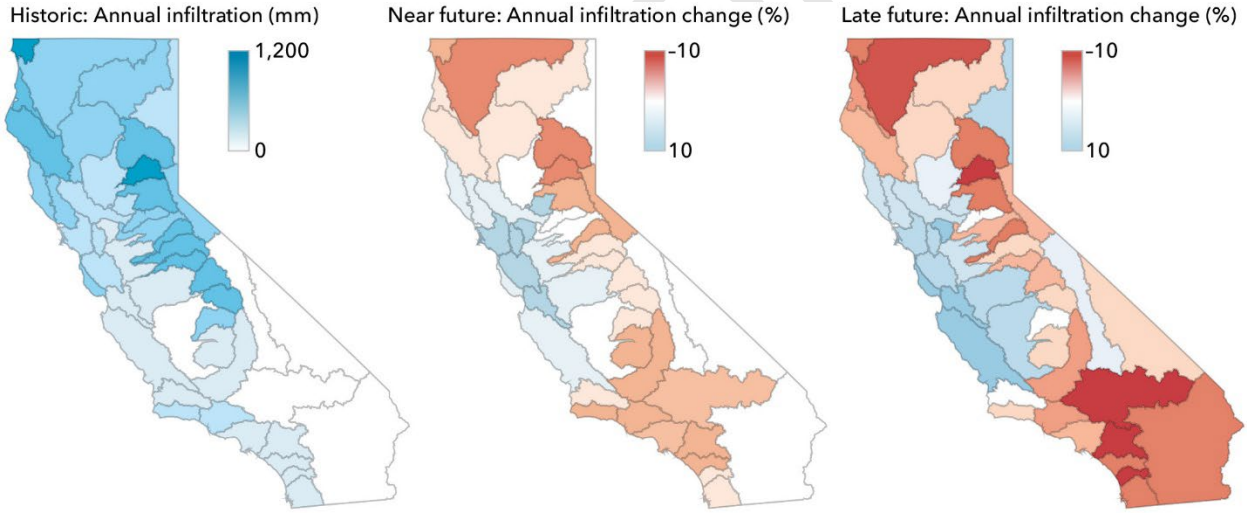


Figure 3-11 Notes: Change is computed using the median values from 20 climate model projections. mm = millimeters. Source: California Watershed Resilience Assessment.

3.3.6 Impacts on Non-Basin Areas

Climate change impacts are also observed in California's non-basin areas, with significant implications for groundwater recharge in both fractured rock non-basin areas and alluvial groundwater basins. Rising average temperatures, increased evapotranspiration, shifts in precipitation patterns, reduced snowpack, and an increased likelihood of extreme events — such as floods, droughts, and wildfires — are altering the state's hydrologic and ecologic balance. Unlike alluvial

groundwater basins, non-basin areas lack substantial water storage capacity, making them more vulnerable to interannual variability in precipitation and prolonged drought conditions. Understanding the potential impacts of climate change on groundwater in non-basin fractured-rock areas will require substantial planning and expansion of existing statewide groundwater monitoring, which is focused on high- and medium-priority groundwater basins.

To support climate adaptation in non-basin areas, California has invested in a variety of strategies to restore natural groundwater infrastructure and increase ecosystem resilience. Two prominent efforts in non-basin areas — meadow restoration and wildfire management — highlight both the challenges and opportunities for protecting groundwater resources in a changing climate.

Meadow Restoration

The Water Resilience Portfolio identified the importance of meadows and wetlands and the need to further invest in restoration projects in non-basin areas as a key response to climate change and a strategy for achieving groundwater sustainability. The portfolio's Action 11 supports the expansion of wetlands and mountain meadows to create habitat, filter runoff, buffer floods, and recharge groundwater. Given the importance of meadows and the ecosystem services that they provide as part of California's natural groundwater infrastructure, there are growing efforts to restore meadows, such as the State's 30X30 goal, which aims to conserve and accelerate the recovery of 30% of California's lands and coastal waters by 2030. Between 2020 and 2022, 71 projects were implemented through interagency collaboration that restored approximately 12,000 acres of meadows within California.

The restoration of mountain meadows can be accomplished using various strategies. Some restorations require ground disturbance and grading, such as the "pond and plug" method. Other methods cause less ground disturbance, such as "process-based restoration," like beaver dam analogs (BDAs). BDAs use onsite materials and leverage natural fluvial processes to increase wetted areas, groundwater elevations, sediment capture, and develop multithreaded channels. Process-based restoration has proven to be economical and scalable for numerous, small, remote degraded meadows. In a recent study conducted by Sevier et al., technicians constructed 35 low-tech BDAs, finding that average water storage in the meadows increased by approximately 3-acre feet over a one-year period (Sevier et al. 2024).

PUBLIC DRAFT

In the face of a changing climate, projects to restore the headwaters and associated meadows of non-basin areas in the Sierra Nevada, Cascades, and Modoc Plateau are critical to integrated watershed management. These projects represent a nexus of natural and built groundwater infrastructure in non-basin areas that support California's largest water projects: the State Water Project and the Central Valley Project. Collaborative restoration efforts among federal, Tribal, State, local, and non-governmental organization (NGO) partners have led to restoration of meadows in the Upper Feather River Watershed (Red Clover, Big Flat, and Thompson Meadows), Pit River Watershed (Ash Creek/Fitzhugh Meadow), Tuolumne River Watershed (Ackerson Meadow), and Kern River Watershed (Troy Meadows).

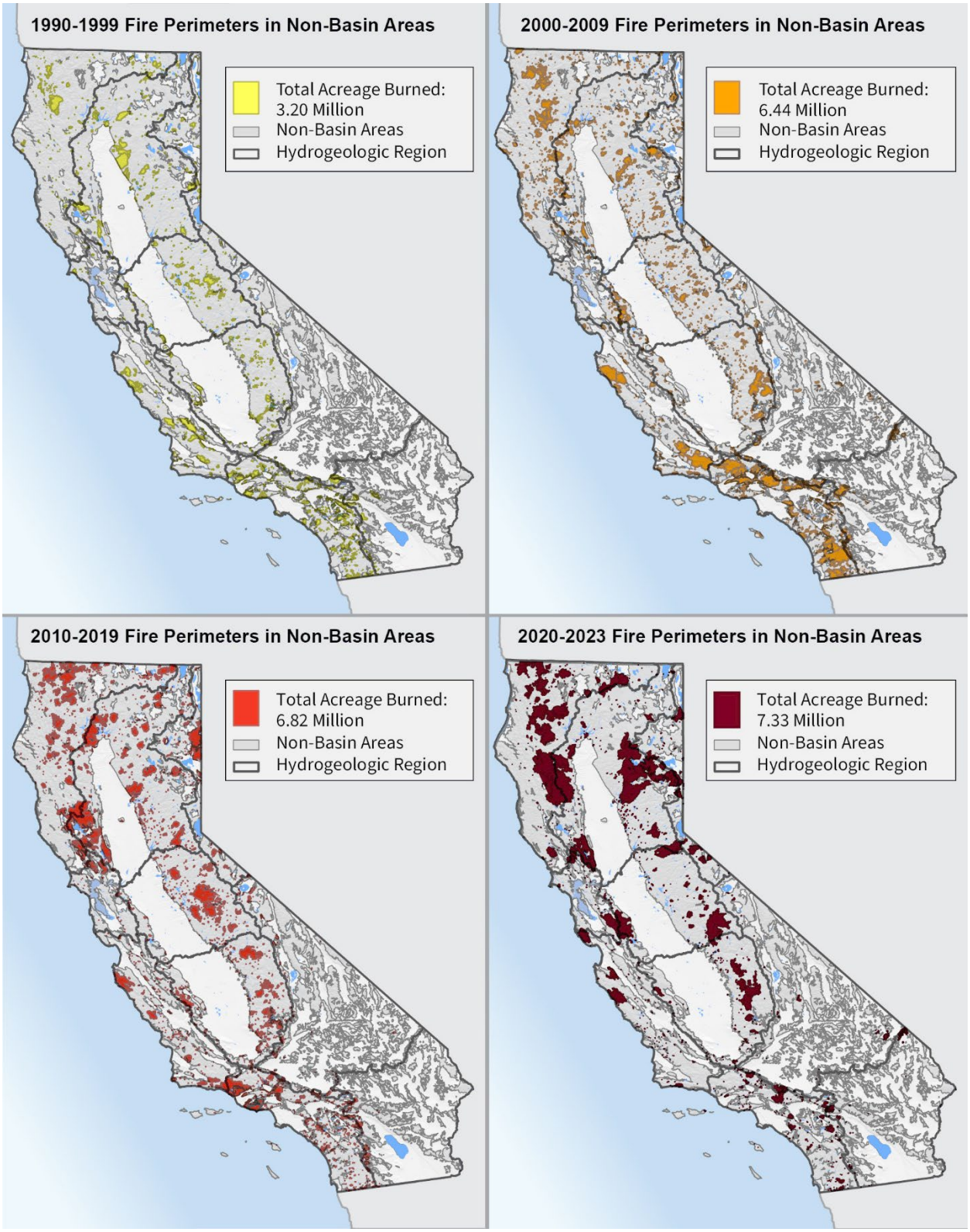
California's meadow restoration projects are crucial for preserving and enhancing the natural groundwater infrastructure of the upper watersheds. The benefits of these projects include local and regional natural groundwater recharge to alluvial groundwater basins and fractured rock non-basin areas and sustained cool-temperature baseflows to streams during hot summer months, which, in turn, support unique and productive ecosystems that have a direct impact on downstream water supply and quality. Functioning and healthy meadows are essential for building natural infrastructure resilience and adapting to California's climate change impacts.

Wildfire

Wildfires can significantly impact natural groundwater infrastructure in non-basin areas and source watersheds (United States Geological Survey 2023). California's non-basin areas have experienced a surge in wildfire activity over the past 20 years, particularly in areas where the terrain is steeper and less accessible to firefighters. The total area burned annually increased from approximately 100,000 acres in 2010 to approximately 4.2 million acres in 2020 (Office of Environmental Health Hazard Assessment 2022). Over 20 million acres have been affected by wildfires between 1979 and 2018 and there were 3,356 fires between 2009 and 2018 — a rate 1.4 times higher than the average number of fires-per-decade between 1979 and 2009 (Buechi et al. 2021) (Figure 3-12).

PUBLIC DRAFT

Figure 3-12 Trends in Location, Size, and Number of Fires in California (1990–2023)



Factors contributing to increased fire intensity and frequency in California's non-basin area source watersheds include hotter, drier, windier conditions; tree mortality; and human factors such as decades of fire suppression and increased human activity and land use in fire prone areas (California Department of Fish and Wildlife 2019).

Wildfires can also cause substantial impacts to groundwater quality in areas with high concentration of human infrastructure, referred to as the wildland-urban interface (WUI). Contaminants from burned residential and commercial structures, vehicles, and other anthropogenic sources can alter watershed hydrology resulting in an influx of nutrients, solutes, and metals into streams and groundwater. Post-fire data collection and research are essential for understanding the impacts of wildfires on surface water-groundwater interactions and groundwater quality. The increasing frequency and intensity of catastrophic wildfires highlight the importance of effective fire and land management, as well as post-fire recovery efforts, to protect and restore natural groundwater infrastructure in non-basin areas.

A 2019 study by the Lawrence Berkeley National Laboratory, conducted in the Cosumnes River watershed in the Central Sierra Nevada Mountains, examined how post-wildfire conditions affect water and energy balances. Using numerical modeling, the study simulated the impacts of wildfires on large-scale hydrological processes, such as streamflow, groundwater levels, snowpack, and snowmelt. The study revealed unexpected feedback following wildfires:

- A delay in streamflow discharge following wet winters with increased snowpack, which indicates a post-fire increase in soil moisture by retaining more snow and reducing ET; and
- Post-wildfire impacts on ET, snow water equivalent, and infiltration are influenced by wet or dry climate conditions, as well as pre-fire and post-fire conditions.

The results of the study highlight the importance of expanding data collection in non-basin areas to monitor changes in streamflow and groundwater levels following wildfires (Maina 2020). The escalating wildfire activity in California over the past two decades has highlighted an urgent need for effective fire management and community preparedness as we navigate the varied impacts of climate change. The interplay of rising temperatures, prolonged droughts, and shifting wind patterns have created a "perfect storm," leading to unprecedented fire intensity and frequency. Wildfires can have complex and varied effects on

PUBLIC DRAFT

groundwater systems in non-basin areas, most of which are still not well understood, including impacts to surface and groundwater supply and quality. Research continues to improve the understanding of the relationship between fire and groundwater, including ET and snowpack differences after fuel reduction, controlled burns, and wildfire; soil permeability changes after low-intensity and high-intensity fires; and water quality impacts from fire, including fire in the wildland/urban interface. This improved understanding of fire impacts on groundwater resources is necessary for long-term planning and policy in non-basin areas and in basin areas that rely on upper watersheds from both surface water and subsurface groundwater flow.

3.4 Groundwater Basin Characterization

Effective management of groundwater resources depends on an in-depth understanding of groundwater basin characteristics. Groundwater basin characterization involves identifying and describing the physical properties of groundwater basins. A groundwater basin is an area underlain by layers of coarse materials, such as sand and gravel, and fine material, such as clay and silt, that together make up alluvial aquifers. The location and composition of groundwater basins in California are shaped by the state's complex climatic and geologic history, which includes periods of glaciation, erosion, and changing sea levels, as well as tectonic activity, volcanic activity, and structural deformation, such as folding and faulting. These geologic processes have influenced the formation, composition, depth, thickness, and hydraulic conductivity of aquifers, affecting how groundwater is stored and moves within a basin.

Because groundwater cannot be directly observed, a conceptual understanding of the subsurface is essential for managing it effectively. A well-developed conceptual model helps integrate diverse datasets, identify data gaps, and guide sustainable planning and management decisions.

To build this foundation, the discussion in this section is divided into three parts:

- Hydrogeologic conceptual models and basin characteristics.
- DWR's Basin Characterization Program.
- Additional basin characterization efforts across California.

PUBLIC DRAFT

3.4.1 Hydrogeologic Conceptual Models and Basin Characteristics

A hydrogeologic conceptual model (HCM) serves as the foundation for groundwater basin characterization. It provides an understanding of a basin's general physical characteristics related to aquifers, aquitards, and geology, as well as regional hydrology, land use, and water quality. An HCM plays a critical role in groundwater management by serving as the starting point for developing water budgets, numerical models, and monitoring networks. By integrating the basin's physical characteristics, an HCM provides groundwater managers with data and information necessary for managing their groundwater basins and refining their understanding over time as new data are collected, analyzed, and incorporated into the HCM.

While an HCM provides an essential conceptual framework, it must be supplemented by hydrogeologic field investigations and data collection to enhance its accuracy and reliability. These include drilling exploratory wells, conducting geophysical surveys, analyzing groundwater levels and flow patterns, assessing water quality, and more. The continued refinement and interpretation of this data enhance the accuracy of the HCM, ensuring that it reflects real-world conditions and can support adaptive groundwater management strategies in response to climate variability and water demands.

This section provides definitions and the latest scientific insights into the physical characteristics of a groundwater basin commonly described in an HCM, along with other key basin characteristics discussed in California's Groundwater. Additionally, this section describes available resources (e.g., tools, maps, and models) that are used for groundwater basin characterization and provides recommendations for improving the State's understanding of HCMs and basin characteristics.

The development of an HCM requires consideration of several key factors that influence groundwater availability, storage, movement, and quality. These include:

1. Aquifers and aquitards.
2. Distribution of geologic materials and textures.
3. Aquifer flow parameters.
4. Base of freshwater.
5. Bottom of basin.
6. Depth to basement.
7. Basin storage capacity.

PUBLIC DRAFT

8. Groundwater storage.
9. Groundwater recharge pathways.
10. Interconnected surface water.
11. Land subsidence.
12. Seawater Intrusion.
13. Brackish groundwater resources.

These factors are briefly discussed below.

1. Aquifers and Aquitards

Groundwater occurs beneath the Earth's surface in the void spaces (e.g., pore space and fractures) of sediments and rocks. These areas or units are typically called either aquifers or aquitards, depending on how water moves through them. Groundwater basins are composed of interlayered aquifer and aquitard units.

An aquifer is a body of rock or sediment that yields significant amounts of groundwater to wells or springs. Coarse-grained sediments such as sands and gravels deposited in alluvial or marine environments tend to function as the primary aquifers in California. Other aquifers, such as those composed of volcanic rocks, igneous intrusive rocks, and carbonate rocks are discussed in the Non-Basin Areas section below.

Aquifers are the units within a groundwater basin that currently are or were historically water-bearing and yield water in significant quantities. An aquifer may comprise an entire groundwater basin, from the ground surface to the bottom of the basin, or may comprise a portion of the groundwater basin. Primary aquifers are bound either by the boundaries of the basin, or by a significant change in aquifer properties such as a change in geologic formations or faulting.

Significant changes in aquifer properties may result from the contact between one geologic formation and another. One example would be the boundary of the basin between the aquifer and crystalline rock, which acts as a barrier to flow. Another example would be two adjacent geologic formations with different properties — one where groundwater flows easily and one that inhibits groundwater flow.

An aquitard is a body of rock or sediment that can store groundwater but does not yield it in significant quantities and restricts groundwater movement. Fine-grained sediments, such as silts and clays, often function as aquitards. Aquitards are often

PUBLIC DRAFT

referred to as confining layers because they limit or slow the vertical movement of groundwater and, under the right hydrogeologic conditions, can confine groundwater so that it is under pressure. Aquitards are capable of allowing some flow between adjacent aquifers and depending on the magnitude of this transfer of water, the aquitard may be referred to as a leaky aquitard. Aquifers and aquitards are identified and characterized through the study of hydrogeologic properties and subsurface materials. Hydrogeologic properties are studied using a variety of tools and techniques, including aquifer testing, analysis of cuttings removed during well drilling, evaluation of groundwater-level responses to pumping, geophysical methods, and other investigative approaches.

Aquifers are classified as being *unconfined* or *confined*. An unconfined aquifer is typically located close to the ground surface and is directly exposed to the atmosphere. The portion of the aquifer where pore spaces are partially filled with air and water is known as the *unsaturated zone*, while the portion where all pore spaces are completely filled with water is called the *saturated zone*. The boundary between saturated and unsaturated zones is defined as the water table (Figure 3-13). An unconfined aquifer's water table surface can range from being at the ground surface to several hundred feet below it. The thickness of an unconfined aquifer varies, and its lower boundary is commonly marked by either a confining bed, which separates it from the confined aquifer below, or a relatively impermeable unit that forms the bottom of the groundwater basin.

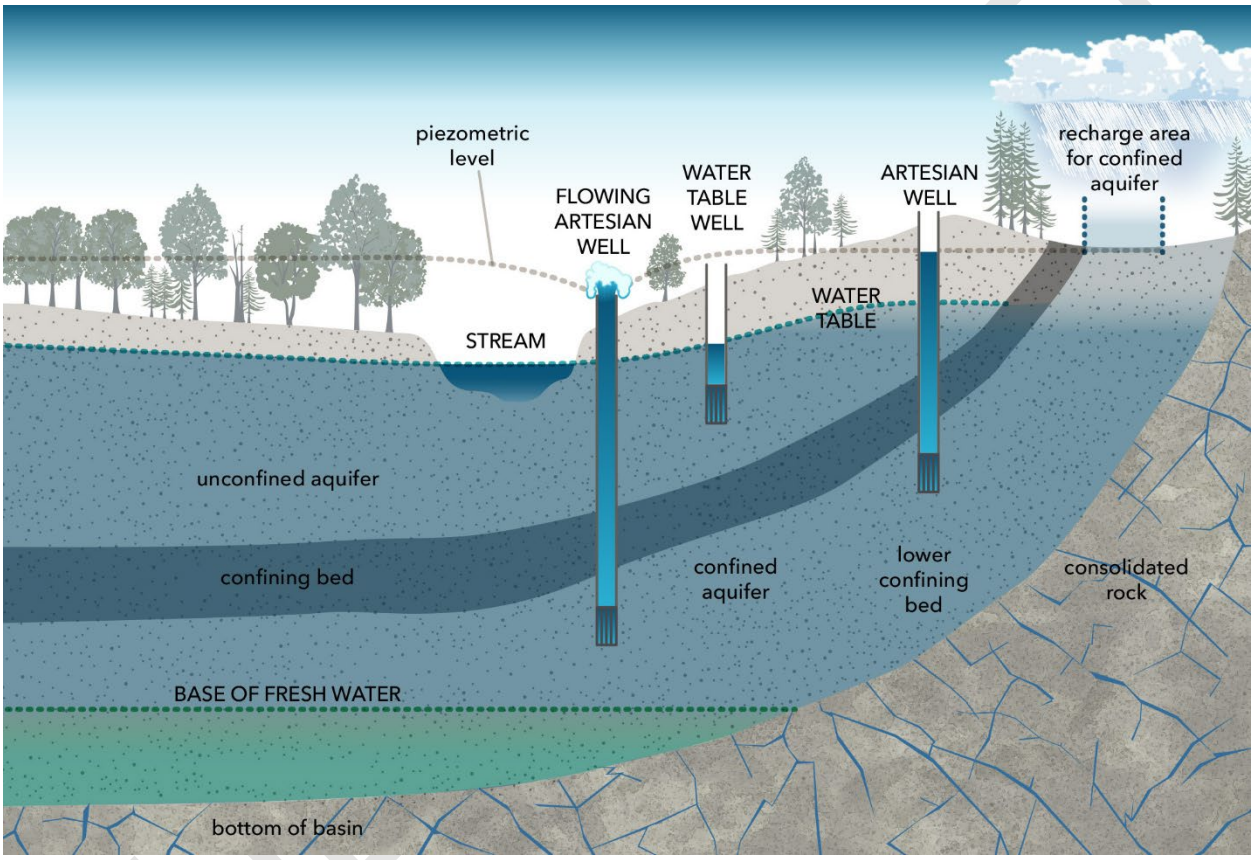
A confined aquifer is commonly located tens to hundreds of feet below the ground surface and is bound above and below by aquitards, or confining units, that restrict the movement of water. Since confined aquifers are under pressure, the groundwater level in a monitoring well can rise above the top of the aquifer and, in some cases, even above the ground surface. The level to which the water rises in an aquifer is called the piezometric level or surface. When the piezometric surface in a well is above the ground surface, it is called a flowing artesian well; it allows water to flow naturally without the need for pumping.

A clear understanding of the depth and extent of aquifers and aquitards enables groundwater managers to make informed decisions, such as identifying suitable sites for groundwater recharge sites or recognizing areas where groundwater pumping may cause undesirable results. In many basins and subbasins, GSAs have already developed HCMs, describing the location and depth of their aquifers and aquitards, as a part of the development of GSPs. However, in some cases, the description may be preliminary or based on incomplete data.

PUBLIC DRAFT

Figure 3-13 presents a schematic of a portion of a groundwater basin showing the unsaturated zone, the water table, an interconnected surface water body, an unconfined aquifer, an aquitard, a lower confined aquifer, and the bottom of the basin. Figure 3-13 also illustrates the transition from freshwater to brackish water and the boundary between the two types of water is defined as the base of freshwater.

Figure 3-13 Hydrogeologic Conceptual Model of an Aquifer System



2. Distribution of Geologic Materials and Textures

The distribution of geologic materials within an aquifer can be described by their grain size, which can range from fine-grained to coarse-grained and is commonly referred to as the material "texture." The distribution of textures is typically represented through a texture model, expressed in units of percent coarse-grained material in the aquifer. Understanding the distribution of textures within an aquifer is essential for groundwater management, as it helps identify areas where water is more likely to be stored and readily accessible for use, as well as areas where water may be harder to access due to slower flow or lower hydraulic conductivity.

The development and refinement of texture models play an important role in improving groundwater flow models, such as DWR's California Central Valley Groundwater-Surface Water Simulation Model — Fine Grid (C2VSimFG) and the Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim), and the USGS's Central Valley Hydrologic Model Version 2 (CVHM2).

The USGS developed a geologic texture model to characterize groundwater basin materials in support of CVHM2. The model was created by analyzing drillers' logs of boreholes and wells and interpolating the data into a 3D model space with a resolution of one square mile laterally by 50 feet vertically (Faunt et al. 2010; Faunt et al. 2024). Depth slices of the CVHM2 texture data can be accessed through DWR's SGMA Data Viewer.

3. Aquifer Flow Parameters

Aquifer flow parameters describe how water moves within an aquifer and are an integral component of groundwater flow models. These parameters can be measured in the field using a variety of methods, such as aquifer tests, pump tests, well yield tests, slug tests, pressure tests, tracer tests, and wellbore flow logging. These tests can provide information about an aquifer's hydraulic properties within the tested volume of aquifer space, though results can vary significantly depending on the method used. These tests may be conducted during or immediately after the completion of a groundwater well.

Often, aquifer flow parameters are compiled, quality-controlled, and used for individual groundwater flow models, but there is no centralized database of aggregated, quality-controlled aquifer pump test data.

Because aquifer test data are limited, it is often necessary to estimate aquifer parameters by extrapolating and interpreting data between aquifer test locations. DWR's Texture2Par (Version 1.0) is a software program developed to generate spatially distributed parameter inputs for numerical groundwater flow models by constructing a three-dimensional hydrogeological model of the aquifer system based on available sediment texture information and measured groundwater flow parameters. Texture2Par establishes empirical relationships between the texture of unconsolidated and loosely consolidated sediment and aquifer flow parameters to estimate vertical and horizontal hydraulic conductivity, specific yield, and specific storage.

PUBLIC DRAFT

4. Base of Freshwater

In some aquifers, groundwater quality can change with depth, transitioning from freshwater near the top of the aquifer to brackish or saline water with higher concentrations of total dissolved solids (TDS) at greater depths. Freshwater is generally defined as groundwater that has low TDS concentrations and is considered suitable for agricultural and domestic uses. The depth at which groundwater quality can no longer be considered "freshwater" is referred to as the base of freshwater. The increased TDS concentration at depth can result from the dissolution of native aquifer materials, the presence of connate water common in marine geologic deposits, the lack of replenishing groundwater resources, and other natural and anthropogenic processes.

The base of freshwater can be determined in several ways, including through direct water quality sampling or analysis of the electrical conductivity responses in geophysical logs. However, it is difficult to sample water quality at great depths because monitoring wells are often not screened at the depth where brackish water occurs. Since brackish water has a high TDS concentration, it also exhibits a higher electrical conductivity response compared to freshwater. As a result, the transition from freshwater to brackish water can be estimated using electrical resistivity logs, commonly referred to as "e-logs." These logs are usually collected as part of oil and gas operations and are available through the California Geologic Energy Management Division's (CalGEM), formerly DOGGR, online mapping application, Well Finder. However, caution is needed when interpreting e-logs for salinity changes, as fine-grained aquitards may also exhibit high electrical conductivity responses, which can be mistaken for salinity variations.

There is uncertainty in the literature regarding the regulatory definition of a TDS threshold that corresponds to "freshwater" as illustrated in Table 3-1. California regulations define the upper limit for water supplied to the public at a TDS concentration of 1,000 mg/L (California Code of Regulations Title 22, Section 64449) and define freshwater as having a TDS concentration of 3,000 mg/L or less (California Code of Regulations 2022, Title 14 Section 1720.1 (e)). Federal Regulations define underground sources of drinking water as having a TDS concentration of 10,000 mg/L or less (40 Code of Federal Regulations Section 144). This results in TDS thresholds for "freshwater" that range from 1,000 mg/L to 10,000 mg/L.

The variability in the TDS threshold for defining freshwater has also resulted in inconsistencies in defining the base of freshwater. In the early 1970s, USGS

PUBLIC DRAFT

published base of freshwater maps for the San Joaquin and Sacramento valleys based on geophysical logging data. The USGS defined the base of fresh water to occur at an electrical conductivity value of approximately 3,000 micromhos, which loosely correlates to a TDS concentration of approximately 2,000 mg/L (Page 1973). More recently, maps have been published for the base of underground sources of drinking water for the Southern San Joaquin Valley based on TDS concentration of 10,000 mg/L and geophysical logs (Gillespie et al. 2017). These inconsistencies in defining the base of freshwater may limit efforts to effectively manage deeper groundwater resources (Kang et al. 2020).

Table 3-1 Regulatory Limits for TDS Concentration That Define "Drinking Water" and "Freshwater" (Modified from Gillespie et al. 2017)

Maximum TDS (mg/L)	Application
1,000	Water supplied to the public (upper limit) [1]
3,000	Beneficial use as a drinking water supply [2] Freshwater for oil and gas wellhead protection [3]
10,000	Underground source of drinking water [4]

Table 3-1 Notes:

1. *California Code of Regulations Title 22, Section 64449 (regulated by the State Water Resources Control Board (SWRCB)).*
2. *SWRCB Resolution No. 88-63 as modified by Resolution No. 2006-0008 (regulated by the SWRCB).*
3. *California Code of Regulations, Title 14 Section 1720.1 (regulated by the California Geologic Energy Management Division).*
4. *40 Code of Federal Regulations Section 144.*

5. Bottom of Basin

The bottom of the basin is an important component of HCMs and groundwater flow models, as it represents a boundary through which no significant groundwater flow occurs. The bottom of a basin is generally considered to be located where saturated unconsolidated material meets rock or sediments of very low hydraulic conductivity, below which no aquifers exist within the basin. However, there is no consistent standard for defining the bottom of the basin. In some basins, the base of freshwater is considered as the bottom of the basin, while in other basins, the interface with marine deposits, bedrock, or basement is considered as the defining boundary.

PUBLIC DRAFT

The USGS has developed maps defining the bottom of the basin in parts of the San Joaquin Valley, including the base of the Tulare formation in the southwestern portion of San Joaquin Valley. This map was originally produced in 2003 and was recently updated in 2022. The USGS has also defined the base of the Mya zone in the Kettleman City area (Page 1981). This map was last updated in the 1980s.

The USGS also developed the base of post-Eocene continental deposits map for the Sacramento Valley. The post-Eocene deposits consist of intercalated, continental sedimentary materials, below which predominantly marine sedimentary deposits occur. The base of the post-Eocene deposits can also be interpreted as the bottom of the basin for the Sacramento Valley. The map was first published in 1997 and digitized in 2022. The bottom of basin maps should be updated with additional existing and newly acquired data (e.g., AEM and e-logs).

6. Depth to Basement

The bottom of the basin is typically described in terms of depth to basement, representing the depth to the top surface of igneous or metamorphic rocks. This depth can be determined by an examination of lithology descriptions or geophysical signatures from well logging data, including those from groundwater wells and oil and gas applications, as well as from surface geophysical studies. However, determining the specific lithologic description or geophysical signature that defines the basement contact is not always straightforward. Expertise in geology, geophysics, and hydrogeology is essential to accurately interpret the available data.

In addition to the required expertise, the availability of a sufficient spatial density of data to depths that reach basement is needed to ensure accurate interpolation between data points. However, in many places in California, there is a lack of lithology and geophysical data that extends to depths as deep as the bottom of the basin. As a result, mapping the depth to basement can be difficult without additional spatial coverage and deeper lithology and geophysical data to improve accuracy. The USGS maintains a depth to [crystalline] basement map that extends from the exposed rock in the Sierra Nevada to beneath the Central Valley (Wentworth et al. 1995). The map was developed through analysis of surficial geology, oil and gas wells, and seismic reflection and refraction data. The map was first published in 1995 and last revised in 2012 and shows depth to basement as deep as 8 miles in the western portions of the San Joaquin Valley.

PUBLIC DRAFT

7. Basin Storage Capacity

Groundwater basins provide California with a natural infrastructure to store water below ground. A groundwater basin can be thought of as a natural underground reservoir, with distinct storage levels that, like a surface reservoir, vary based on geology, water quality, and changing groundwater levels. These storage levels are shown in Figure 3-14 and are described below.

The ***basin storage capacity*** is the total volume of pore space within the aquifer system, extending from the land surface to the bottom of the basin, where impermeable material prevents further groundwater movement. It includes both saturated and unsaturated zones and represents the maximum potential volume of water that could be stored in the basin, regardless of the water quality or salinity. This definition parallels that of surface water reservoir storage capacity, which refers to the volume available for storing surface water.

Basin storage capacity can be estimated by analyzing hydrogeologic conceptual models, texture models, aquifer parameters, and geologic data. In 1975, DWR estimated California's total groundwater basin storage capacity to be between 850 and 1,300 maf (California Department of Water Resources 1975). To put this into perspective, the combined storage capacity of all major surface reservoirs in California is about 40 million acre-feet, a small fraction of the estimated basin storage capacity. However, the 1975 estimate of groundwater basin storage capacity has not been updated using the extensive data collected over the past several decades from groundwater basin studies, numerical models, and monitoring programs. For the purpose of discussion in this report, it is assumed that California's total groundwater basin storage capacity is more than 1,000 maf.

In general, a basin's storage capacity and structure remain relatively stable over time. However, human activities can cause a change to the basin storage capacity due to an alteration in the basin's natural structure. One such scenario is subsidence or compaction, which can reduce the storage capacity of a basin.

Available basin storage capacity, as shown in Figure 3-14, refers to the unsaturated portion of the basin — found above the current groundwater level — that can accept additional recharge. Unlike total basin storage capacity, available basin storage capacity changes over time as groundwater levels fluctuate and pore space saturation changes. It can be estimated by using the basin storage capacity estimates and subtracting from it the total groundwater storage that can be estimated by using groundwater level data.

PUBLIC DRAFT

Bottom of Basin is defined as the lower boundary of the aquifer, where impermeable or very low-permeability rock or sediment restricts further groundwater movement. It marks the deepest limit of basin storage capacity.

Figure 3-14 Schematic Showing Basin Storage Capacity Terms (on the left side of the column) and Groundwater Storage Terms (on the right side of the column)

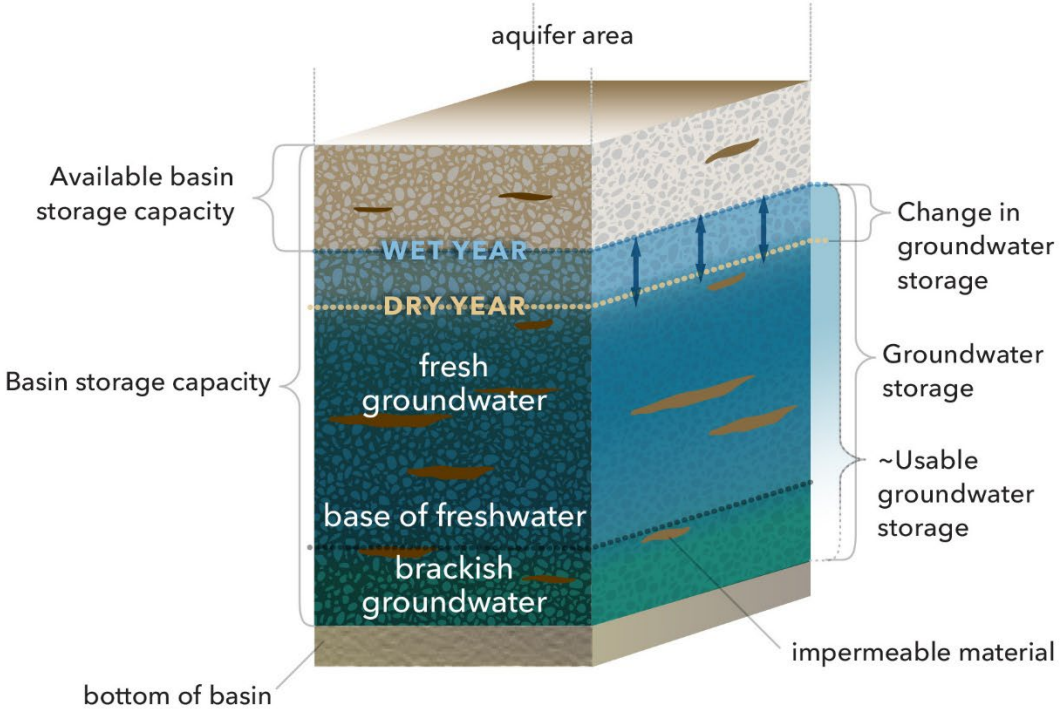


Figure 3-14 Notes: Usable groundwater storage is shown here with a dashed line to indicate that it is variable and depends on factors such as depth, salinity levels, advancements in treatment technology, and the costs of treatment and energy. Definitions of all terms shown in the figure are provided in the text.

8. Groundwater Storage

Groundwater storage, as shown in Figure 3-14, refers to the total volume of groundwater held within the pore spaces and fractures of the saturated portion of an aquifer. It is calculated as the amount of groundwater (fresh and brackish) present in the saturated pore space, extending from the water table to the bottom of the basin, where rock or sediments of very low hydraulic conductivity exist. Because groundwater storage is dependent on groundwater levels, it is not a constant value and changes as groundwater levels change. However, groundwater storage is usually reported as a single value, representing the total groundwater storage in a given year, typically based on fall measurements at the end of water

year. The USGS estimated that in 1961, there was approximately 800 maf of groundwater storage in the Central Valley at depths of up to 1,000 feet (Williamson et al. 1989).

Understanding how groundwater storage changes from year to year under various water year types, groundwater pumping rates, and groundwater management conditions is essential for effective water resources planning. The ***change in groundwater storage*** is defined as the difference in groundwater storage volume between two time periods within a specific geographic area, often influenced by factors like climate variability, recharge rates, and pumping (Figure 3-14). This change is represented in the figure by the vertical distance between groundwater levels during a wet year and a dry year. Typically, groundwater storage decreases from a wet year to a dry year due to increased withdrawals and reduced recharge during dry conditions. Conversely, groundwater storage increases from a dry year to a wet year as recharge replenishes the aquifer and as groundwater withdrawals decrease. Groundwater storage estimates include groundwater that may be too deep to extract economically or too salty (e.g., brackish groundwater) to be used for agricultural purposes or human consumption.

Usable groundwater storage, as shown in Figure 3-14, is the portion of groundwater storage that can be economically and practically extracted while maintaining acceptable water quality. It typically lies above the base of freshwater, though this threshold may evolve into even brackish groundwater with changes in the economic value of water. Economic factors considered include costs associated with treating for water quality (e.g., waters with high concentrations of TDS), costs of groundwater extraction (e.g., depth of groundwater to be extracted), and costs associated with remediating impacts caused by groundwater extraction (e.g., dry wells, land subsidence, seawater intrusion, etc.).

California's usable groundwater storage was previously estimated to be about 143 maf (California Department of Water Resources 1975). At that time, total basin storage capacity was estimated to range between 800 and 1,300 maf, implying that usable storage capacity was only 11% to 18% of the total basin storage capacity. However, with advancements in water treatment technology, improved pump efficiency, and the increasing economic value of water, the potential amount of practically and economically recoverable groundwater storage may now be significantly higher. As extraction and treatment become more cost-effective, previously unusable groundwater — such as deep or brackish water — may become a viable resource, warranting a reevaluation of usable storage capacity in California's groundwater basins.

PUBLIC DRAFT

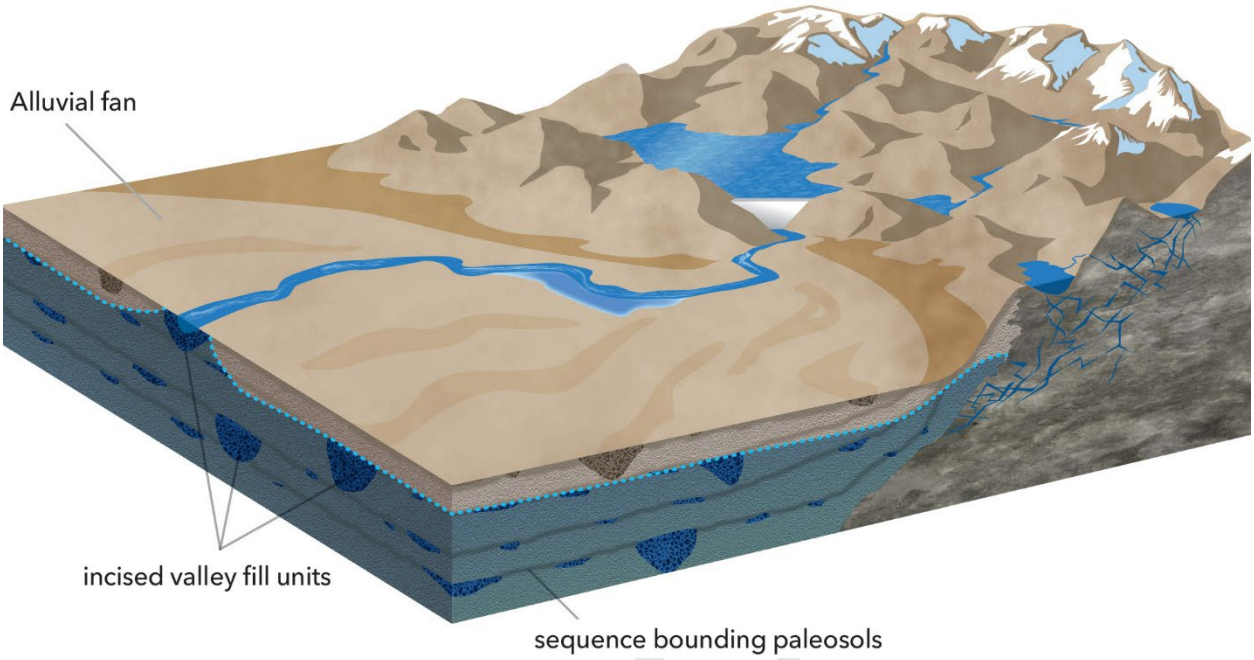
9. Groundwater Recharge Pathways

Natural groundwater recharge can occur in areas where water infiltrates from the ground surface into an underlying aquifer. The pathway that the water takes can be short and direct or long and tortuous, depending on the texture of the underlying materials, the depth and distance to groundwater, and whether the aquifer is shallow and unconfined or deep and confined. Replenishment of shallow aquifers can occur quickly when water is traveling through coarse-grained materials, like sands and gravels. However, in areas dominated by fine-grained materials, like silts and clays, replenishment can occur, but it is usually slow (or restricted), potentially causing mounding of the water table or ponding of water to the surface.

Replenishment of water in deep aquifers can take years or even decades, depending on the recharge pathway. The recharge area for a deep aquifer is generally located at a higher elevation or some distance away from the zone being used as a source of water supply. For example, in the San Joaquin Valley, a recharge area for deep aquifers is located higher in the foothills or mountains surrounding the valley, where water infiltrates through mountain meadows and streams or into permeable outcrops, such as alluvial fans and incised valleys (Figure 3-15). In the Central Valley, alluvial fans are typically composed of silts, sands, and gravels, which constitute the aquifer structure where water is stored and transmitted (Faunt et al. 2024; Weissmann et al. 2005). Paleo-valleys, also referred to as incised valley fills, are incised into the alluvial fans and are dominated by coarse grained materials. They can serve as preferential pathways, allowing water to move quickly from the surface into deeper aquifers.

PUBLIC DRAFT

Figure 3-15 Schematic of Alluvial Fans and Incised Valley Fills Can Serve as a Recharge Pathway to Get Water into Deeper Sections of an Aquifer



Groundwater recharge pathways are also important for managed aquifer recharge efforts and there have been numerous efforts to identify optimal locations for recharge. The Soil Agricultural Groundwater Banking Index (SAGBI), developed by the University of California, Davis, and University of California Agriculture and Natural Resources Extension, is a suitability index for assessing groundwater recharge potential on agricultural land. SAGBI is based on five key factors that are necessary for successful agricultural groundwater banking: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition.

Another tool designed to assess groundwater recharge potential is the Groundwater Recharge Assessment Tool (GRAT). Developed by Sustainable Conservation and The Earth Genome, GRAT integrates hydrologic, agronomic, and geologic information to evaluate potential recharge locations. GRAT analyzes data to help determine when, where, and how much water can be recharged in the most cost-effective way. It provides an online viewer to display publicly available data used in GRAT. This tool also offers specialized services for registered users, allowing them to import additional data and run custom scenarios.

Stanford University developed the Fastpath Tool, a web-based application designed to identify permeable pathways using airborne or field-based electromagnetic geophysical data. The tool provides plan-view maps that display

PUBLIC

the total percentage of coarse-grained material, the length of permeable pathways from the ground surface to the water table, and the depth to the first clay layer.

Although these tools provide information that aids in identifying potential areas for conducting groundwater recharge, the results are limited by the datasets used in the analysis or the specific recharge component considered, such as soil conditions. A more comprehensive approach to aquifer recharge potential mapping would require integrating multiple datasets into a continuous 3D model and analyzing the entire aquifer system. This process would enable the development of aquifer recharge potential maps that characterize different parts of the aquifer and support various recharge methods, including surface water spreading, recharge basins, dry wells, and aquifer storage and recovery.

10. Interconnected Surface Water

Surface water bodies interact with groundwater across all landscapes, both under natural conditions and in response to human activities. When surface water bodies are connected to an aquifer by a continuously saturated zone, the surface water body is considered to be an Interconnected Surface Water (ISW) (Title 23 CCR Section 351[o]). An example of an ISW is shown in Figure 3-15 (above). Due to their connectivity with groundwater, when groundwater levels decline, flow in ISWs decreases. Similarly, when groundwater levels increase, flow in ISWs also increases. This relationship, and identification of ISW, is important for the management of the combined groundwater surface water system.

As described by the water cycle, no new water is created when groundwater is pumped. Instead, groundwater pumping alters components of groundwater and surface water flow. Pumping lowers groundwater levels, which, over time, results in a reduction in streamflow or volume of water in a surface water body in two ways: (1) a reduction of inflow to an ISW from groundwater or (2) an increase in outflow from an ISW to groundwater. Both cases result in less water in the surface water body. These reductions in surface water volume due to pumping are called depletions. Additional information on this topic is available in DWR's Depletions of Interconnected Surface Water Paper Series.

Determining whether a surface water body is an ISW can be challenging. A common approach is to compare groundwater elevation data at wells near the surface water body with the elevation of the bottom of the surface water body. Additional methods used to assess ISW include thermal imaging, isotope analysis, tracer studies, water quality testing, geophysical surveys, aquifer tests, flow

PUBLIC DRAFT

measurements, and groundwater modeling. Numerical groundwater models are particularly valuable for integrating known information about the surface water and groundwater systems, allowing for basin-wide or regional assessments to identify the extent and the location of ISW.

11. Land Subsidence

The sinking of an area of land is called land subsidence. There are multiple factors that can cause land subsidence, including tectonic activity, mining, soil compaction, oil and gas production, and groundwater extraction. Excessive groundwater pumping lowers groundwater levels and pore pressures, causing fine-grained sediments, if present within an aquifer system, to lose support and compact, which leads to the sinking of the ground surface. Land subsidence has been documented in different parts of California and has historically been most significant in the San Joaquin Valley and select parts of the Sacramento Valley (California Department of Water Resources 2022). It has caused billions of dollars in damages to water conveyance systems, flood control facilities, transportation infrastructure, and groundwater wells (Borchers and Carpenter 2014).

In California, unconsolidated alluvial aquifer systems containing fine-grained units or layers that have undergone extensive groundwater development are typically the most susceptible areas to subsidence (Galloway and Burbey 2011; Borchers and Carpenter 2014). These fine-grained units generally consist of two types of low-hydraulic conductivity deposits: laterally discontinuous fine-grained sediments (interbeds) within the aquifers and laterally extensive fine-grained sediments (confining units or aquitards) separating individual aquifers in the aquifer system. The interbeds and confining units, typically comprised of clays, are often several orders of magnitude more compressible than the coarse-grained materials constituting the aquifers and create confining conditions by impeding vertical flow of water within the aquifer system (Freeze and Cherry 1979; Kelley et al. 2018; Poland et al. 1975).

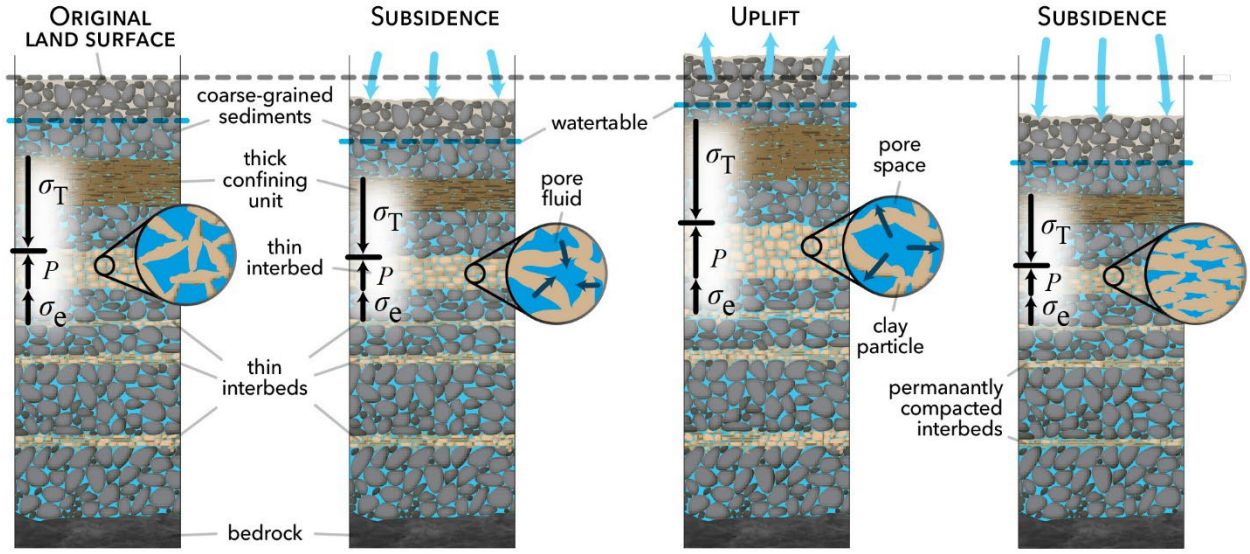
Subsidence due to groundwater extraction is driven by changes in pore-fluid pressure (expressed in terms of an equivalent hydraulic head or a "groundwater level") and the compressibility of the aquifer system. The "aquifer system" includes a combination of the aquifer units, confining units, and interbeds. This relationship is based on the principle of effective stress, in which stress exerted by the weight of overlying rock and water (overburden) is balanced by pore-fluid pressure and the intergranular stress on the aquifer-system skeleton (effective stress) (Terzaghi 1925; Meinzer 1928). As the hydraulic head is lowered (i.e.,

PUBLIC DRAFT

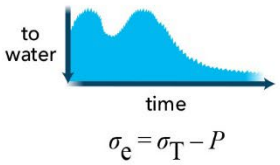
pore-fluid pressure is reduced), the overburden stress is increasingly transferred to the granular skeleton of the aquifer system, leading to an increase in effective stress that compresses the skeleton. Conversely, when the hydraulic head is raised, the increased pore-fluid pressure reduces effective stress, allowing the aquifer-system skeleton to expand. The greatest historical effective stress imposed on the aquifer system is called the "preconsolidation stress." It typically corresponds to the lowest groundwater level, which is called the "preconsolidation head" (Leake and Prudic 1991).

PUBLIC DRAFT

Figure 3-16 Illustration of Subsidence Mechanics



The weight of the overlying rock and water is balanced by the pore-fluid pressure and the intergranular or effective stress.



$$\sigma_e = \sigma_T - P$$

Groundwater withdrawal from confined aquifers reduces fluid pressures (P). As the total stress (σ_T) remains nearly constant, a portion of the load is shifted from the confined fluid to the skeleton of the aquifer system, increasing the effective stress (σ_e) and causing some compression and resultant subsidence.

As water level increases, a portion of the load is shifted from the skeleton to the fluid, decreasing the effective stress and causing some expansion and resultant small uplift of land surface.

Under the principle of effective stress, the compaction of a sequence of thick interbedded aquifers can proceed only as rapidly as pore pressures can decay toward equilibrium with reduced pressures in the pumped aquifers. Most of the land subsidence occurs as a result of the permanent compaction of the fine-grained sediment (interbeds and confining units), which may be delayed due to the slow drainage of the thick interbeds and confining units.

If the effective stress is less than the preconsolidation stress, changes in hydraulic head will result in elastic (or reversible) compression of both the coarse- and fine-grained sediments in the aquifer system. Short-term fluctuations in groundwater levels, such as seasonal or daily variations, can lead to elastic subsidence (Galloway et al. 1999). However, when the effective stress exceeds the preconsolidation stress, the skeletal structure of interbeds and confining units may undergo significant, permanent rearrangement, resulting in inelastic (or irreversible) compaction. Due to the typically high compressibility of fine-grained sediments, both elastic and inelastic subsidence are several orders of magnitude

higher in the interbeds and confining units compared to coarse-grained sediments. The fundamental concepts of effective stress are illustrated in Figure 3-16.

The change in effective stress and resulting compaction process in fine-grained units is not instantaneous; the low hydraulic conductivity of these units results in dewatering that can occur for many years until equilibration occurs between the coarse- and fine-grained sediments. During this dewatering process prior to equilibration, the preconsolidation head decreases to a new value, referred to as the critical head. This critical head value is the "new" preconsolidation head for the fine-grained units. Depending on the stress history and hydrogeological structure of the aquifer system, critical head values can vary across different fine-grained units. Critical head values are generally above historical low groundwater levels that are measured in the coarse-grained materials unless groundwater levels have persisted at historical lows long enough for equilibration to occur between the coarse- and fine-grained sediments.

Residual subsidence refers to the continued decrease in land surface elevation after the primary cause of subsidence (generally groundwater level declines) has ceased. In an equilibrated aquifer system, the groundwater level values in the fine- and coarse-grained sediments are effectively equal. During groundwater extraction, the groundwater levels do not simultaneously decline for both sediment types; rather, water levels decline first in the higher hydraulic conductivity materials (sands and gravels where wells are often screened) and do so more rapidly. While these coarse-grained materials experience negligible compaction due to their typically low compressibility, the water level decline generates a stress gradient between the coarse-grained and fine-grained units. At the boundaries, the fine-grained units will drain into the coarse-grained sediment under an increase in effective stress. The effective stress gradually propagates through the fine-grained unit as the clay is dewatered. Residual subsidence can occur for years to centuries after the preconsolidation stress is exceeded and can persist even after groundwater levels recover (Helm 1978; Ireland et al. 1984; Lees et al. 2022).

Monitoring subsidence is typically conducted using one of four methods: spirit-leveling surveys that measure elevation changes between ground benchmarks, borehole extensometers that measure compaction within a defined depth of the aquifer system. Continuous Global Positioning System (CGPS) stations that track precise ground movement over time, and satellite-based Interferometric Synthetic Aperture Radar (InSAR) that detects land surface displacement across large areas. DWR publishes statewide InSAR subsidence data on the CNRA Open Data website

PUBLIC DRAFT

and the SGMA Data Viewer. The recent InSAR data show accelerated land subsidence in parts of the Central Valley, primarily due to increased groundwater pumping during the 2012–2016 and 2020–2022 droughts. While land subsidence rates decreased following the wet 2023 water year, they are likely to increase again during future dry periods unless groundwater levels are stabilized through reduced groundwater extraction or increased groundwater recharge. Maps displaying the locations of land subsidence in California are provided in Chapter 6, "Groundwater Conditions." Additional information on monitoring and mitigating land subsidence can be found in DWR's Subsidence Best Management Practices.

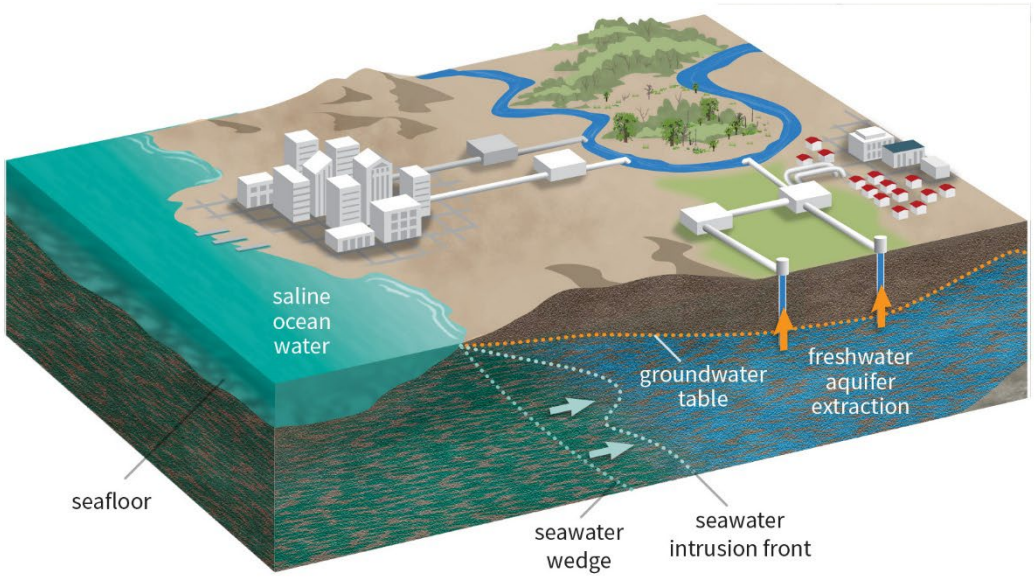
12. Seawater Intrusion

California has nearly 100 groundwater basins adjacent to an ocean, bay, or delta, where freshwater aquifers come into contact with seawater that occupies the pore spaces within the aquifer. This interaction typically creates a seawater wedge due to the difference in density between freshwater and seawater, as shown in Figure 3-17. When groundwater levels in the aquifer decline inland, the hydraulic gradient changes, allowing the interface between seawater and freshwater to move further inland, forming a seawater intrusion front. This movement of seawater into the aquifer results in a decrease in the amount of freshwater available in the basin and renders wells within the affected area unsuitable for pumping freshwater.

Additionally, sea level rise due to climate change exacerbates seawater intrusion in coastal basins by increasing the landward hydraulic gradient. The effects of seawater intrusion include degradation of water quality with increased salt concentrations and a reduction in usable groundwater storage.

PUBLIC DRAFT

Figure 3-17 Schematic of Seawater Wedge and a Seawater Intrusion Front



The presence of seawater in groundwater aquifers can be monitored by measuring concentrations of chloride or total dissolved solids (TDS). Seawater is typically defined as having a chloride concentration of 19,000 mg/L or a TDS concentration greater than 35,000 mg/L (Izbicki 1996; California SWRCB 2016; California State Water Resources Control Board 2023a). In addition to direct measurements of chloride and TDS, electrical conductivity (EC) serves as a useful proxy for assessing groundwater quality and detecting seawater intrusion.

In addition to sampling extracted groundwater, EC can be measured in boreholes or from the surface using electromagnetic geophysical methods such as electromagnetic soundings or towed-EM surveys. EC can also be estimated from airborne electromagnetic (AEM) data and used to estimate the extent of seawater intrusion over large areas. DWR's recent collection of AEM data may be useful in characterizing the three-dimensional extents and preferential pathways of seawater intrusion. However, geophysical data must be used in tandem with other subsurface data because the source of high electrical conductivity values in the subsurface can indicate either high TDS water or the presence of clay layers. While these datasets give a snapshot of subsurface intrusion conditions, long-term changes are best characterized through groundwater quality monitoring at key well locations.

PUBLIC DR

13. Brackish Groundwater Resources

Increasing water scarcity and the effects of climate change on water resources have resulted in the need to consider salty groundwater, also known as brackish groundwater, as a potential water source that can be treated and utilized. Groundwater that contains a moderate to high TDS concentration is considered brackish groundwater. Brackish groundwater is typically identified as having a TDS concentration ranging between 1,000 mg/L and 10,000 mg/L (State Water Board 2023; Anning et al. 2018). While brackish groundwater can be used for industrial operations, it is generally too salty to be used directly for drinking water or agricultural purposes. However, it can be treated (through desalination) and/or blended with less-salty water, opening possibilities as a new source of water for irrigation, industry, and drinking water (California Department of Water Resources 2024d). Brackish groundwater represents an important alternative drinking water resource that is already in use in the South Coast Hydrologic Region (Anning et al. 2018; Sweetwater Authority 2017).

The expanded use of brackish groundwater faces some challenges, including the cost for treatment of specific water quality constituents such as arsenic, nitrate, and uranium, which are commonly found in brackish water (Anning et al. 2018). Additionally, there are complex regulatory frameworks that govern the use of brackish aquifers and disposal of desalinated brines. While cost is a major consideration in developing this resource, the treatment of brackish groundwater is generally less expensive than desalinating seawater (which has a TDS of 35,000 mg/L) or developing additional surface water supplies (McCann et al. 2018).

The USGS estimates that California's Central Valley and coastal basin aquifers contain substantial volumes of brackish groundwater at depths ranging from 50 to 1,500 feet below ground surface (Stanton et al. 2017), though more data is needed to better quantify this resource.

Next Steps for Improving the Understanding of HCMs and Basin Characteristics

The previous sections reviewed the state-of-the-science and available resources for developing the various components of HCMs and characterizing groundwater basins. In many cases, the available resources (maps, models, and tools) are out of date, inconsistent, not centralized, or do not reflect California's current groundwater conditions. To address existing information gaps and strengthen the foundation for effective groundwater management, DWR should consider taking

PUBLIC DRAFT

the following steps to improve understanding of critical components of HCMs and basin characteristics:

- Aquifers and Aquitards: Support GSAs through the continued development and refinement of HCMs that more accurately define the extent of water-bearing units.
- Distribution of Geologic Materials/Texture: Develop tools to support the integration of lithology logs and AEM data into the development of a comprehensive texture model.
- Aquifer Flow Parameters: Develop and maintain a centralized database of measured aquifer flow parameters to improve data accessibility, enable the consistent development of groundwater flow models, and support the refinement and enhancement of tools that estimate aquifer flow parameters (e.g., DWR's Texture2Par tool).
- Base of Freshwater: Coordinate with State and federal agencies to establish a TDS threshold for defining the base of freshwater.
- Bottom of Basin and Depth to Basement: Update delineation of the bottom of basin, depth to basement, and bedrock with additional existing and newly acquired data (e.g., AEM and e-logs).
- Basin Storage Capacity: Update the estimates for total, usable, and available basin storage capacity, starting with the Central Valley and subsequently expanding to all priority groundwater basins statewide.
- Groundwater Storage: Coordinate with local, State, and federal agencies to update the estimates of total groundwater storage and usable groundwater storage.
- Groundwater Recharge Pathways: Establish a standardized process and develop aquifer recharge potential maps across the state.
- Interconnected Surface Water: Provide guidance and information on how to define and quantify depletions of interconnected surface water to support effective groundwater management.
- Land Subsidence: Conduct technical studies to improve the understanding of the mechanics of land subsidence and support the development of management strategies that can reduce further land subsidence.
- Seawater Intrusion: Utilize existing water level, water quality, geologic, and geophysical data to determine the extent of seawater intrusion along coastal basins.

PUBLIC DRAFT

- Brackish Groundwater Resources: Coordinate with State and federal agencies to better define the volume of brackish groundwater available as a potential future water source.

DWR aims to address these recommendations through the implementation of the recently launched Basin Characterization Program, described below.

3.4.2 DWR's Basin Characterization Program

DWR has a long history of characterizing California's groundwater basins and subbasins through this publication and ongoing Basin Characterization Program efforts. DWR's Groundwater Basin Characterization Program (BC Program) builds on this historical role and provides the latest data and information to help local communities better understand and manage their groundwater basins. The BC Program supports the implementation of actions for a broad range of state and local water resource initiatives, including the Newsom administration's California's Water Supply Strategy, *Water Resilience Portfolio*, SGMA, California Water Plan, and efforts related to flood and drought response. The BC Program also aims to increase local, State, and federal coordination on various groundwater-related projects, including, but not limited to, groundwater recharge, modeling, watershed studies, water conveyance, and habitat restoration.

Under the Basin Characterization Program, DWR is conducting a series of statewide, regional, and local groundwater evaluations to improve the understanding of groundwater aquifer systems in various parts of the state. At the statewide scale, DWR completed the Statewide Airborne Electromagnetic (AEM) Survey Project in 2024, which provided an advanced geophysical dataset across the state's medium- to high-priority basins to improve the understanding of large-scale aquifer structures. At the local and regional scale, BC Program investigations may include the collection and digitization of new and existing data such as AEM, lithology logs, geophysical logs, aquifer tests, well construction information, and other relevant datasets. These data will be integrated and analyzed to create state-stewarded maps and models, which will be regularly updated as new data become available. These maps and models will describe the distribution of aquifer materials, aquifer structures, important aquifer units, and recharge pathways and will be updated and maintained by DWR. New tools and guidance will be created to integrate and analyze a wide range of data, including geologic, geophysical, and hydrogeologic information.

PUBLIC DRAFT

To support data access and data equity, all BC Program datasets, tools, maps, and models will be published on the California Natural Resources Agency (CNRA) Open Data website. Additionally, the BC Program will continue to develop new online GIS-based visualization tools to serve as a central hub for accessing and exploring groundwater-related data in California. These visualization tools will enable both the public and technical users to interact with the data in a 3D space, providing a more immersive and informative experience.

The following components are key elements of the Basin Characterization Program that will support local and regional groundwater management and enhance understanding of California's aquifer systems:

- **State-Stewarded Maps and Models:** Standardized, State-curated geologic and hydrogeologic maps and models that are updated regularly as new data become available to support consistent groundwater management across basins.
- **Data Collection and Digitization:** Systematic efforts to compile, digitize, and centralize new and existing datasets — including AEM surveys, lithology and geophysical logs, and well construction data — for easier integration and use.
- **Analysis Tools and Process Documents:** Development of tools and guidance documents to help users interpret complex groundwater data and support local technical studies and decision-making.
- **Basin Characterization Exchange:** A centralized, online platform for sharing BC Program datasets, tools, maps, and models, including advanced 3D visualization capabilities for public and technical users.

These components are discussed in detail below.

State-Stewarded Maps and Models

Maps and models that describe the physical properties and hydrogeologic conceptual models of California's aquifers are an important part of effectively managing the state's aquifer systems. They help groundwater managers understand how groundwater is stored and moves within the aquifer system. Several of these maps and models were initially developed in the 1970s and do not include decades of new data and conceptualization. Even models developed more recently often do not incorporate the newly acquired Statewide AEM Survey Project data or digitized lithology and geophysical logs data.

PUBLIC DRAFT

As part of the Basin Characterization Program, DWR will integrate new and existing data (using the data analysis tools described below) to update or develop these maps and models. The maps and models will be State-stewarded, meaning that they will be regularly updated as new data become available, ensuring that groundwater management activities are informed by the most up-to-date information. It is important that DWR coordinates with local, State, and federal agencies undertaking similar work to ensure that the developed maps and models are beneficial to multiple sectors and users. The maps and models that will be developed and stewarded by DWR under the BC Program are listed below:

- Groundwater Basin Hydrostratigraphic Models.
- Texture Models.
- Basin Storage Capacity Models.
- Base of Freshwater Maps.
- Bottom of Basin (Bedrock) Maps.
- Aquifer Recharge Potential Maps.

The development of these maps and models will initially focus on the Central Valley before expanding to other areas of the state. The maps and models will be published as they are developed, with first iterations expected between 2025 and 2027.

Data Collection and Digitization

As part of the Basin Characterization Program, DWR has expanded its historical data to include the collection and digitization of advanced geologic, hydrogeologic, and geophysical data. The BC Program's most notable data collection and digitization effort to date has been the Statewide AEM Survey Project. The Statewide AEM Survey Project provided foundational information about large-scale aquifer structures in California's groundwater basins. After completion of the Statewide AEM Survey Project in 2023, the BC Program expanded to include additional data collection and compilation through a series of local and regional investigations.

Data collection and digitization are major undertakings that require extensive planning, coordination, and resources. By leveraging economies of scale, DWR can conduct statewide efforts more efficiently and consistently than fragmented local efforts. These efforts support improved basin-scale understanding and

PUBLIC DRAFT

groundwater sustainability planning. Key components of DWR's expanded data initiatives under the Basin Characterization Program include:

- **Statewide AEM Survey Project:** A comprehensive airborne geophysical survey completed in 2023 that mapped large-scale aquifer structures across California's medium- and high-priority basins.
- **Preliminary Hydrogeologic Interpretations of Statewide AEM Survey Data:** Initial analyses and mapping derived from AEM data to characterize subsurface conditions and inform groundwater models.
- **Local and Regional Investigations:** Targeted studies conducted in specific basins or subregions to collect supplemental data and refine hydrogeologic understanding at finer spatial resolutions.
- **Data Digitization:** The systematic conversion of legacy and newly acquired geologic, hydrogeologic, and well data into digital formats to improve accessibility, integration, and analysis.

STATEWIDE AEM SURVEY PROJECT

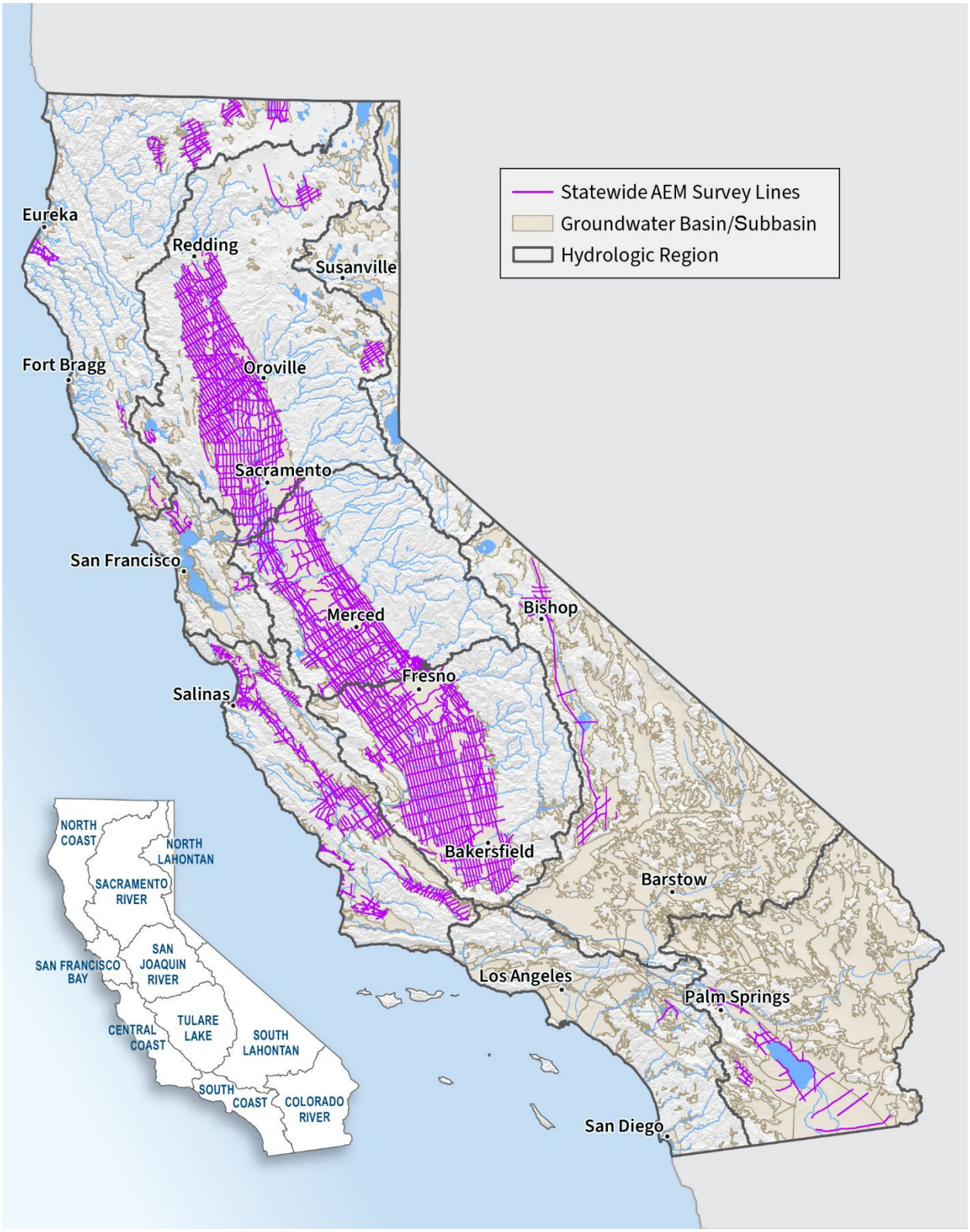
In 2018, California Proposition 68 was passed, which provided DWR with funding to launch the Statewide AEM Survey Project (AEM Project) to support the implementation of SGMA. The goal of the AEM Project was to improve the understanding of large-scale aquifer structures across the state's groundwater basins. Beginning in 2018 and continuing through 2020, three AEM pilot studies were conducted, led by Stanford University, to help determine the optimal workflow of AEM data collection and processing to inform the development of the AEM Project.

In 2021, the AEM Project kicked off the collection of advanced geophysical data in all high- and medium-priority groundwater basins, where data collection was feasible. The AEM Project data collection effort was completed in 2023, taking approximately two and a half years. The AEM Project provided the State with 16,000 miles of AEM data collected across 95 groundwater basins. To support data accessibility, all AEM Project data were published in a timely manner and DWR developed data visualization tools to allow the public to view the data online.

AEM data were collected in a reconnaissance grid with a line spacing of approximately 2 by 8 miles (Figure 3-18). The grid was defined to allow the maximum amount of data to be collected while capturing the geologic heterogeneity unique to California. Additionally, DWR coordinated closely with GSAs and with state and federal agencies to plan flight lines over areas of interest.

PUBLIC DRAFT

Figure 3-18 **Statewide AEM Survey Project Flight Lines**



Prior to starting the surveys, DWR undertook a robust outreach effort to ensure the public was aware of the surveys. This included meetings with GSAs, sending notification letters to parcel owners, social media announcements, and media advisories. DWR also kept the public informed of survey timelines through an online survey schedule.

AEM DATA COLLECTION AND INVERSION

The Statewide AEM Surveys were conducted during the spring and fall seasons of 2021 through 2023. AEM data collection consists of a helicopter towing a large loop, approximately 100 feet in diameter, containing geophysical equipment (Figure 3-19). During the AEM surveys, the helicopter flew at a groundspeed of 50 to 60 miles per hour carrying the equipment approximately 100 feet above the ground surface.

During an AEM measurement, an electric current is generated in the transmitter loop, which penetrates into the ground, and the response is measured. The AEM data are processed and inverted (Viezzoli et al. 2008) to provide a distribution of electrical resistivity values versus depth, where electrical resistivity describes the ability of a material to resist an electric current (Figure 3-20a).

The AEM method can measure electromagnetic properties to depths of up to 1,000 feet. The vertical resolution of the AEM method decreases with depth, with data having a higher resolution of approximately 7 feet in the shallow subsurface and the resolution decreasing to approximately 100 feet in the deeper subsurface. Consequently, while AEM surveys provide valuable large-scale insights into aquifer structure and geology, higher resolution characterization may require analysis of complementary ground-based methods, such as surface geophysics, borehole geophysics, or well logs.

PUBLIC DRAFT

Figure 3-19 Schematic of the SkyTEM AEM System

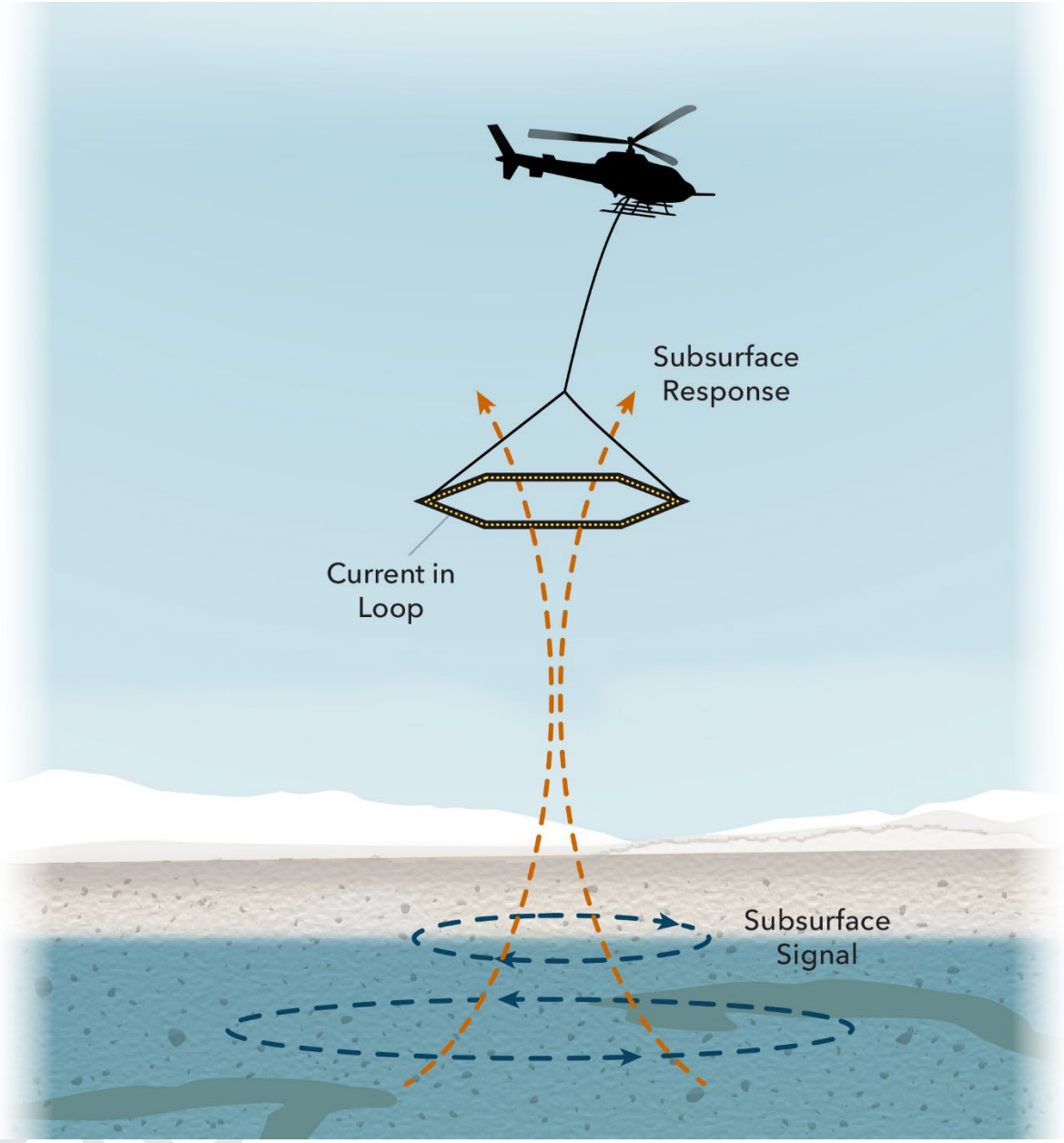


Figure 3-20 Example of (a) AEM Electrical Resistivity Cross Section, (b) AEM Coarse Fraction Cross Section, and (c) the Resistivity, lithology, and salinity relationship (modified from Palacky 1987; Behroozmand et al. 2022)

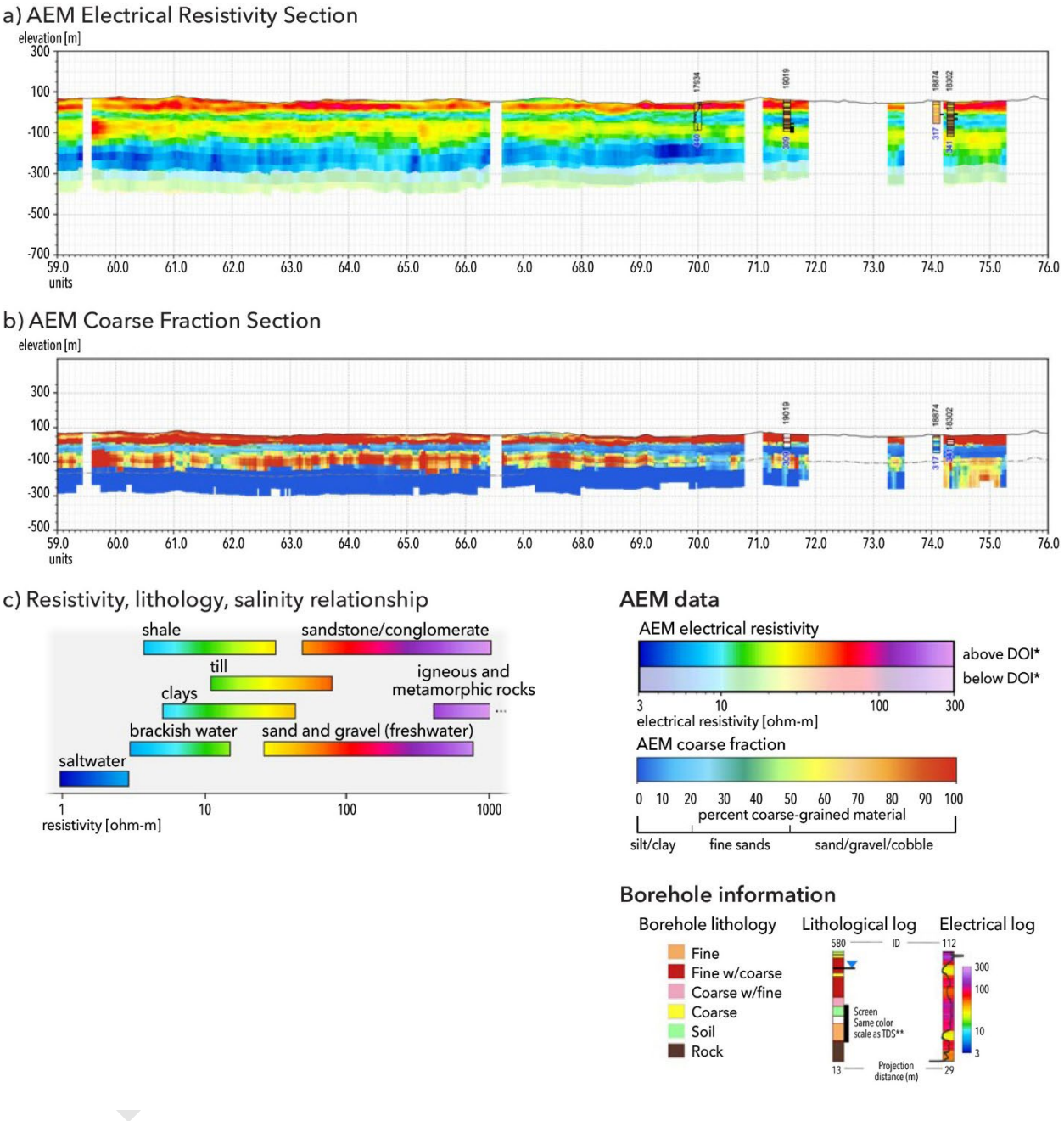


Figure 3-20 Notes: a) Example AEM dataset inverted for electrical resistivity. The profile shows elevation along the y axis and distance along the x axis. AEM data below the depth of investigation are translucent. b) Example AEM data interpretation for texture/percent coarse-grained material. c) Generalized relationship between electrical resistivity values and geologic material type.

AEM DATA INTERPRETATION

Collection of electromagnetic data can support mapping subsurface geology and aquifer properties because of the relationship between electrical resistivity and geologic properties (Palacky 1987) (Figure 3-20c). Materials that have low electrical resistivity values are typically interpreted as either fine-grained sediments, such as silts and clays, or as indicators of high salinity groundwater. Materials that have high electrical resistivity values are interpreted as coarse-grained materials, such as sands and gravels, crystalline or volcanic rock, or unsaturated materials. However, because there is a wide range of electrical resistivity values corresponding to a given material type, it is important to develop site-specific relationships between electrical resistivity values and lithology when interpreting AEM data.

In the Statewide AEM Survey Project, electrical resistivity data were interpreted to estimate the percentage of coarse-grained material (also referred to as *material texture*) (Figure 3-20b) using a modified Accumulated Clay Thickness approach (Christiansen et al. 2014; Foged et al. 2014). The approach utilized supporting datasets, including lithology logs, electrical resistivity logs, water quality, water levels, and local geology (Behroozmand et al. 2022). To support this process, two lithology logs and e-logs per Public Land Survey System square mile section along a survey flight line were compiled, quality-controlled (for location accuracy and lithology description), and digitized. Groundwater quality and groundwater level data were utilized in the interpretation only when the density and quality of data were sufficient.

Interpreting AEM data for percent coarse-grained material provides valuable insights for both the development of a texture model, often used in groundwater flow modeling, and identification of sites for groundwater recharge and hydrostratigraphic characterization. Aquifer zones dominated by coarse-grained materials (greater than 50% coarse-grained material) typically act as primary groundwater storage areas, where water can move more easily both horizontally (e.g., flowing into a pumping well) and vertically (e.g., percolating downward during groundwater recharge). Conversely, aquifer zones dominated by fine-grained materials (less than 20% coarse-grained material) generally act as barriers that inhibit or slow groundwater movement.

DIGITIZED SUPPORTING DATA

As a part of DWR's Statewide AEM Survey Project, lithology logs and geophysical logs were used to support the AEM data interpretation. The logging information, considered supporting data, was compiled from groundwater sustainability

PUBLIC DRAFT

agencies, counties, the Online System for Well Completion Reports (OSWCR), the California Geologic Energy Management Division (CalGEM) Well Finder, and the USGS.

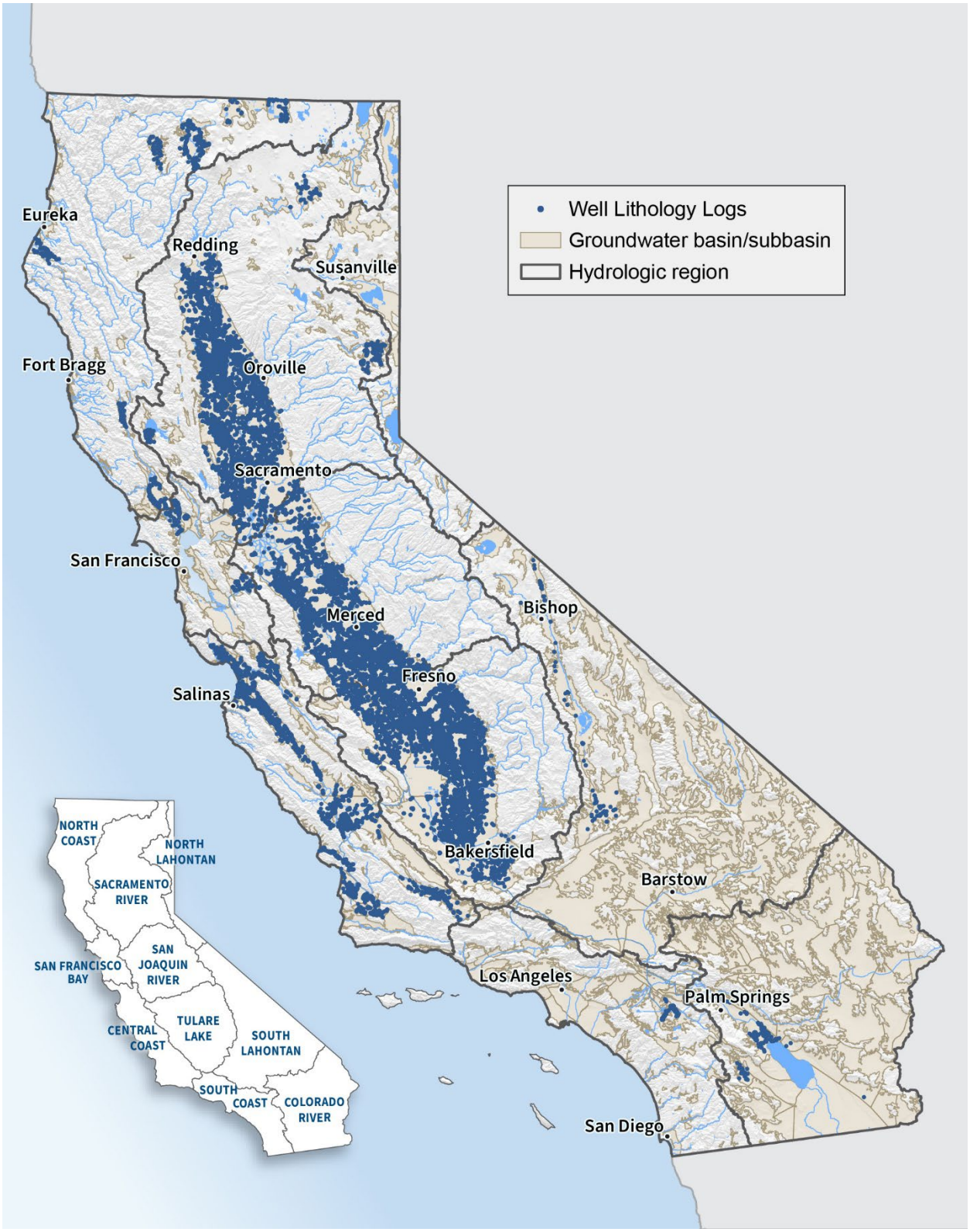
The supporting data were reviewed for quality to obtain two "best available" lithology logs per public land survey square mile section along an AEM survey flight line. The "best available" lithology logs were defined as logs with verified location accuracy of less than about 165 feet (50 meters) and with an average lithology description interval of less than about 100 feet (30 meters). If the lithology log was not in a digital format, the log was digitized and tabulated by transcribing the original lithology descriptions and categorized into the Unified Soil Classification System and texture classification.

The supporting data were also reviewed for quality to obtain all "best available" geophysical logs within a public land survey square mile section along an AEM survey flight line. The "best available" geophysical logs used were less than 40 years old and with an image quality that could be digitized. If the geophysical log was not in digital format, the electrical resistivity track of the geophysical log was digitized. Additional geophysical logs were purchased from a private company when available.

For the AEM Project, a total of 14,371 lithology logs and 1,186 geophysical logs were accurately located and determined to be "best available" data (Figure 3-21). Of those wells, a total of 6,036 lithology logs and 309 geophysical logs were digitized and 632 geophysical logs were purchased specifically for the AEM Project and are now available for public use.

PUBLIC DRAFT

Figure 3-21 Supporting Data Digitized as a Part of the Statewide AEM Survey Project



DATA ACCESS

All AEM data are publicly available on the California Natural Resources Agency Open Data Portal Statewide AEM Survey page and can also be viewed online through DWR's various data viewers. DWR's SGMA Data Viewer shows the AEM data displayed as sections along a survey line or as depth slice maps. The AEM 3D Viewer allows the user to view and interact with the AEM data and lithology logs in a 3D space. All digitized supporting data are also made publicly available and well locations and metadata can be viewed on DWR's Supporting Data Viewer.

PRELIMINARY HYDROGEOLOGIC INTERPRETATIONS OF STATEWIDE AEM SURVEY DATA

The AEM data from the Statewide AEM Surveys has dramatically increased the ability to visualize and analyze large-scale aquifer structures within California's priority groundwater basins. The section below provides preliminary hydrogeologic interpretations of the AEM electrical resistivity data and AEM percent coarse-grained material for various groundwater-related applications. The examples demonstrate how the AEM datasets can be used as a standalone product to improve the understanding of aquifer structure. A complete discussion of the preliminary hydrogeologic interpretations can be found in the 2024 issue of the California Geology Magazine.

Although a preliminary interpretation was conducted, complete hydrogeologic interpretations require the AEM data to be incorporated and analyzed alongside other existing datasets, which will be the focus of the next phase of DWR's Basin Characterization Program.

AEM-DEFINED TEXTURE MODEL FOR THE CENTRAL VALLEY AND COMPARISON TO ALLUVIAL FANS

The AEM interpretation for coarse-grained material can be utilized to develop a texture model, which describes the distribution of coarse-grained material in the aquifer. This newly available data and continued efforts to add additional datasets and analytical tools are advancing the understanding of basin characteristics. For example, the AEM data help illustrate how past depositional environments controlled the distribution of fine- and coarse-grained materials and aquifers within each basin. Figure 3-22a shows the AEM coarse-fraction profiles for the Central Valley. The texture varies with depth and a single location may have a distribution of both fine- and coarse-grained layers distributed in the subsurface.

Figure 3-22b shows the distribution of coarse-grained materials (50–100%) in the Central Valley. The San Joaquin River and Tulare Lake hydrologic regions contain a high percentage of coarse-grained materials, especially in the eastern and southern portions of the valley. In the Sacramento River Hydrologic Region, there

PUBLIC DRAFT

is an increase of coarse-grained materials along the northern and eastern portion of the valley. Generally, the source of coarse-grained materials along most of the eastern portion of the Central Valley is a combination of uplift, erosion, and glacial outwash from the Sierra Nevada in the central and southern areas and volcaniclastic sediments from the Cascade Mountains in the north (Marchand 1977; Lettis 1982; Weissman et al. 2002; Weissmann et al. 2005; Faunt et al. 2010). Figure 3-22c shows the distribution of fine-grained materials (0–20% coarse) in the Central Valley. The western portions of the Central Valley are dominated by fine-grained materials deposited in lacustrine and floodplain environments and derived from the Coast Range (Lettis 1982; Sarna-Wojcicki 1995; California Department of Water Resources 2014).

Figure 3-23 shows the average percent coarse-grained values within the top 50 feet for the San Joaquin Hydrologic Region along with the location of alluvial fans of glaciated and non-glaciated origin. Figure 3-15 provides a schematic showing the geologic stratigraphy typically associated with the alluvial fans in the San Joaquin Hydrologic Region. The high percentage of coarse-grained materials (50–100%) correlates well with the location of the alluvial fans of glaciated origin, and the AEM data will likely be a useful tool for mapping the extent and depth of alluvial fans. Unfortunately, AEM data were not collected in urban areas due to safety and data quality limitations, so the AEM data alone does not capture the full extent of the alluvial fans. Generally, the alluvial fans of glaciated origin show a higher concentration of coarse-grained materials, while alluvial fans of non-glaciated origin show a higher concentration of low- to medium-percentage coarse-grained materials (30–60%).

PUBLIC DRAFT

Figure 3-22 Texture Models of the Central Valley for (a) All Textures, (b) 50-100% Coarse-grained Materials, and (c) 0-20% Coarse-grained Materials

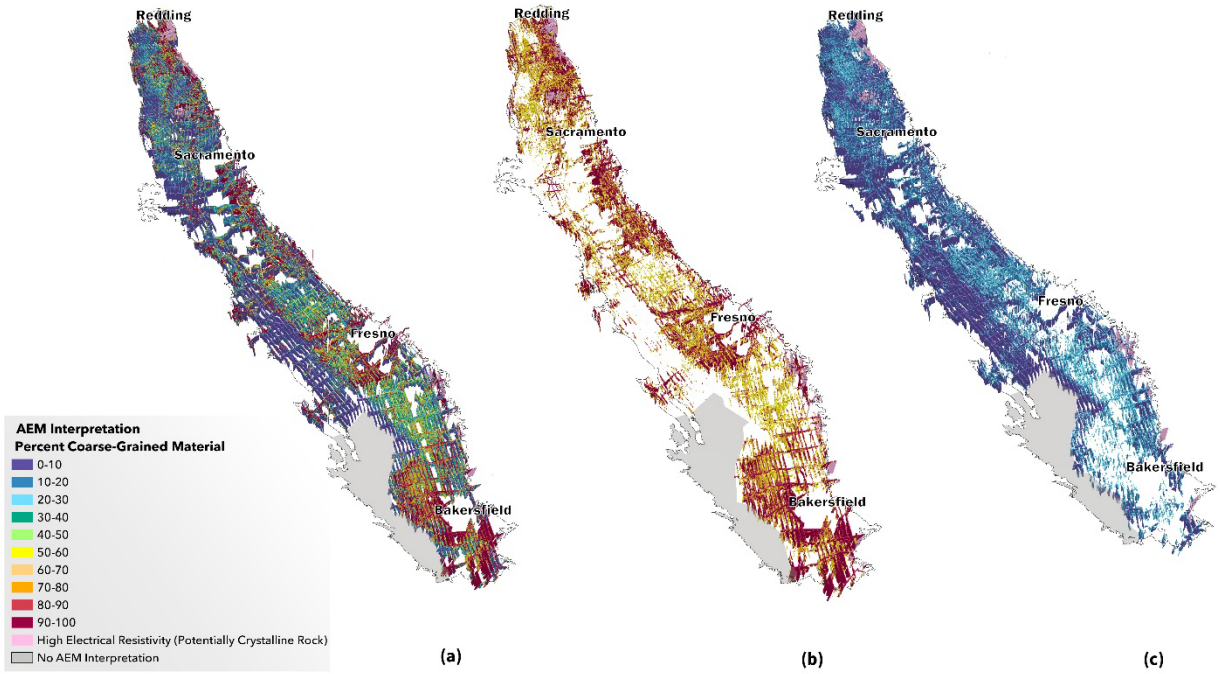
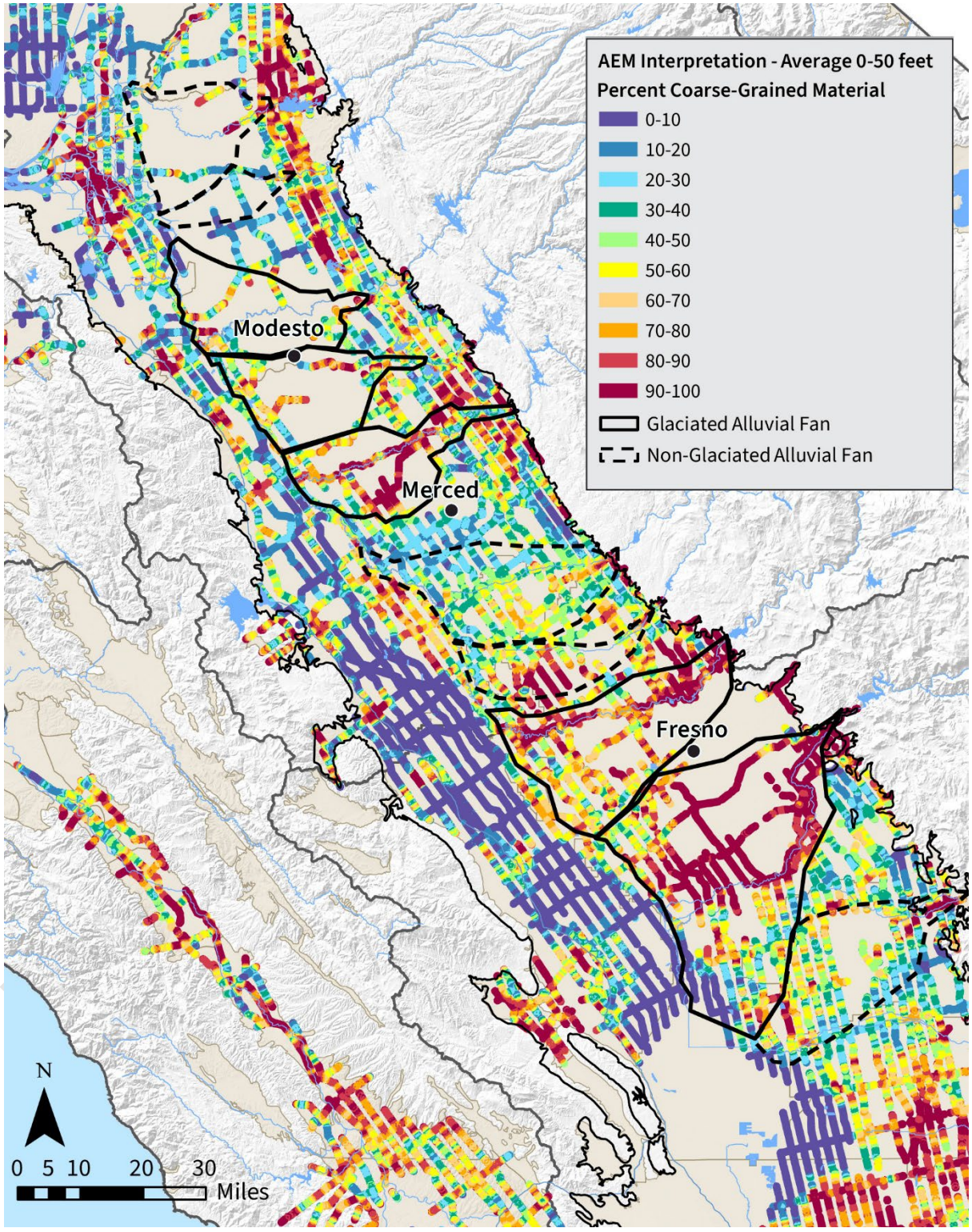


Figure 3-22 Notes: a) Fence diagram showing the AEM data interpretations as texture for the Central Valley. The distribution of percent coarse-grained material (i.e., texture) is interpreted to depths up to 350 meters (1,150 feet) in the Central Valley. The low percent coarse-grained material (e.g., silt/clay) are shown in blue, intermediate coarse-grained material (e.g., fine sands) are shown in light green and blue, and high percent coarse-grained material (e.g., sands and gravels) are shown in yellow, orange, and red. b) Fence diagram showing the distribution of the predominately coarse-grained materials (50–100%). c) Fence diagram showing the distribution of predominantly fine-grained materials (0–20% coarse grained). The AEM data can be further examined in detail (along with borehole lithology and texture) on the AEM 3D Viewer.

PUBLIC

Figure 3-23 Average percent Coarse Grained Materials from AEM Data Relative to Mapped Alluvial Fans (modified from Weissmann et al. 2005 and Faunt et al. 2024)



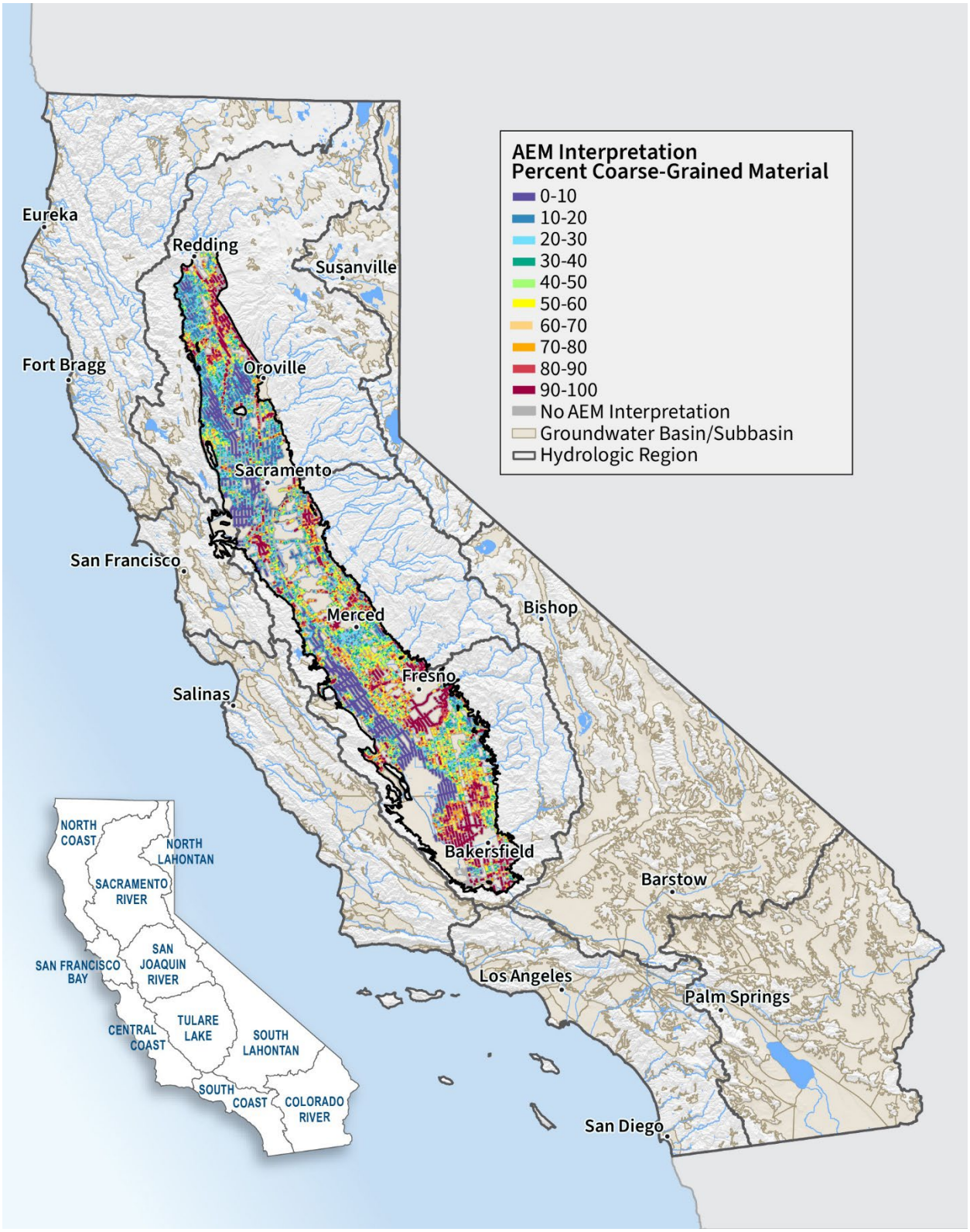
AEM-DEFINED SHALLOW GROUNDWATER RECHARGE MAP FOR THE CENTRAL VALLEY

Coarse-grained materials, like sands and gravels, can serve as pathways that allow water to travel from the ground surface into an aquifer in an effective and efficient manner. The texture information interpreted from AEM data can improve understanding of the shallow subsurface below the soil profile. This can identify where the subsurface is dominated by coarse-grained materials, helping groundwater managers better understand potential locations for groundwater recharge facilities. The texture data can support identifying both surficial groundwater recharge sites, where there is a pathway of coarse-grained dominated materials from the surface to the aquifer, and groundwater injection facilities (e.g., aquifer storage and recovery), where there is a large volume of coarse-grained material at depth that can store water.

Figure 3-24 shows the surficial groundwater recharge locations as interpreted from the AEM data. The map was developed by integrating the percent coarse values from the surface to a depth of 50 feet. The areas that have a high concentration of coarse-grained materials (>60% coarse) are shown in red and orange and may be good locations for conducting surficial groundwater recharge operations. Areas that have a high concentration of fine-grained materials (<20% coarse) are shown in blue and are likely not prime locations for conducting surficial groundwater recharge operations. Note that this map is limited to the resolution of the AEM data and local studies may show areas to be more or less conducive to groundwater recharge than indicated by this regional study.

PUBLIC DRAFT

Figure 3-24 Surficial Groundwater Recharge Map (from AEM data)



The surficial groundwater recharge map was compared to the University of California, Davis, Sand Soil Map (Walkinshaw et al. 2023). Although there was agreement between the maps in some areas (e.g., along river corridors and alluvial fans) there were differences in several areas. This is because the Sand Soil Map only examined approximately the top 6.6 feet (2 meters) of the subsurface while the surficial groundwater recharge map shows the average conditions within the top 50 feet. The surficial groundwater recharge map was also compared to the California Geologic Survey map of surficial geology (Jennings et al. 1977). The surficial groundwater recharge map shows a significant increase in hydrogeologic information compared to the surficial geologic map, which maps only the extent of the Quaternary Alluvium as exposed at the ground surface. The surficial groundwater recharge map was also compared to the USGS CVHM2 texture model. There is generally a good correlation between the texture model (top layer) and the surficial groundwater recharge map, although the surficial groundwater recharge map provides increased resolution and shows more areas that appear to have good groundwater recharge potential.

LOCATIONS OF POTENTIALLY HIGH-SALINITY GROUNDWATER

In some cases, the AEM method can be used to determine the location of high salinity groundwater because high salinity fluids have a very low electrical resistivity signature that dominates the signal over the geologic material type (Figure 3-20c). For example, a geologic material, like sand, saturated with freshwater will have a different electrical resistivity signal than the same material saturated with saline water. Therefore, the AEM method can be used to support defining areas with seawater intrusion, brackish water (from oil and gas production), and the base of freshwater (Geobel et al. 2019; Ball et al. 2020; Gottschalk et al. 2020; Ball et al. 2023). It is critical to incorporate water quality information, where available, into the interpretation of AEM data for high salinity waters because silts and clays also have low electrical resistivity values and, therefore, may be misidentified.

Seawater intrusion may occur along coastal aquifers and typically takes the shape of a seawater wedge (Figure 3-17). Figure 3-25 shows a 3D view of the AEM data from the Monterey Bay area. The area in purple shows where a resistivity-to-lithology transform could not be developed due to the presence of very low electrical resistivity values. These areas with very low electrical resistivity values show a similar wedge shape indicative of seawater (Figure 3-17) and suggest this area may contain high salinity water, which agrees with the known seawater intrusion in the Monterey Bay area (see Chapter 6, "Groundwater Conditions").

PUBLIC DRAFT

Accurate interpretation of AEM data for seawater intrusion requires a high density of water quality estimates in wells with known screen intervals, which were not available at the time of the AEM Project. Therefore, AEM data were not interpreted for seawater intrusion as part of the Statewide AEM Surveys. However, the results show promise for future efforts to evaluate seawater intrusion.

Figure 3-25 AEM Data Interpretation for the Monterey Bay Area

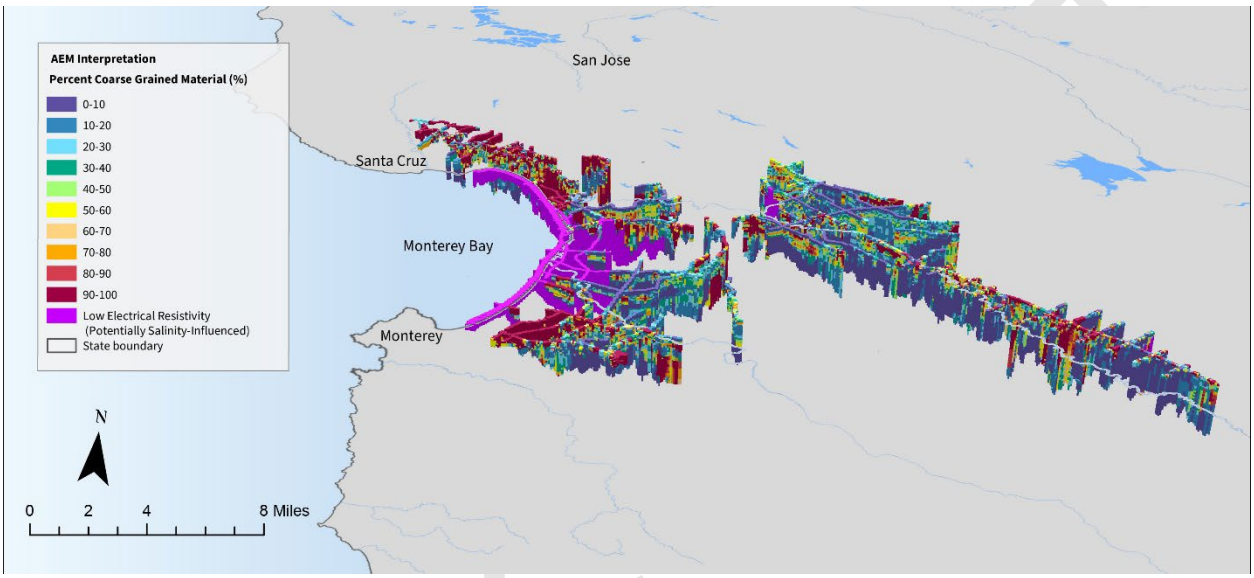


Figure 3-25 Note: The area adjacent to Monterey Bay shows very low electrical resistivity values (in purple) that may correlate to the presence of high salinity groundwater.

LOCAL AND REGIONAL INVESTIGATIONS

Under the Basin Characterization Program, DWR will also be collecting and analyzing data through a series of local and regional investigations to support SGMA implementation initiatives and fill data gaps. The groundwater investigations will include the collection of additional data based on a review of the Statewide AEM Survey Project data and local SGMA implementation initiatives, like groundwater recharge, surface water-groundwater interaction, subsidence, vulnerable domestic wells, disadvantaged communities, seawater intrusion, base of fresh water, etc. Additional data collection methods may include infill AEM, surface-based geophysics (i.e., towed electromagnetic methods [tTEM] or surface water electromagnetic methods [floaTEM]), advanced geophysical logging (i.e., nuclear magnetic resonance (NMR) logging or e-logging), installing new wells or reactivating existing wells, etc. The BC Program will also coordinate with other DWR programs, like Technical Support Services and California's Groundwater Monitoring, for additional data collection methods (e.g., extensometers, water quality testing, aquifer tests, infiltration tests, etc.).

PUBLIC DRAFT

By conducting these groundwater basin investigations and incorporating recently acquired data, the BC Program aims to develop documents that will help GSAs and local communities better evaluate groundwater resources and address their groundwater-related concerns and questions. The sections below highlight two local investigations that are underway, with results that will be published and shared in future semi-annual or periodic updates to California's Groundwater.

LOCAL INVESTIGATION: MADERA AND NORTH KINGS

The Madera and North Kings Local Investigation focuses on providing information to support floodplain habitat restoration, surface water-groundwater interaction, groundwater recharge, and domestic well assistance activities. The area of interest is located within the Kings and Madera subbasins and concentrated on the eastern side of the San Joaquin Valley, between the Upper San Joaquin and Fresno rivers. The goal of the investigation is to aid GSAs in determining locations for deep recharge (to replenish water into the main producing zone of the aquifer), shallow recharge (to provide water for vulnerable shallow domestic wells), and support floodplain restoration. To achieve the investigation's goals, DWR examined the Statewide AEM Survey Project data, collected infill AEM survey data, and conducted focused ground-based surveys at potential groundwater recharge sites. Results and analyses from the surveys are described in POPOUT 1.

To support defining potential groundwater recharge locations, a high-resolution texture model was created that integrated all existing AEM and lithology log information. The texture model was then analyzed along with other relevant data to develop Aquifer Recharge Potential Maps for the area, described in POPOUT 2.

LOCAL INVESTIGATION: PAJARO

The Pajaro Local Investigation focuses on providing information to support floodplain habitat restoration, levee setbacks, surface water-groundwater interaction, and groundwater recharge. The area of interest is situated within the Pajaro Subbasin at various locations along the Pajaro River and Salsipuedes Creek and at current and potential recharge sites. The goal of the investigation is to aid DWR, the GSA, local flood control agencies, the United States Army Corps of Engineers, and academia in better understanding the composition of materials in the shallow subsurface for reuse in levee setbacks or to assess recharge potential. To achieve the investigation goals, DWR conducted high-resolution tTEM surveys and interpreted the data for material texture.

PUBLIC DRAFT

REGIONAL INVESTIGATIONS

DWR plans to undertake a series of regional investigations to improve the understanding of aquifer recharge potential and subsidence potential in the Sacramento and San Joaquin valleys. These investigations will be conducted in coordination with local, State, and federal agencies with interest and expertise in each region. Information regarding regional investigations will be published in future updates to California's Groundwater.

DATA DIGITIZATION

To support the development of state-stewarded maps and models, the BC Program will continue and expand its efforts to digitize existing lithologic and geophysical logging data. All data to be digitized will go through a quality control process to determine (1) accurate well locations (within 164 feet [50 meters]) and (2) high-quality descriptions. All digitized lithology and geophysical logging data will be made publicly available and will be imported back into the original database (when applicable).

Analysis Tools and Process Documents

To support the development of the State-stewarded maps and models outlined above, new tools will be created to integrate and analyze a wide range of data, including geologic, geophysical, and hydrogeologic information. By combining and assessing various datasets, these tools will help create a more complete picture of California's groundwater basins. All tools and associated documentation will be made publicly available for GSAs to use to support the development of local maps and models. The tools listed below will be made available through the CNRA Basin Characterization, Data Analysis Tools and Process Documents landing page.

A brief description of the following tools is provided below:

- Data2Texture.
- Data2HSM.
- Texture2Par.

In addition, a detailed description of the aquifer recharge potential mapping analysis is included after the description of these tools.

DATA2TEXTURE

The Data2Texture tool is an advanced spatial data interpolation tool for estimating the distribution of sediment textures. The role of the Data2Texture tool is to integrate different types of subsurface data and interpolate it into the model

PUBLIC DRAFT

space. Data that can be integrated into the analysis includes boring logs, AEM-based texture data, NMR/e-logs, or any data related to sediment texture. The primary way of combining and interpolating all this data is through ordinary cokriging, a geostatistical spatial analysis that calculates a potentially anisotropic weighted moving average of point data using a variogram. By interpolating point data without enforcing hydrostratigraphic units, the tool can produce an initial 2D or 3D texture model revealing large-scale patterns and correlative relationships.

DATA2HSM

The Data2HSM suite of tools utilizes a variety of machine learning and neural network analyses to develop a hydrostratigraphic model (HSM) from AEM data, lithology logs, geophysical logs, and/or texture models. The Data2HSM suite of tools allows the user to choose between three analysis processes that can be used individually or in series: Smart Interpretation (SI), Gaussian Mixture Model (GMM), and Geological Pseudolabel Deep Neural Network (GeoPDNN).

Advancements in machine learning tools allow for the automation and enhancement of hydrogeologic modeling from AEM data. SI is a semi-automatic tool that reduces manual effort by training a regression model to delineate hydrostratigraphic surfaces based on a limited set of user-selected points. The GMM is an unsupervised classification tool that groups AEM data into user-defined clusters, representing stratigraphic units, while applying a stratigraphic coordinate transformation to maintain geologic continuity. The GeoPDNN is a semi-supervised tool that integrates point-based datasets into realistic stratigraphic surfaces using a neural network, which can also be applied to mapping features such as the water table, base of freshwater, or top of bedrock. These tools streamline hydrostratigraphic modeling, improving efficiency, accuracy, and automation in groundwater analysis.

TEXTURE2PAR

Texture2Par (current version 1.0) is a tool developed to work with the IWFM and MODFLOW groundwater flow modelling code. It processes texture data to estimate important hydraulic parameters like hydraulic conductivity, specific yield, and specific storage. The upcoming version 2.0, available late 2025, will include the incorporation of AEM data and the 3D texture model developed with Data2Texture.

AQUIFER RECHARGE POTENTIAL MAPPING PROCESS DOCUMENT

The Aquifer Recharge Potential (ARP) mapping analysis produces maps that are intended to be a screening tool to identify locations that have relatively higher potential for managed aquifer recharge (MAR). The ARP analysis integrates

PUBLIC DRAFT

multiple subsurface properties and analyzes them together as a proxy to understanding infiltration rates, aquifer connectivity pathways, and water storage capacity. Different ARP map types can be developed for various MAR methods, including surface spreading, on-farm recharge, recharge basins, dry wells (gravity-fed pits), and aquifer storage and recovery (ASR).

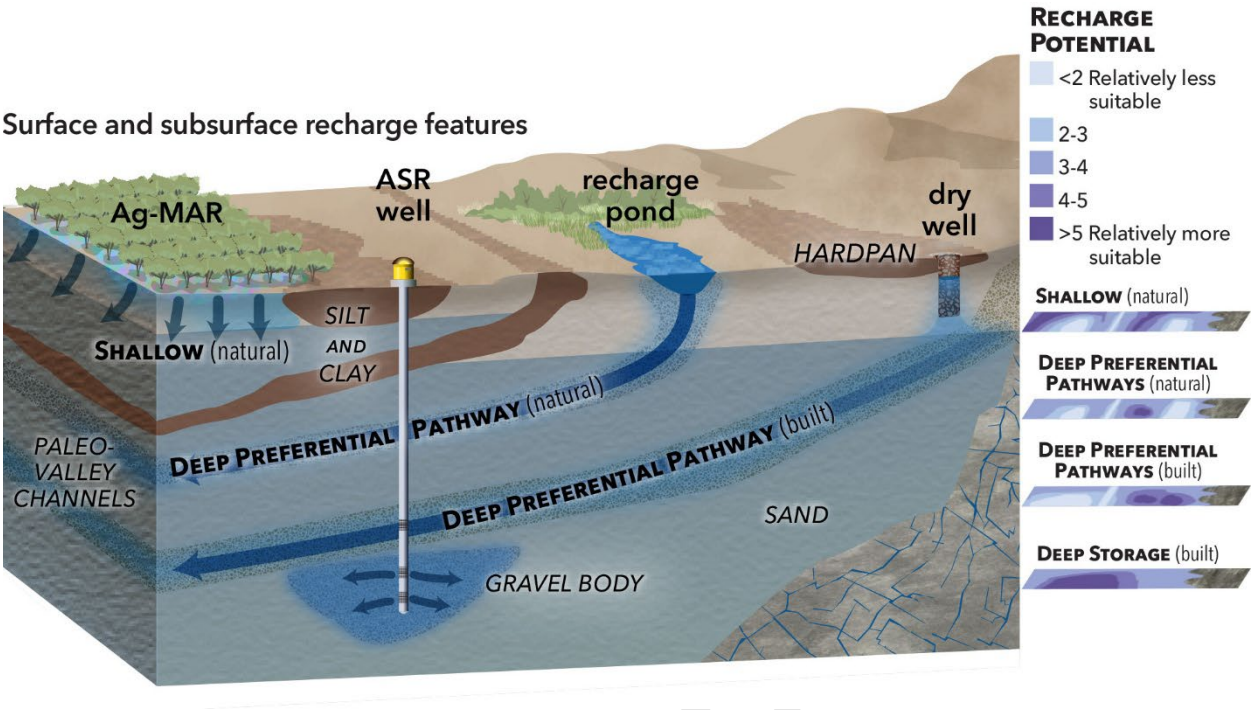
The ARP analysis incorporates subsurface properties that can be used as a proxy for infiltration rates and the ability to store larger volumes of water in the subsurface. The ARP analysis produces a series of maps that describe groundwater recharge infiltration pathways for a variety of goals. The ARP map types are: Shallow (Natural), Deep Preferential Pathways (Natural), and Deep Preferential Pathways (Built) (See Popout 2 for example ARP maps). The infiltration type, recharge goal, and recharge method for each ARP map are described in Table 3-2. The aquifer recharge potential flow paths for various methods and associated aquifer recharge potential maps are shown in Figure 3-26.

Table 3-2 Aquifer Recharge Potential Map Types

ARP Map	Shallow (Natural)	Deep Preferential Pathways (Natural)	Deep Preferential Pathways (Built)
Infiltration Type	Pathways from the surface to the shallow portion of the aquifer	Pathways from the surface to the deep portion of the aquifer	Pathways from the surface to the deep portion of the aquifer
Infiltration Type	Through soil layer	Through soil layer	Bypassing soil layer
Recharge Goal	Flood control, shallow groundwater well supply, habitat restoration	Flood control, deep groundwater well supply, mitigate subsidence	Deep groundwater well supply, mitigate subsidence
Recharge Methods	Ag-MAR, surface water spreading, managed natural lands	Minimally developed groundwater recharge facilities, Ag-MAR, surface water spreading	Dedicated groundwater recharge facilities, dry wells

PUBLIC DRAFT

Figure 3-26 Hydrogeologic Conceptual Model of the Subsurface, Aquifer Recharge Potential Types, and Associated ARP Maps



The ARP mapping process considers several parameters, including soil conditions, groundwater levels, and aquifer texture. These parameters are divided into the following five sub-indices that represent conditions more suitable or less suitable for MAR:

- Soil conditions.
- Depth to groundwater.
- Depth to shallow fine-grained layer.
- Shallow sediment texture.
- Interconnected coarse bodies.

Each sub-index describes a range of considerations for MAR, from near-surface conditions (e.g., soil hydraulic conductivity) to subsurface conditions (e.g., access to subsurface flow pathways and sediment coarseness). After sub-indices are gathered, they are grouped and weighted based on their relative importance to recharge and applicability to the recharge method. A list of sub-indices, along with their purpose, data source, and binning criteria is included in Table 3-3. ARP maps that were developed for the Madera and North Kings Local Investigation are provided in POPOUT 2.

PUBLIC

Table 3-3 Summary of Sub-Indices Description, Data Source, and Binning Criteria for Each ARP Map Type

	Soil Conditions Sub-Index	Depth to Groundwater Sub-Index	Depth to Shallow Fine-Grained Layer Sub-Index	Shallow Sediment Coarseness Sub-Index	Interconnected Coarse Bodies Sub-Index
Description	Soil and surface conditions	Recent spring depth to groundwater	Depth to clay layer that may inhibit infiltration	Infiltration potential in shallow subsurface (top 50 feet)	Sand and gravel channels (e.g., paleo-valleys or incised valley fills)
Purpose	Infiltration capacity through surface soils	Storage capacity and management objectives	Percolation efficiency	Shallow percolation efficiency and storage capacity	Efficient percolation pathways to deeper aquifer
Data Source	California Soil Resource Lab at UC Davis and UC Agriculture and Natural Resources	Groundwater level data	3D subsurface texture model	3D subsurface texture model	3D subsurface texture model
Grouping Criteria	SAGBI score (unitless)	Depth to water from ground surface (feet)	Depth to clay from ground surface (feet)	Percent that is classified as coarse material (%)	Range of percent coarse values (%)

PUBLIC DRAFT

Basin Characterization Exchange

The Basin Characterization Program launched the Basin Characterization Exchange (BCX) in early 2025 as a public meeting series and networking platform for the basin characterization community to exchange technical information and project details, share case studies and lessons learned, define and develop needed guidance, and highlight future research topics. The BCX also plays a pivotal role in advancing the goals and activities of the BC Program. BCX meetings include regular program updates, and participants have early opportunities to test data

analysis tools and submit comments on draft documents. The BCX is open to local, State, and federal agencies, consultants, NGOs, academia, and interested parties who participate in basin characterization efforts.

POPOUTS

POPOUT 1: MADERA AND NORTH KINGS LOCAL INVESTIGATION: AEM DATA INTERPRETATION AND INCISED VALLEY FILL IDENTIFICATION

The percent coarse data from the Statewide AEM Survey Project in this area shows good agreement with the non-glaciated alluvial fans to the north of the San Joaquin River and the glaciated San Joaquin River alluvial fan (Figure 3-27a) (Weissmann et al. 2005; Faunt et al. 2010). In addition to the alluvial fans, DWR also identified several areas of coarse-grained materials outside of the alluvial fans, on the eastern side of the San Joaquin Valley. These areas of coarse-grained material, both within and outside of the alluvial fans, could serve as new locations for groundwater recharge, where deeper alluvial fan materials are connected to the surface. The infill AEM flight lines were developed to provide additional resolution to the Statewide AEM Survey reconnaissance flight lines with a goal of providing insight into these coarse-grained dominated recharge locations (Figure 3-27a). The infill AEM data were collected in spring 2023 using advanced AEM data collection methodologies to improve the vertical and horizontal resolution of the data (Gottschalk et al. 2024).

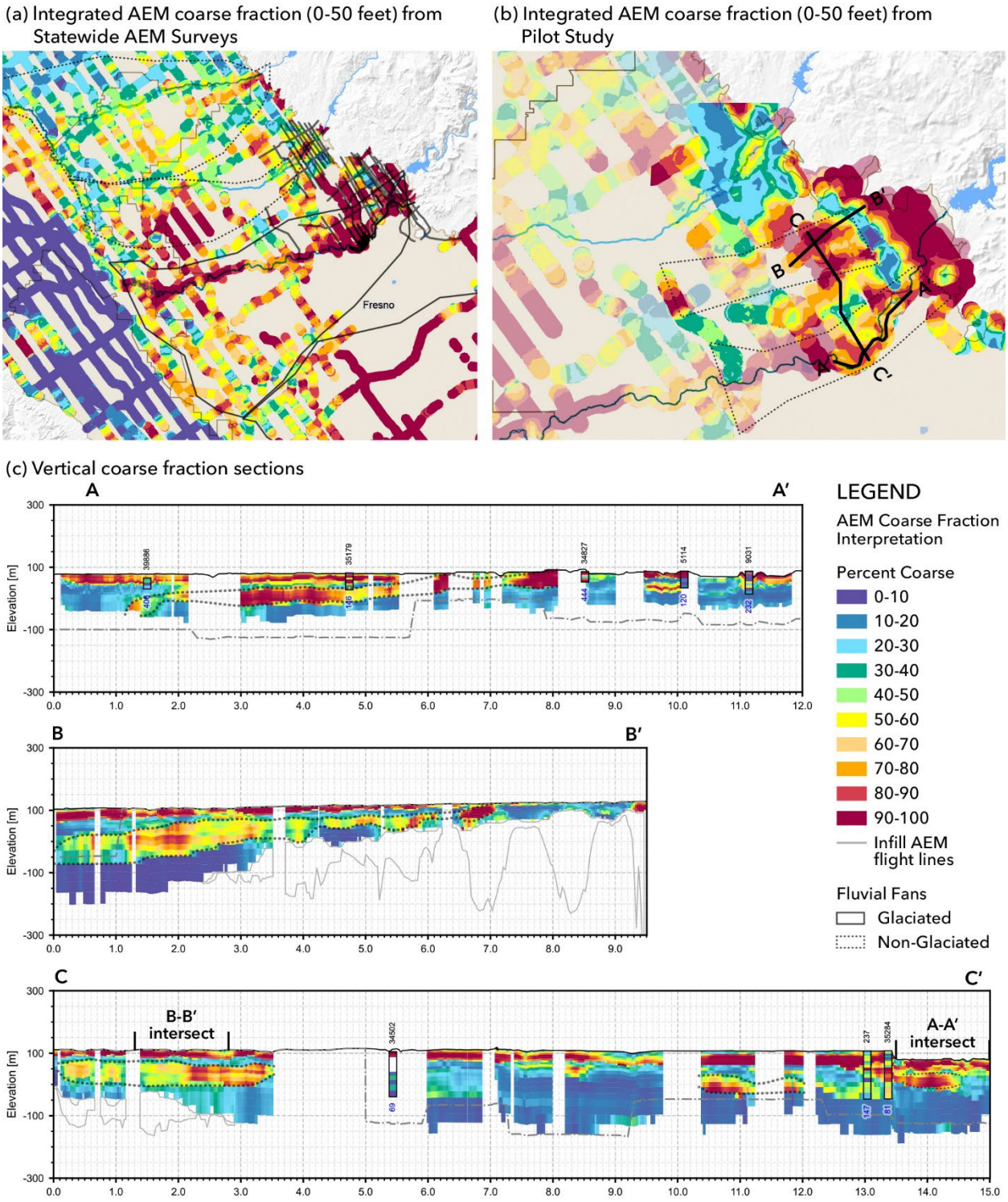
Preliminary results of the infill AEM data show good correlation with the Statewide AEM Survey data and show areas of coarse-grained dominated materials in the top 50 feet (Figure 3-27b). Figure 3-27c shows select vertical percent coarse sections in an east-west direction (A–A’ and B–B’) and north-south direction (C–C’).

The east-west vertical sections of AEM-derived percent coarse data highlight the coarse-grained dominated pathways from the surface to deeper aquifer units (A–A’ and B–B’ in dashed lines). This coarse-grained dominated, down sloping unit is consistent with the coarse-grained dominated channel geometry that would be expected in an incised valley fill (IVF) deposit within an alluvial geologic setting as shown in Figure 3-15. An IVF is a fluvial geologic feature in an alluvial fan where channels are incised into the surrounding geologic material and subsequently filled with predominantly coarse-grained materials.

The north-south vertical section of the AEM-derived percent coarse data highlights the coarse-grained dominated crescent shaped buried IVF channels (C–C’ in dashed lines). This coarse-grained dominated crescent shape is consistent with the expected cross-section of an IVF deposit.

PUBLIC DRAFT

Figure 3-27 Integrated percent coarse values from the surface down to 50 feet deep derived from (a) Statewide AEM Survey Project data and (b) Local Investigation infill AEM data (c) Vertical coarse-fraction sections identifying potential incised valley fill units



Analysis of the plan view and vertical sections suggest the possible location of two IVF deposits (Figure 3-27b). Using AEM data to determine the location of potential IVF deposits was also highlighted in Knight et al. 2022. These potential IVF locations may provide a direct pathway to get water from the surface into a deeper aquifer system quickly, hence supporting effective and efficient groundwater recharge and overall sustainable groundwater management.

POPOUT 2: MADERA AND NORTH KINGS LOCAL INVESTIGATION: TEXTURE MODEL AND AQUIFER RECHARGE POTENTIAL MAPS

An updated, high resolution texture model and aquifer recharge potential maps were developed as part of the Madera and North Kings Local Investigation. The AEM infill and Statewide AEM Survey Project data (shown in Popout 1) were combined with digitized lithology logs and analyzed using the Data2Texture tool to develop a high-resolution, three-dimensional texture model of the subsurface.

The 3D texture model was integrated along with groundwater levels and soil conditions (from SAGBI) using the Aquifer Recharge Potential mapping process to develop the Aquifer Recharge Potential maps (Figure 3-28). The maps show the areas where aquifer conditions are best suited for shallow recharge (Figure 3-28a) and where there are pathways to deeper sections of the aquifer through soils (Figure 3-28b) and bypassing soils (Figure 3-28c).

PUBLIC DRAFT

Figure 3-28 Aquifer Recharge Potential Maps for the Upper San Joaquin River Local Investigation Area for Shallow (Natural), Deep Preferential Pathways (Natural), and Deep Preferential Pathways (Built) Map Types



Figure 3-28 Note: ARP values range from 0 to 6 (light to dark blue) with higher ARP values corresponding to locations with higher recharge potential.

3.4.3 Other Basin Characterization Efforts in California

Numerous efforts are underway within DWR and at State, local, and federal agencies to improve the understanding of California's groundwater basins. This section highlights a select number of basin characterization mapping efforts in California, aside from DWR's Basin Characterization Program described above.

Additionally, modeling efforts incorporate aspects of basin characterization as part of Hydrogeologic Conceptual Model (HCM) development and numerical modeling, primarily focusing on water budget analysis rather than basin characterization. Since basin characterization is not the primary objective of these models, they are not discussed in this section but are briefly covered in Chapter 4, "Groundwater Use, Extraction, and Water Budgets."

California Geological Survey

3D GEOLOGIC MODELING

In 2021, the California Geological Survey (CGS) began development of a multi-benefit 3D geologic framework mapping pilot project (3D Geo) to support sustainable groundwater management, seismic hazard mitigation, carbon sequestration, and mineral resource evaluations. The pilot project was a 3-year effort focused on the southern San Joaquin Valley. The project was developed based on the needs of GSAs and data availability, density, and quality required for 3D geologic mapping and modeling. The 3D Geo pilot project aimed to produce a regional block model of geologic formations with updated 3D fault mapping, including focused models of notable aquifers and potential carbon storage reservoirs, and a web map with searchable and downloadable data products.

United States Geological Survey

The United States Geological Survey (USGS) undertakes local, statewide, regional, and national efforts to map and characterize geologic, geophysical, geochemical, hydrogeologic, and hydrologic conditions across the United States. In addition, the USGS develops numerical tools, such as numerical flow models, as well as hydrologic, geologic, geophysical, and geochemical methods to help local, State, and federal agencies. Their work benefits multiple sectors including groundwater and mineral resources, as well as ecosystems, land use, natural hazards, and geologic mapping.

The USGS California Water Science Center (CAWSC) focuses their efforts in California and leads several efforts to improve the understanding of groundwater conditions, hydrogeologic characterization, and integrated hydrologic modeling in California's watersheds and groundwater basins.

Three of the USGS's programs related to basin characterization are highlighted below.

CALIFORNIA OIL, GAS, AND GROUNDWATER PROGRAM

The USGS's California Oil, Gas, and Groundwater (COGG) Program, in cooperation with the California State Water Resources Control Board, focuses on understanding potential risks to groundwater quality from oil and gas development and operations. To characterize groundwater quality effects, the COGG program uses geochemical principles to determine whether constituents found in groundwater samples may come from oil and gas sources and which pathways are likely responsible for fluid migration. To support that effort, the COGG Program

PUBLIC DRAFT

undertakes salinity and geologic mapping, important components to understanding the location of groundwater resources and fluid flow mechanics. Work completed to support salinity and geologic mapping include digitizing geophysical well data, collecting airborne electromagnetic (AEM) data, drilling wells, monitoring groundwater levels, collecting groundwater quality samples, and developing 3D geologic framework models.

The COGG Program's study areas are primarily located within alluvial groundwater basins that have historical or functioning oil and gas operations, generally in the Tulare Lake, Central Coast, and South Coast hydrologic regions.

EARTH MRI

The USGS's Earth MRI Program is a national program that aims to improve the understanding of the geologic framework in the United States and to enhance the understanding of the distribution of domestic critical mineral resources. As a part of the Earth MRI Program, geophysical and LiDAR (topographic) surveys are conducted and integrated to create state-of-the-art geologic maps. While the program focuses on critical mineral resources, many of the datasets can also be utilized to support improving the understanding of basin structure, which supports basin characterization. Below are links to the USGS's Earth MRI surveys conducted within California (map of Earth MRI project areas):

- Geophysical Surveys
    - Hyperspectral mapping of the Southwestern US.
    - Southeast Mojave Airborne Magnetic and Radiometric Surveys.
    - Western Mojave AEM and Magnetic Surveys.
    - Salton Sea GeoFlight Magnetic and Radiometric Surveys.
    - Mountain Pass Airborne Magnetic and Radiometric Surveys.
- Lidar Elevation Mapping (3D Elevation Program)
    - Imperial, Riverside, and San Diego Counties.
    - Kern, Riverside, and San Bernardino Counties.
    - FEMA Levee in California.

GEOLOGIC MAPPING

The USGS National Cooperative Geologic Mapping Program studies geologic processes through geologic mapping, regional analyses, detailed gravity and aeromagnetic surveys, and multi-dimensional geologic models. Under this

PUBLIC DRAFT

program, the Western Basin and Range — Eastern California Shear Zone project and Geologic Mapping in the Southern Pacific Border and Sierras Provinces, California project combined surficial and bedrock geologic mapping, geophysical surveys, and high-resolution topographic data analysis with tectonic, geomorphic, structural, volcanic, and geochronologic studies to better understand the framework and evolution of the Mojave Desert region, San Francisco Bay Delta, and basins in central and northern California. This work is relevant to understanding the distribution and geometry of groundwater basins and faults/folds that may influence groundwater flow, as well as providing new detailed geologic mapping useful for hydrogeologic framework studies.

3.5 Non-Basin Areas

Any area outside a defined groundwater basin or subbasin is considered a non-basin area. Non-basin areas consist of impermeable granitic, metamorphic, volcanic, or consolidated sedimentary rocks, with groundwater stored within fractures or other voids produced after the rocks were formed.

Over millions of years, California's non-basin areas — composed of mountains, hills and some valleys — eroded to provide the sediments deposited in low-lying areas and depressions to form the modern-day alluvial groundwater basins. At the same time, fractured rock in non-basin areas has undergone local and regional-scale faulting, fracturing, and weathering, allowing surface water and precipitation to infiltrate into rock fractures and eventually reach the groundwater table. A significant portion of groundwater in non-basin areas eventually flows downgradient to join surface water streams as baseflow or emerges as springs or seeps. This hydraulic connectivity between precipitation, surface water, and groundwater links fractured rock non-basin areas to alluvial groundwater basins (Belitz et al. 2019; Armengol et al. 2024). Although groundwater in non-basin areas may not be as accessible or quantifiable as groundwater in alluvial basins, non-basin area groundwater plays an important role in the state's hydrology.

Non-basin areas support a wide range of beneficial uses and users, including rivers, streams, springs, forests, meadows, native vegetation, groundwater dependent ecosystems, wildlife such as insects, fish, birds, and mammals, as well as human communities. Water users in these areas include individual households, municipal and small community water systems, public utilities, commercial and industrial operations, and land-based industries such as agriculture and timber. The 2019–2021 average annual groundwater use in non-basin areas accounts for about 7% of the state's groundwater use (see Chapter 4, "Groundwater Use,

PUBLIC DRAFT

Extraction, and Water Budgets"). Although this use is significantly lower than that in basin areas, non-basin areas are an integral part of California's natural groundwater infrastructure, playing an important role in recharge, subsurface flow, and overall watershed dynamics, which collectively influence the state's groundwater availability and sustainability.

To further understand the significance of non-basin areas in California's groundwater system, the following sections explore key topics that highlight their hydrogeologic importance and management implications:

- **Population in Non-Basin Areas:** Over 7.2 million Californians live in non-basin areas, most relying solely on local fractured-rock groundwater for drinking water and other uses.
- **Hydrogeologic Provinces of Non-Basin Areas:** California's non-basin groundwater is best described through the lens of the 11 hydrogeologic provinces defined by the USGS. These provinces, based on geologic, hydrologic, and climatic features, offer a framework for understanding groundwater occurrence, recharge, and flow in fractured-rock terrains distinct from the alluvial basins.
- **Recharge Areas in Non-Basin Areas:** Non-basin areas play a critical role in groundwater recharge through precipitation infiltration, spring discharge, and lateral flow to valley aquifers — linking mountain systems with lowland groundwater basins.
- **Non-Basin Areas Characterization Efforts:** State and federal agencies have increasingly recognized the importance of fractured-rock groundwater, prompting expanded studies, mapping, characterization, and monitoring to address data gaps and integrate non-basin areas into long-term water planning.

3.5.1 Population in Non-Basin Areas

According to the 2020 U.S. Census, more than 7.2 million people reside in California's non-basin areas, where many residents are solely dependent on non-basin area groundwater for domestic and public water supplies. Statewide, over the last 20 years, the population living in non-basin areas has varied by county, with most counties experiencing growth and a few experiencing declines (Table 3-4). Despite these regional differences, the overall statewide population in non-basin areas has grown by over one million people, an increase of 16% over the past twenty years.

PUBLIC DRAFT

Table 3-4 Non-Basin Population by County and Decade (2000 to 2020)

County Non-Basin Area	2000 Census Population	2010 Census Population	2020 Census Population	Population Change 2000–2020
Alameda	208,140	224,096	259,672	51,532
Alpine	954	846	768	-186
Amador	25,996	27,455	29,694	3,698
Butte	62,473	65,021	40,768	-21,705
Calaveras	33,717	37,369	36,598	2,881
Colusa	486	410	303	-183
Contra Costa	398,686	452,679	501,807	103,121
Del Norte	3,404	3,196	3,266	-138
El Dorado	126,831	154,306	164,765	37,934
Fresno	17,876	18,853	19,124	1,248
Glenn	641	557	663	22
Humboldt	16,531	16,515	15,878	-653
Imperial	211	207	179	-32
Inyo	1,121	1,115	1,062	-59
Kern	20,580	23,485	23,656	3,076
Kings	63	57	148	85
Los Angeles	939,398	952,171	955,004	15,606
Lake	29,657	32,362	34,213	4,556
Lassen	10,489	10,115	9,707	-782
Madera	25,706	28,414	27,095	1,389
Marin	188,642	191,355	198,024	9,382
Mariposa	16,834	17,230	16,805	-29
Mendocino	29,736	29,456	32,791	3,055
Merced	79	157	187	108
Modoc	1,592	1,551	1,595	3
Mono	9,639	10,650	9,153	-486
Monterey	77,019	73,720	75,283	-1,736
Napa	28,391	30,398	30,280	1,889
Nevada	80,422	85,060	87,835	7,413
Orange	581,872	643,068	683,823	101,951
Placer	115,263	128,861	137,816	22,553
Plumas	6,912	6,477	6,418	-494
Riverside	231,203	363,273	407,183	175,980
Sacramento	26,631	37,149	41,075	14,444

PUBLIC DRAFT

County Non-Basin Area	2000 Census Population	2010 Census Population	2020 Census Population	Population Change 2000–2020
San Benito	2,161	2,441	2,904	743
San Bernardino	103,609	107,165	111,155	7,546
San Diego	1,869,401	2,115,673	2,282,870	413,469
San Francisco	1,497	2,933	3,297	1,800
San Joaquin	0	1	81	81
San Luis Obispo	117,605	123,620	127,880	10,275
San Mateo	221,834	219,964	230,665	8,831
Santa Barbara	52,768	52,842	54,925	2,157
Santa Clara	57,960	63,236	65,125	7,165
Santa Cruz	32,832	33,478	36,835	4,003
Shasta	45,583	49,159	49,251	3,668
Sierra	1,624	1,368	1,415	-209
Siskiyou	24,254	23,656	23,878	-376
Solano	124,233	121,455	127,389	3,156
Sonoma	60,900	61,235	57,523	-3,377
Stanislaus	101	925	1,798	1,697
Sutter	69	77	62	-7
Tehama	1,579	1,411	1,517	-62
Trinity	12,222	12,792	15,306	3,084
Tulare	9,826	10,302	11,242	1,416
Tuolumne	54,504	55,365	55,620	1,116
Ventura	68,196	80,588	79,664	11,468
Yolo	313	353	286	-27
Yuba	13,731	12,383	12,421	-1,310
Total Non-Basin Area	**6,193,997**	**6,820,056**	**7,205,747**	**1,011,750**

3.5.2 Hydrogeologic Provinces of Non-Basin Areas

Groundwater occurrence in California's non-basin areas is determined in large part by the geology, hydrology, and climate. A useful approach to describing and illustrating this occurrence is to reference the 11 Hydrogeologic Provinces delineated for California by the USGS in 2003. Each hydrogeologic province represents a large region with relatively similar geologic, climatic, and hydrologic characteristics (Figure 3-29). This delineation provides a context for evaluating groundwater resources that occur outside mapped alluvial groundwater basins (Johnson and Belitz 2003; Belitz et al. 2003).

PUBLIC DRAFT

Figure 3-29 Hydrogeologic Province Non-Basin Areas



The 11 hydrogeologic provinces defined by the USGS differ from the 10 hydrologic regions established by DWR. Hydrologic regions are based on surface water hydrology and major watershed boundaries, primarily serving water management planning, resource allocation, and regulatory purposes. In contrast, the USGS hydrogeologic provinces are defined by major geomorphic and geologic boundaries, including watershed boundaries, alluvial basin boundaries, rock type, faulting, and climate. Using these provinces to describe groundwater in non-basin areas is appropriate because they consider factors related to fractured rock rather than the eroded and transported sedimentary and alluvial products of the fractured hard rock that comprise alluvial groundwater basins. While DWR's hydrologic regions are delineated based on surface water movement and management, the USGS hydrogeologic provinces offer both a surface and subsurface perspective, aiding in the understanding of groundwater recharge, flow, and storage processes across California's diverse geologic settings.

In addition to geology (for instance faults and fractured rock), hydrology, and climate, other features such as springs and meadows are indicators of groundwater in non-basin areas. Faults can create pathways or barriers to groundwater flow and are often associated with the presence of springs in non-basin areas (Keegan-Treloar et al. 2022). Springs sustain groundwater dependent ecosystems and streams, while providing fresh water for human use. Springs often occur because faults modify groundwater flow pathways leading to discharges with sufficiently high pressure. Fault-controlled spring systems, meadows, and groundwater dependent ecosystems are the surface expressions of groundwater, especially in non-basin areas, and the maps provided in this section are intended to encourage further studies of these features and illustrate the occurrence of non-basin area fractured-rock groundwater.

This section provides a summary of groundwater-related information and maps for nine hydrogeologic provinces, focusing on natural infrastructure and groundwater features, including recent (Quaternary Period) faulting, springs, and meadows. It does not include the Central Valley and the Southern California Islands hydrogeologic provinces and instead focuses on California's non-basin fractured-rock areas within the nine remaining hydrogeologic provinces. This distinction is made because the Central Valley province is characterized by extensive alluvial deposits forming significant groundwater basins, while the Southern California Islands province comprises island regions with unique hydrogeologic settings and relatively little development. In contrast, the other nine provinces predominantly consist of non-basin, fractured-rock terrains, which exhibit different groundwater characteristics and management considerations.

PUBLIC DRAFT

The nine hydrogeologic provinces described below are:

1. Northern Coast Ranges Hydrogeologic Province.
2. Klamath Mountains Hydrogeologic Province.
3. Cascades and Modoc Plateau Hydrogeologic Province.
4. Sierra Nevada Hydrogeologic Province.
5. Basin and Range Hydrogeologic Province.
6. Southern Coast Ranges Hydrogeologic Province.
7. Transverse and Selected Peninsular Ranges Hydrogeologic Province.
8. San Diego Drainages Hydrogeologic Province.
9. Desert Hydrogeologic Province.

1. Northern Coast Ranges Hydrogeologic Province

The Northern Coast Ranges Hydrogeologic Province includes 79 alluvial groundwater basins and 126 watersheds. The boundary with the Klamath Mountain province is primarily defined by watersheds, where possible, that approximate the Coast Range Fault. The boundary between the Northern Coast Ranges and Central Valley provinces is defined by the boundary of the Sacramento groundwater basin. The non-basin area covers approximately 12,300 square miles and makes up about 85% of the total province area (Johnson and Belitz 2003; Belitz et al. 2003). The majority of the province is within the North Coast Hydrologic Region; however, portions can also be found in the San Francisco Bay and Sacramento River hydrologic regions.

The province contains bedrock that is composed of Jurassic- and Cretaceous-aged rocks (approximately 200 to 66 million years old). The majority of the bedrock is classified as mélange, which is geologic terrane "that has been deformed and mixed by prolonged and complex tectonic movement, and lacks continuity of structure, rock type, or age" (North Coast Regional Water Quality Control Board 2010). There are three distinct geologic units: the Great Valley Sequence to the east, the Franciscan Complex, and the Salinian Block. The Franciscan Complex is an assemblage of highly variable, metamorphosed and deformed igneous, sedimentary, and metamorphic rocks that were scraped off the leading edge of a subducting oceanic plate beginning around 165 million years ago and continuing to about 12 million years ago; most of the exposed rocks of the Franciscan Complex were accreted to coastal areas of modern-day California and Oregon between around 120 and 32 million years ago (Wakabayashi 2015). The sedimentary rocks

PUBLIC DRAFT

include sandstone, siltstone, shale, conglomerate, greywacke, and chert deposits. The province primarily consists of relatively low-hydraulic conductivity rocks (Belitz et al. 2003).

As a result of intense tectonic forces during and after subduction, the province contains areas of volcanism and is heavily folded and faulted by the San Andreas fault system with most of the folds and faults trending northwestward (Planert and Williams 1995). The volcanic fields of the province formed between 11 to 2.5 million years ago (Wagner et al. 2011; Stanley and Rodriguez 2014) and include the Sonoma Volcanic Field and the Clear Lake Volcanic Field. These volcanic fields exhibit complex faulting and fracture patterns that provide the geologic and structural framework for modern-day geothermal energy production in the Geysers-Clear Lake Area (McLaughlin and Donnelly-Nolan 1981; Wagner et al. 2011). In the Clear Lake Volcanic field, groundwater is naturally heated in the subsurface and has been harnessed for geothermal energy at the Geysers power plant (Figure 3-30). The San Andreas Fault system runs almost the entire length of the province and has shaped the landscape south of the Mendocino Triple Junction, an area near Cape Mendocino where the San Andreas Fault joins the Mendocino Fracture Zone (Wallace 1990). The movement along the fault system for the past 20 million years has generally been right-lateral strike-slip, expressed in local areas of uplift or subsidence, often reflected as parallel sequences of linear valleys and ridges. (California Geological Survey 2015).

The province hosts portions of major river systems, including the Smith, Klamath, Trinity, Eel, and Russian Rivers. The Klamath and Trinity rivers exploit the fault zone that forms a boundary between this province and the Klamath Mountains Hydrogeologic Province to the northeast. The climate in the province is classified as both Mediterranean, with warm to hot, dry summers and cold, wet winters, and Coastal, with cool to mild summers and cold, wet winters. Average annual rainfall in the province ranges from 22 to 79 inches. Recharge to the groundwater system includes direct percolation of precipitation and irrigation waters, infiltration of runoff from surrounding hills or upland areas, seepage from rivers and creeks, and subsurface inflow from non-basin areas to alluvial groundwater basins (Mathany and Belitz 2014a).

Groundwater resources in the province are supplied by both alluvial aquifer and non-basin area fractured-rock groundwater systems. Between 2003 and 2023, the number of public supply wells in non-basin areas of the province increased from 280 to 571, representing a 104% rise (Belitz et al. 2003; California Department of Water Resources 2024e).

PUBLIC DRAFT

The USGS, in cooperation with the California State Water Resources Control Board, implemented the California Groundwater Ambient Monitoring and Assessment (GAMA) Program to provide statistically robust assessments of untreated groundwater quality within primary aquifer systems used for drinking water (Mathany and Belitz 2014b). The assessment characterized conditions using relative concentrations. Concentrations are considered high if they are greater than a benchmark. For inorganic constituents, concentrations are moderate if they are greater than one-half of a benchmark. For organic constituents and perchlorate, concentrations are moderate if they are greater than one-tenth of a benchmark; this lower threshold was used because organic constituents are generally less prevalent and have smaller concentrations relative to benchmarks than inorganic constituents. Low values include non-detections and values less than moderate concentrations (Mathany and Belitz 2014a).

For groundwater quality in the Northern Coast Ranges, naturally occurring boron has been measured at high concentrations, sourced from igneous rocks, evaporite minerals, seawater, and geothermal water. Investigations in the Geysers-Clear Lake area have identified elevated concentrations of boron, arsenic, and lithium, likely due to groundwater interaction with the hydrothermal systems (Mathany and Belitz 2014b).

Faults and springs influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-31; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3).

PUBLIC DRAFT

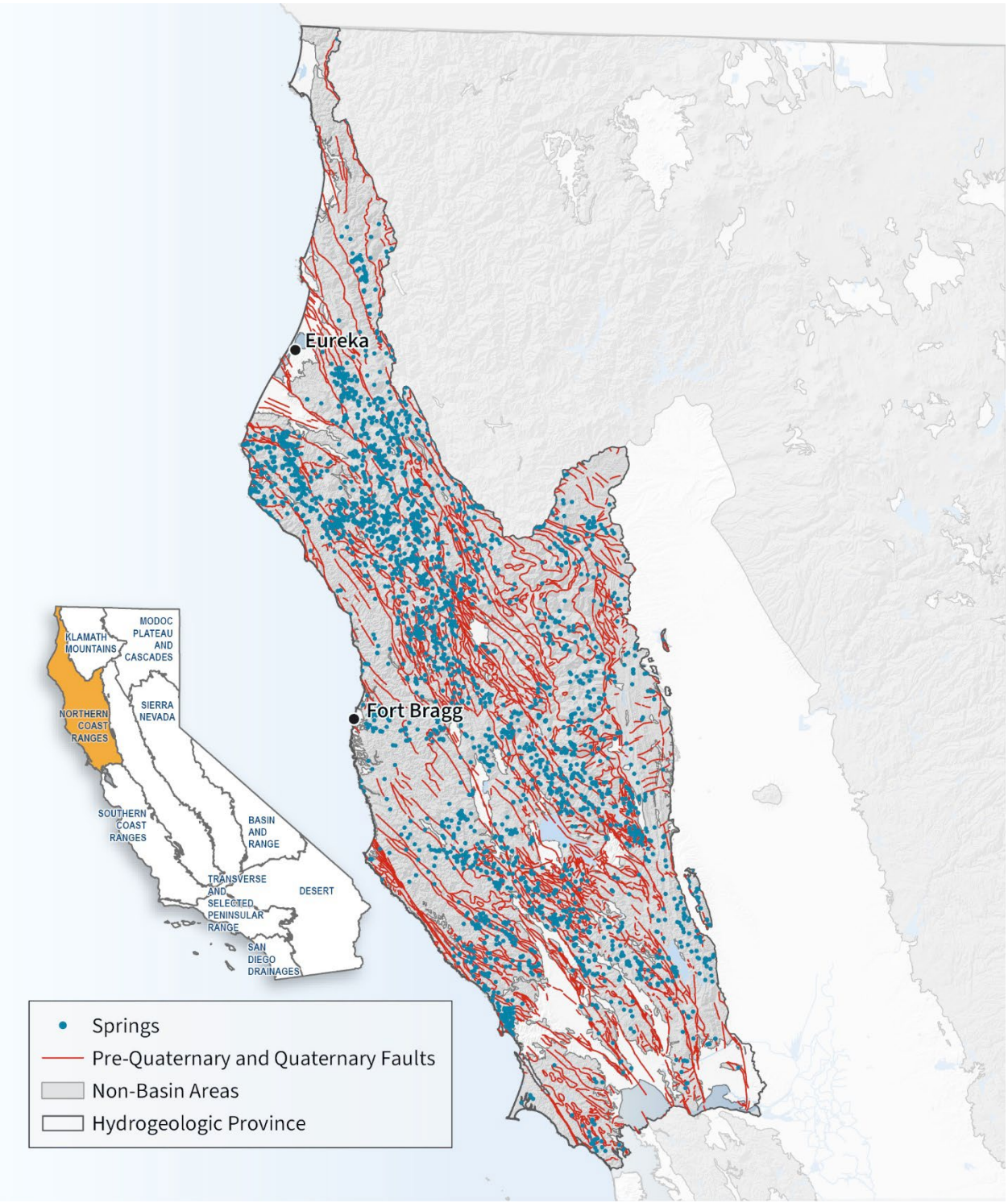
Figure 3-30 Geysers Power Plant in the Geothermal Field, Near Clear Lake, California



Photo Credit — Julie M. Donnelly-Nolan.

PUBLIC

Figure 3-31 North Coast Ranges Hydrogeologic Province Non-Basin Area – Faults and Springs



2. Klamath Mountains Hydrogeologic Province

The Klamath Mountains Hydrogeologic Province includes seven alluvial groundwater basins and 51 watersheds. The boundary with the Northern Coast Ranges province is defined by watershed boundaries that, where possible, approximate geologic boundaries. The boundary with the Modoc Plateau and Cascades province is defined by groundwater basin and watershed boundaries that, where possible, approximate geologic boundaries. The boundary with the Central Valley province is defined by the boundary of the Sacramento groundwater basin. The non-basin area covers approximately 8,700 square miles and makes up about 99% of the total province area (Johnson and Belitz 2003; Belitz et al. 2003). The majority of the province is within the North Coast Hydrologic Region, with the southeast portion located within the Sacramento River Hydrologic Region.

The province is composed of complex bedrock including Paleozoic ocean-floor sedimentary and igneous rocks, along with metasedimentary, metavolcanic rocks, and Mesozoic plutonic granitic rocks. Dark iron- and manganese-rich rocks often altered to serpentine dominate the province with younger, light-colored granitic intrusions in places. The province was formed by plate collisions resulting in accreted terranes. Rugged topography, shaped by tectonic uplift, features steep slopes, rapidly eroding terrain, and incised drainages, especially in the west where benches with gold-bearing gravels remain (California Geological Survey 2002; California Geological Survey 2015). Recent tectonic uplift has created a landscape of rapidly downcutting streams and steep slopes that are subject to rapid erosion and landsliding. The granitic rocks in particular weather to into loose, unconsolidated material that is prone to landslides and rapid runoff (North Coast Regional Water Quality Control Board 2010).

Faults and springs both influence and indicate the occurrence of non-basin area groundwater and are shown in Figure 3-32; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3).

The province is primarily drained by the Klamath, Trinity, Sacramento, and Smith River systems. The province consists almost entirely of relatively low-hydraulic conductivity rocks (Belitz et al. 2003). Groundwater recharge occurs through precipitation and runoff that percolate into the fractured rock through faults and fractures at higher elevations. Seeps and springs are a common occurrence throughout the province and along road cuts in the non-basin fractured-rock areas (Figure 3-33). The climate of the province is characterized by warm, dry summers

PUBLIC DRAFT

and cool, moist winters. Average annual rainfall ranges from approximately 69 inches on the western edge of the province to 40 inches in the central and eastern parts of the province. (Bennett and Fram 2014).

Figure 3-32 Klamath Mountains Hydrogeologic Province Non-Basin Area – Faults and Springs

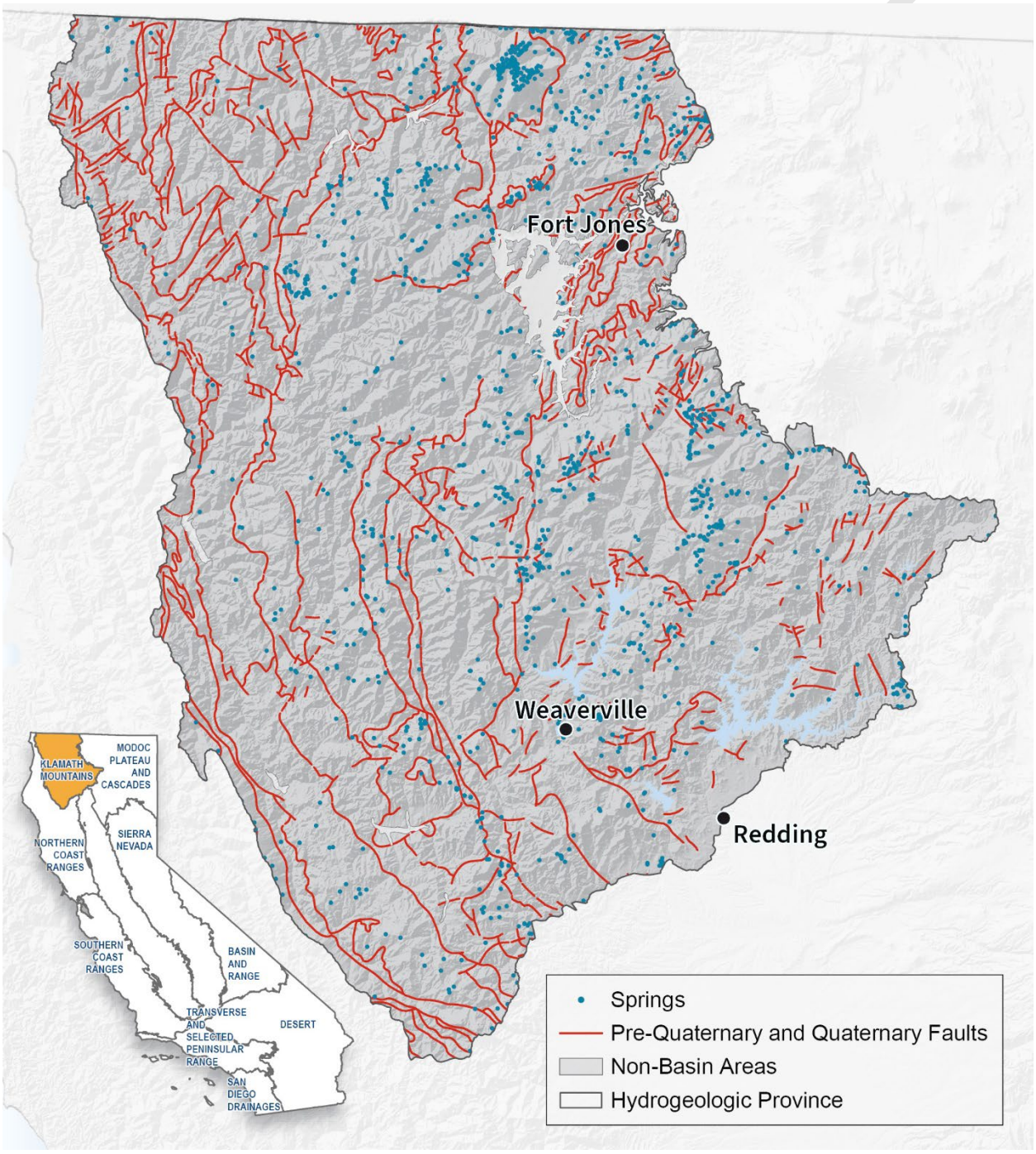


Figure 3-33 Groundwater Seeps in Fractured Rock – Klamath Mountains Province, State Highway 299 near Big French Creek, California



Photo Credit — DWR Northern Region Office 2020.

While the primary aquifer systems in the province are localized zones of fractured bedrock, most drinking water is drawn from springs and wells tapping into glacial, alluvial, or fluvial sediments. However, many of the thin glacial, alluvial, or fluvial sediments do not support sufficient quantities of groundwater resulting in many wells bypassing the sediments and accessing groundwater in the fractured bedrock beneath. Between 2003 and 2023, the number of public supply wells in non-basin areas of the province increased from 110 to 126, representing a 15% rise (Belitz et al. 2003; California Department of Water Resources 2024e).

Trace elements such as arsenic, antimony, and boron were found at high concentrations in about 3% of sampled wells. Elevated levels of iron and manganese were also detected in about 13% of sampled wells, potentially affecting water quality by causing metallic-tasting or foul-smelling water and producing black, brown, or reddish staining on surfaces that come into contact with the water (Bennett et al. 2014; Bennett and Fram 2014). These constituents are naturally derived from the surrounding rock, where geochemical conditions — such as mineral composition and groundwater chemistry — promote their release into groundwater.

Past mining activity in the province, specifically at Iron Mountain in Shasta County, took place within the copper-belt that exists in California, running northwest to southeast from the Oregon border along the mountain foothills of the Klamath Mountains and Sierra Nevada provinces (California Department of Conservation 2000). Iron Mountain, about 9 miles northwest of Redding, is composed of brittle, fractured, hydrothermally altered volcanic bedrock that contains massive sulfide deposits that are between 350 to 400 million years old. Around 1896, Iron Mountain began to be mined for copper and sulfide-rich rock, followed by mining for gold, iron, zinc, and pyrite. Mining activity at Iron Mountain inadvertently allowed both water and air to reach the enormous sulfide deposits deep within the mountain, where water and oxygen reacted with the sulfide ores (mostly pyrite), to produce sulfuric acid and to dissolve the heavy metals in the ore. This created the toxic phenomenon known as acid mine drainage (AMD), a metal-rich, acidic water. At Iron Mountain, AMD water percolated down through the mines and the tailings, further dissolving and mobilizing heavy metals (copper, zinc, and cadmium) along the way, eventually joining the local fractured rock groundwater and emerging as heavy-metal contaminated springs and seeps. Nearly 100 years of mining-related AMD led to substantial environmental degradation, including fish kills in the Sacramento River, heavy metal-contaminated sediments deposited in the Keswick Reservoir, threats to Redding's municipal drinking water supplies, and spring/seep water samples in 1990 with negative pH values that classified the

PUBLIC DRAFT

water as some of the most acidic water ever sampled. Cleanup operations by the U.S. Environmental Protection Agency's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund") program began in 1986. Clean up methods such as surface-water diversion, tailings removal, dredging and treatment of contaminated sediments, and lime neutralization treatment of the most acidic, metal-rich flows, have since reduced copper and zinc loads by 95% (United States Geologic Survey 2025).

Hydroelectric dams and their associated reservoirs significantly impaired the Klamath River's water quality, contributing to a decline of over 90% in native fall and spring-run Chinook salmon populations. This sharp reduction in native fish had and has profound impacts on the food sources of indigenous tribes in the region and the commercial fishing industry (Sherriff 2024). Prolonged drought further exacerbated conditions, leading to toxic algae blooms and public health advisories for the river and its reservoirs. After decades of debate, the largest dam-removal project in the United States resulted in the removal of four hydroelectric dams and lakes constructed in the early 1900s on the Klamath River, allowing the river to flow freely from Oregon to the Pacific Ocean. However, the completion of the dam removal project has had an impact on local groundwater supplies. As the lakes were drained, groundwater levels in some domestic and community wells surrounding the former lakes declined or went dry, as reported for a well serving 11 homeowners. The Klamath River Renewal Corporation (KRRC), a nonprofit managing the dam removals and restoration activities, provided water deliveries to impacted residents until KRCC completed facilitation of funding of a long-term water supply solution in 2025 (Alexander 2024; Klamath River Renewal Corporation 2025).

3. Cascades and Modoc Plateau Hydrogeologic Province

The Cascades and Modoc Plateau Hydrogeologic Province includes 55 alluvial groundwater basins and 70 watersheds. The boundary with the Klamath Mountains province is defined by groundwater basin and watershed boundaries that, where possible, approximate geologic boundaries. The boundary with the Sierra Nevada province is also defined by groundwater basin and watershed boundaries that, where possible, approximate geologic boundaries. The boundary with the Central Valley province is defined by the boundary of the Sacramento groundwater basin.

The non-basin area portion of the province covers approximately 7,000 square miles and accounts for about half of the total province area (Johnson and Belitz 2003; Belitz et al. 2003). The climate varies with elevation and longitude, and the

PUBLIC DRAFT

province is mostly classified as high, cold desert, arid to semi-arid, with average annual precipitation of 10–20 in/yr in most of the area and 20–40 in/yr at higher elevations. Much of the precipitation falls as snow, particularly at elevations above 4,500 ft, and nearly all of the precipitation occurs in the winter (between November and May). Summers are hot and dry. Precipitation is greatest on the western side of the province and at high elevations, reaching over 80 inches per year on Mount Shasta and in Lassen Volcanic National Park (Planert and Williams 1995; Shelton et al. 2013; Fram and Shelton 2015). The majority of the province is within the Sacramento River Hydrologic Region, with portions of the province within the North Coast and North Lahontan hydrologic regions.

This province features abundant Miocene- to Holocene-aged (from 23 million years ago to present) volcanic rocks, including lava flows and pyroclastic deposits. The province is characterized by high elevation volcanic flow deposits emanating primarily from Mount Shasta, Lassen Volcanic Highlands, Medicine Lake Highlands, and Columbia River Flood Basalts.

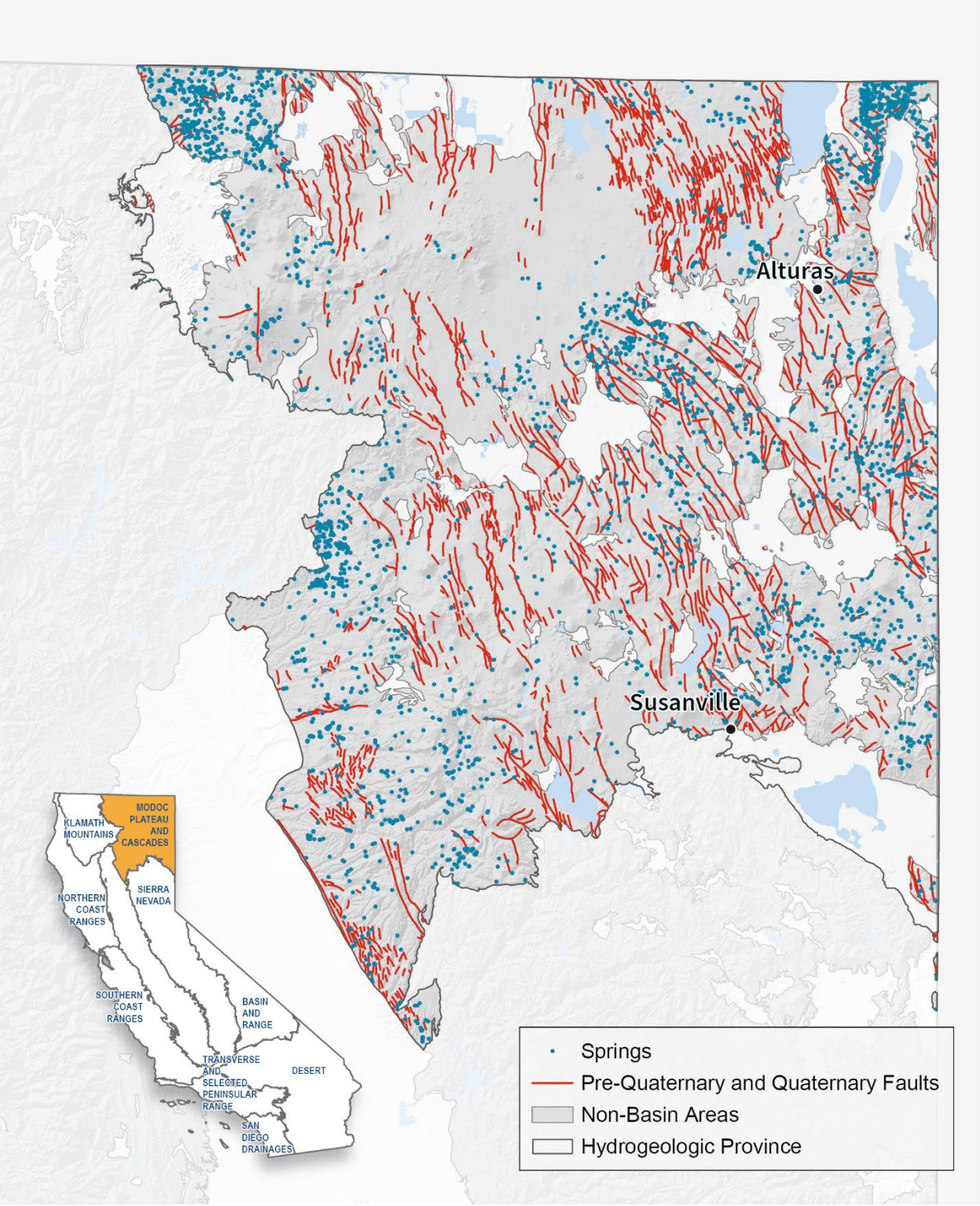
The province's non-basin fractured-rock area is dominated by regionally extensive, flat-lying, basalt and andesite lava flows and pyroclastic deposits that developed joints and fractures during deposition, cooling, and weathering. Topography is shaped by regional north-northwest-trending faults associated with basin and range extensional tectonic activity, which extends east into Nevada.

Springs account for about 10% of the province's public drinking-water supplies (Fram and Shelton 2015). Natural infrastructure features such as faults and springs influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-34; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3). These features can enhance recharge, storage, and discharge by concentrating flow paths. Between 2003 and 2023, the number of public supply wells in the non-basin area increased from 40 to 176, representing a 340% rise (Belitz et al. 2003; California Department of Water Resources 2024e), highlighting the growing reliance on fractured volcanic areas for public supply.

The joint and fracture features provide pathways for groundwater recharge through infiltration of precipitation. Most of the province's non-basin area groundwater recharge comes from stream-channel infiltration, infiltration of precipitation, and subsurface flow through volcanic rock features. Deep percolation of irrigation water in alluvial groundwater basins also provides recharge to fractured rock areas.

PUBLIC DRAFT

Figure 3-34 Cascades and Modoc Plateau Hydrogeologic Province Non-Basin Area – Faults and Springs



In this province, groundwater is stored and transmitted through fractures, volcanic pipes, collapsed lava tubes, tuff beds, rubble zones (interflow) between lava flows, and joints. Figures 3-35 and 3-36 show diagrammatic examples of volcanic basalt outcrops and structures that are known to be conducive to groundwater flow, as seen in the Miocene-aged (between 23 and 5.3 million years ago) Columbia River Basalt Group east of the Cascades in northeastern California, Oregon, and Washington (Camp and Ross 2004).

The ability of volcanic rock to store and transmit groundwater depends on factors such as the number and connectivity of joints, joint density relative to welding and compaction, horizontal partings within tuffs, the extent of rubble zones between lava flows, and the interconnection of vesicles in the lavas (Planert and Williams 1995; GSI Water Solutions 2009). Faulting can also affect groundwater movement in the province's flood basalt flows, creating both pathways and barriers to groundwater flow with the amount of leakage dependent on the fault's physical properties (Figure 3-37). These systems can be interconnected or isolated, resulting in variability in groundwater levels, well yields, and water quality at local and regional scales (Fram and Shelton 2015).

PUBLIC DRAFT

Figure 3-35 Diagram of Volcanic Flood Basalt Columns Showing Potential Groundwater Recharge and Flow Pathways

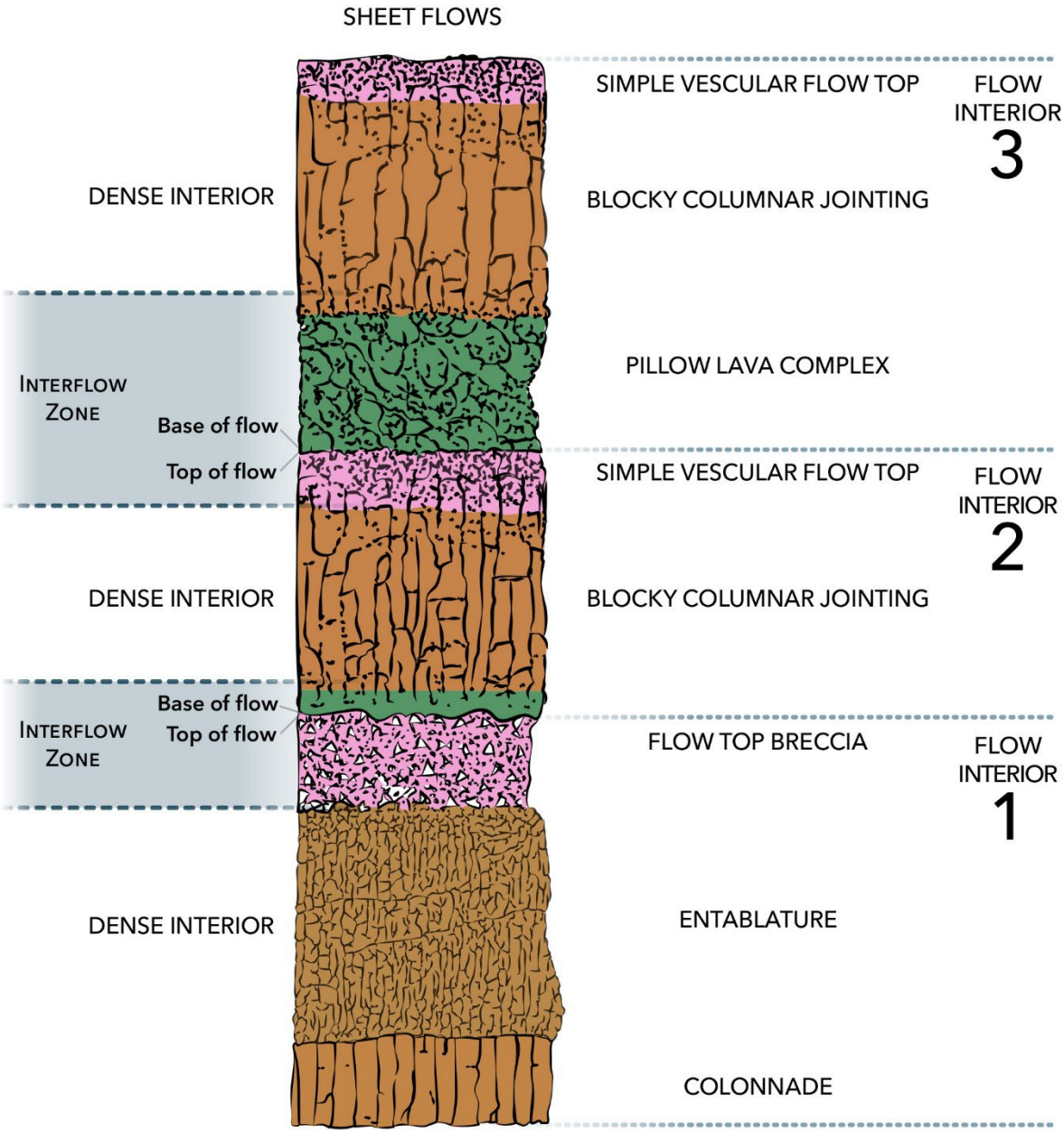


Figure 3-35 Source — Tolan et al. 2009.

Figure 3-36 Diagram Showing Potential Groundwater Pathways in Interflow Zones Between Basalt Flow Units

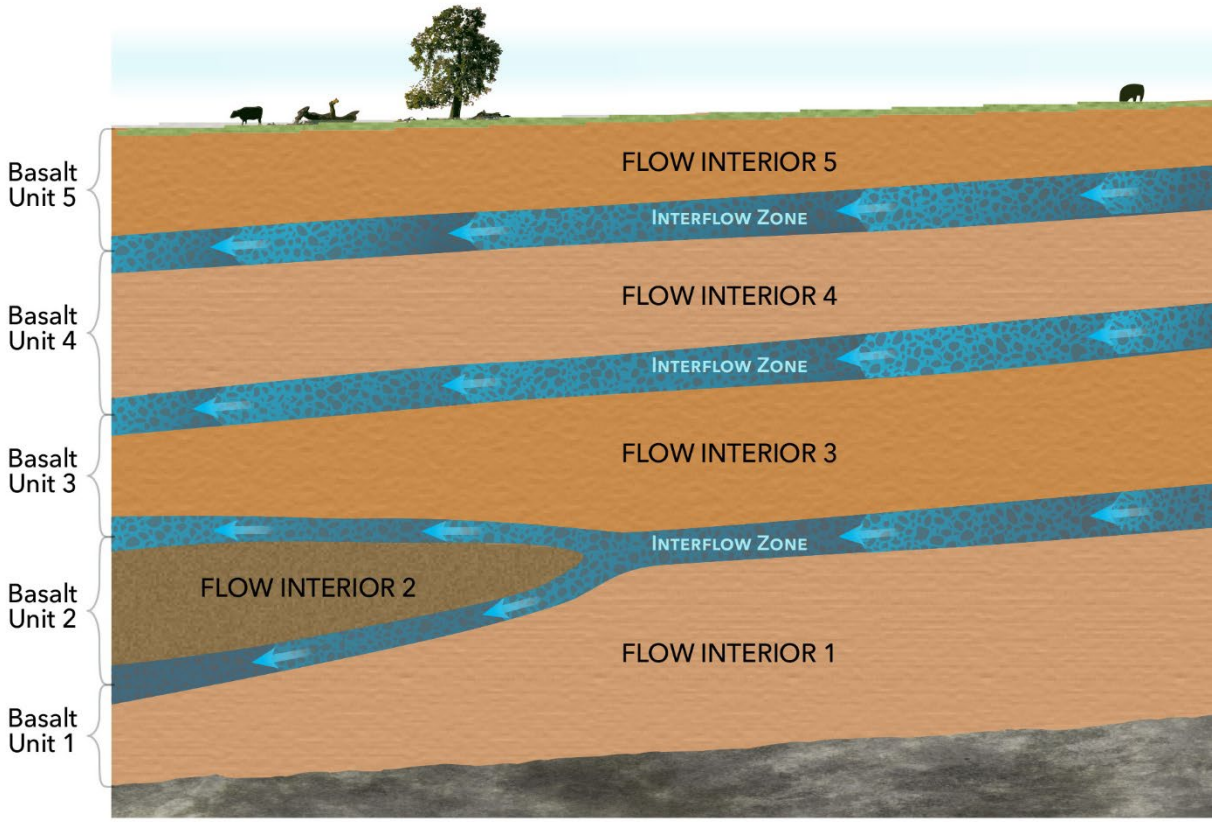


Figure 3-36 Source — Tolan et al. 2009.

PUBLIC

Figure 3-37 Diagram Showing Faults as Potential Groundwater Barriers and Flow Pathways Across Basalt Flow Units

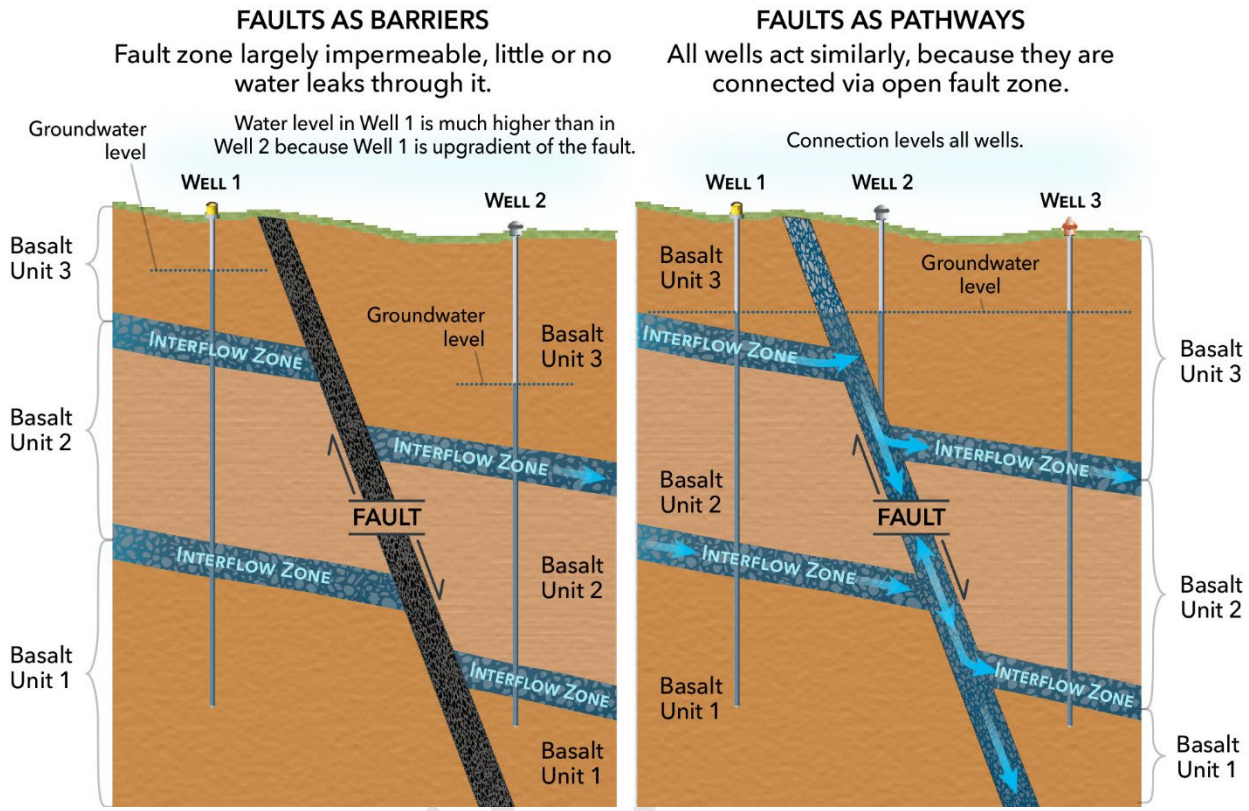


Figure 3-37 Source — Tolan et al. 2009.

The Medicine Lake Highlands volcanic area portion of the province is intricately tied to extensive groundwater systems and has been shown to feed large volume springs and local alluvial groundwater basins, sometimes tens of miles downgradient from the Highlands. This area is composed of Pleistocene- to Holocene-aged (2.6 million years ago to present) volcanic basalt, andesite, and dacite flows.

The isotopic ratios of hydrogen and oxygen in water can be used to interpret the sources of groundwater recharge. These stable isotopic ratios reflect the altitude, latitude, and temperature of precipitation and also the extent of evaporation of the water in surface-water bodies or soils prior to infiltration into the aquifer (Shelton et al. 2013).

Several studies have used oxygen isotope signatures to demonstrate that fractured rock basalt aquifer systems have highly variable groundwater flow rates and resident times, and that groundwater can follow preferential flow paths to

travel more than 0.5 miles per year, while deeper, less fractured basalt layers show much slower transport rates (Johnson et al. 2000; Rose et al. 1996). For example, the oxygen isotope values of the large-volume Fall River spring group indicate that recharge from snowmelt originated at higher elevations about 30 miles away on the Medicine Lake Highlands and Volcano, with groundwater travel time to the springs calculated to be within the range of 12 to 20 years (Davisson and Rose 2014) and up to about 42 years (Curry 2014). The Medicine Lake Highlands groundwater input to the Fall River springs system, the largest spring system in the state, has been estimated to be about 1 million to 1.4 million acre-feet per year (Curry 2014) (Figures 3-38 and 3-39).

Nearby, the oxygen isotope values of the large-volume springs that form the Rising River and Crystal Lake are consistent with snow melt recharge originating at higher elevations in the Lassen Volcanic Highlands and Volcano, about 27 miles south, with an estimated recharge rate of about 37 inches of precipitation per year over about 145 square miles (Rose et al. 1996).

A detailed study and analysis conducted by Curtis et al. 2020, describes the regional contribution of baseflow to perennial streams from the higher elevation permeable volcanic fractured rock non-basin areas in this province to be on the order of about 75% (Curtis et al. 2020). The study concludes that "with projected declines in snowpack under warmer climates, groundwater discharge […] may provide a greater proportion of total streamflow under future climatic conditions."

Volcanic rocks can influence groundwater chemistry by releasing elevated levels of silica, fluoride, and occasionally arsenic from volcanic glass and minerals, while geothermal activity may introduce heat, dissolved gases, and minerals that affect pH and salinity. As a result, groundwater quality varies with depth across the province, and high concentrations of inorganic constituents, such as arsenic, boron, molybdenum, and vanadium with health-based benchmarks were found in about 6% of wells tested. Iron or manganese were found in high concentrations in about 15% of wells tested (Shelton et al. 2013; Fram and Shelton 2015).

PUBLIC DRAFT

Figure 3-38 Ahjumawi Lava Springs, Part of the Fall River Springs System, Cascades and Modoc Plateau Hydrogeologic Province



Photo Credit — CalTrout's Tyanna Blaschak (2025).

Figure 3-39 Ahjumawi Lava Springs' Crystal Spring Fish Trap, Part of the Fall River Springs System, Cascades and Modoc Plateau Hydrogeologic Province



Photo Credit — CalTrout's Tyanna Blaschak (2025).

Northern California's non-basin volcanic regions play a critical role in the state's water supply, energy generation, and ecosystem health. Spring-fed rivers originating in these fractured-rock areas contribute significantly to hydroelectric power and surface water storage, while also sustaining vital cold-water habitats during dry periods. Local governments and federal land managers retain key authorities to manage and protect these resources. The Medicine Lake Highlands exemplifies the complex interplay between groundwater resource value, cultural significance, and competing land-use pressures in the Cascade Province.

Spring-fed rivers originating in non-basin areas contribute significantly to the state's water and energy systems, supplying up to 40% of the state's hydroelectric power and about half the total water storage capacity of Lake Shasta (4.5 maf) (Isler 2016; Davisson and Rose 2014; Curry 2014). These cold-water springs also provide much needed habitat for aquatic species, supporting a wide range of instream biota during low-flow seasons and drought conditions (Curtis et al. 2020) (Figure 3-40).

Figure 3-40 Burney Falls, Where Groundwater Emerges from Volcanic Deposits, Cascades and Modoc Plateau Hydrogeologic Province



Photo Credit — CalTrout's Tyanna Blaschak (2025).

Unlike alluvial groundwater basins, the California Water Code and associated State policies do not specifically address groundwater resources in fractured-rock groundwater found in non-basin areas. This regulatory gap persists despite growing interests in using these resources for industrial and commercial purposes, such as bottled water and geothermal development. However, county ordinances

and federal land managers retain authority to protect or preserve these groundwater systems.

A notable example is Medicine Lake (Figure 3-41), located within the caldera of Medicine Lake volcano. The surrounding Medicine Lake Highlands, also known as Sáttítla (an Ajumawi word for "obsidian place"), have been the focus of past attempts to develop commercial geothermal energy resources, activities which were opposed by the Pit River Tribe and groups such as the Native Coalition for Medicine Lake Highlands Defense and the Mount Shasta Bioregional Ecology Center. For millennia, the Sáttítla Highlands have been the sacred ancestral homelands of the Pit River Tribe and Modoc Peoples. Many other Tribes and indigenous peoples in the region, including the Karuk, Klamath, Shasta, Siletz, Wintu, and Yana, hold deep connections to this area.

Local Tribes and non-governmental organizations have long advocated for permanent protection of the area, and on January 14, 2025, former President Biden announced the designation of the Sáttítla Highlands National Monument. The new monument encompasses 224,676 acres of varied habitat on the Modoc, Shasta-Trinity, and Klamath national forests and provides protection to Tribal ancestral homelands, historic and scientific treasures, rare flora and fauna, and the headwaters of vital sources of water.

PUBLIC DRAFT

Figure 3-41 View West Across the Medicine Lake Caldera Toward Mount Shasta, Cascades and Modoc Plateau Hydrogeologic Province



Photo credit — Julie M. Donnelly-Nolan.

4. Sierra Nevada Hydrogeologic Province

The Sierra Nevada Hydrogeologic Province includes 22 alluvial groundwater basins and 161 watersheds. The boundary with the Central Valley Province is defined by the boundaries of the Sacramento and San Joaquin groundwater basins. The boundary with the Cascades and Modoc Plateau, Basin and Range, and Transverse and Selected Peninsular Ranges Provinces are defined, where possible, by groundwater basin and watershed boundaries that approximate geologic boundaries.

The non-basin area portion of the province covers approximately 24,700 square miles and accounts for about 97% of the total area (Johnson and Belitz 2003; Belitz et al. 2003). The province extends across the eastern portions of the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, the southern portion of North Lahontan Hydrologic Region, and, in the south, a portion of the South Lahontan Hydrologic Region.

PUBLIC

The Sierra Nevada mountains were formed from large-scale block faulting, pluton emplacement, and uplift over the last 150 million years, and the mountains consist primarily of Mesozoic and Paleozoic metamorphosed igneous and sedimentary rocks (Fram and Belitz 2012). This region is also known for its gold-bearing formations, which supported extensive hard rock and placer mining during the California Gold Rush and continues today.

Seismic activity occurs in the southern portion of the province near the intersection of two of California's most prominent structural features, the San Andreas Fault and the Garlock Fault (Planert and Williams 1995; Fram and Belitz 2012). The province's complex geologic history influences groundwater conditions by controlling the hydraulic conductivity of fractured bedrock aquifers, the distribution of mineralized zones, and the availability of recharge through faults, joints, and weathered rock zones.

The Sierra Nevada province has a Mediterranean climate, with warm, dry summers and cool/cold, wet winters. Annual precipitation ranges from 10 to 80 inches per year (in/yr); most of the precipitation falls in the winter season, between October and April. Precipitation is typically greater at higher elevations and more northerly locations. Above about 6,500 ft, most of the precipitation falls as snow. Runoff from Sierra Nevada watersheds, primarily in the form of snow melt, provides much of California's developed water (Fram and Belitz 2012). Groundwater recharge occurs primarily by infiltration of precipitation and seepage from surface-water bodies.

Groundwater in the province occurs primarily in granitic and metamorphic bedrock fractures and faults and in scattered permeable lava flow units and volcaniclastic deposits. These fracture systems and permeable units can be isolated or interconnected, resulting in variable groundwater levels, well yields, or groundwater quality. Most groundwater occurs in fractures within 200 ft of the ground surface and is recharged through infiltration of rain and snowmelt into the fractures (Page et al. 1984; Fram and Belitz 2012; Somers and McKenzie 2020). Groundwater is used extensively for municipal, community, and domestic drinking-water supplies in the Sierra Nevada, and most of this groundwater comes from hard-rock aquifers rather than from groundwater basins (Fram and Belitz 2012). Between 2003 and 2023, the number of public supply wells in non-basin areas increased from 1,170 to 1,529, growth of 31% (Belitz et al. 2003; California Department of Water Resources 2024).

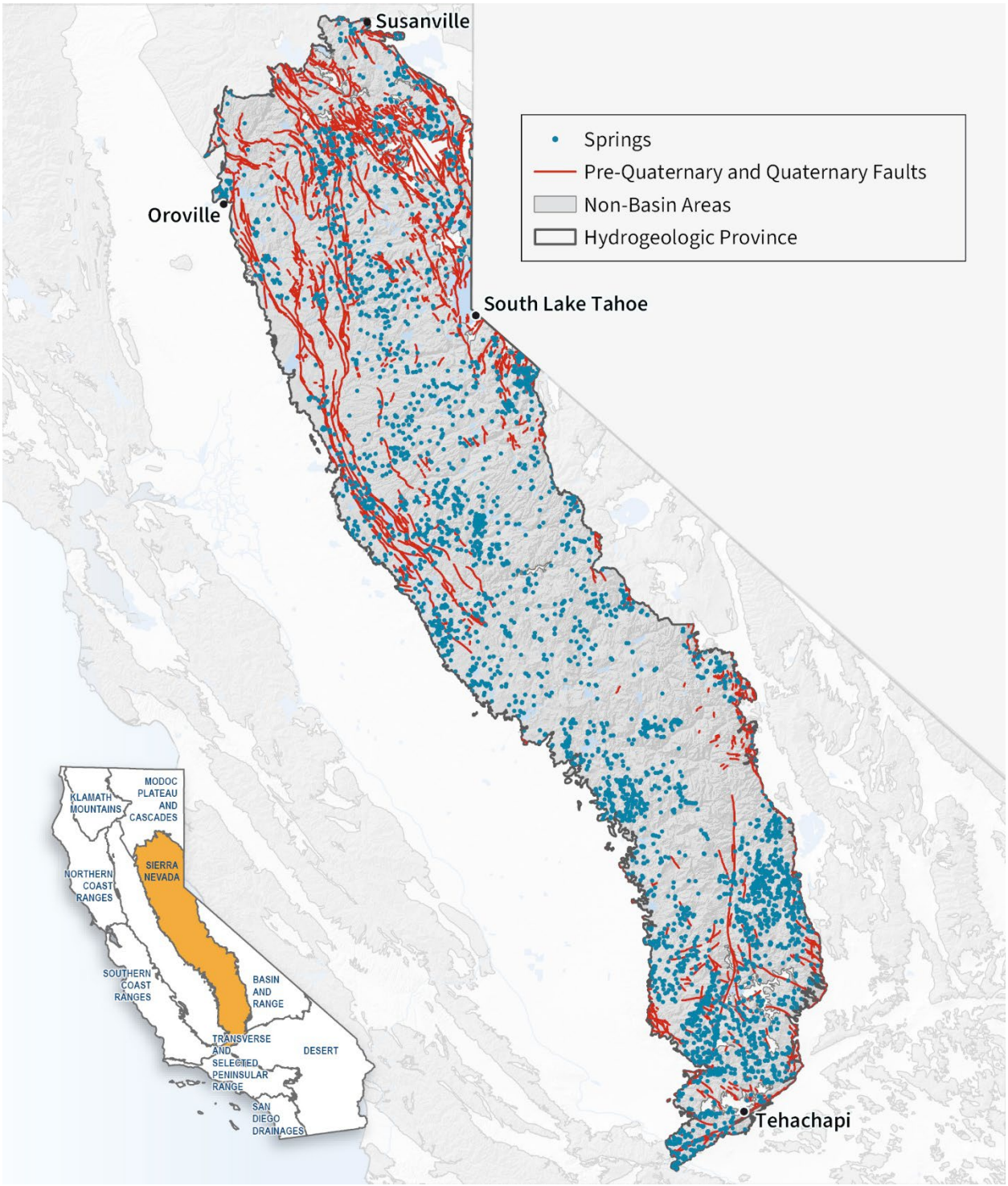
PUBLIC DRAFT

Specific to the Sierra Nevada province, the intermountain landscape of the province favors the formation of meadows that are found in areas with impermeable bedrock at the base of alluvial fans or in valley low points. The province has approximately 17,000 meadows consisting of approximately 167,000 acres, or approximately 58% of the meadows in California. These meadows provide habitat for amphibians, particularly Yosemite toads, and open space for cattle grazing. An investigation by Son and Tague looked at the impacts of climate warming on hydrologic fluxes (snow, evapotranspiration (ET), moisture deficit, and streamflow) in the Sierra Nevada and the modelled results show that increasing the air temperature by 2 degrees Celsius reduces snow accumulation and accelerates snowmelt, increases annual ET, and decreases annual streamflow in snow-dominated watersheds (Son and Tague 2018). Climate trends for the Sierra Nevada suggest warmer winter temperatures, resulting in a more rain-dominated precipitation regime and/or earlier snowmelt, which would result in decreased late-season groundwater availability and lowering of the water table (Kitlasten and Fogg 2015). Collectively, these impacts will affect meadows, which are relatively shallow features supported by groundwater from snowmelt, by reducing the areal footprint of meadows and soil moisture, and thus reducing habitat for the Yosemite toad and other amphibians and meadow-dwelling creatures in the Sierra Nevada (Roche et al. 2012; Kitlasten and Fogg 2015).

Faults and springs in the province influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-42; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3).

PUBLIC DRAFT

Figure 3-42 Sierra Nevada Hydrogeologic Province Non-Basin Area - Faults and Springs



In the western Sierra Nevada, rain and snowmelt infiltrate into fractured rock and run off to the Central Valley, supporting agricultural, urban, and environmental water needs.

Groundwater quality can vary widely across the province depending on rock type, groundwater age, human activities, and the extent and interconnectivity of the fractured rock in the non-basin area. Studies by the USGS, in cooperation with the California State Water Resources Control Board, as part of the California Groundwater Ambient Monitoring and Assessment (GAMA) Program, have shown that organic constituents with health-based benchmarks were not present in high concentrations in the central and southern parts of the province and were only present in 1% of the northern part of the province. Organic constituent concentrations are presumably low across the province, as most of the lands are undeveloped forests, shrublands, and grasslands. (Fram and Belitz 2012). In the central part of the province, inorganic constituents were present at high or moderate concentrations in about 77% of the primary aquifers. Arsenic, boron, fluoride, molybdenum, and uranium were the constituents most frequently present at high or moderate concentrations, derived from dissolution of naturally occurring minerals in the granitic and metamorphic rocks of the aquifers. Dissolution requires certain groundwater geochemical conditions (such as pH and dissolved oxygen concentration), enough time for dissolution to occur, and the presence of minerals containing these constituents. Mining activities throughout the province may increase dissolution rates by exposing rocks to air and increasing porosity and permeability, thereby increasing contact between minerals and groundwater (Fram and Belitz 2012). Naturally occurring arsenic, often concentrated in mineralized zones disturbed by mining, can exceed drinking water standards in groundwater near historical mine sites (Welch et al. 2000; Fram and Belitz 2012).

In the Sierra Nevada province, hard rock mining for gold that began over 175 years ago often took place in rock formations rich in sulfides (California Department of Conservation 2000). Acid mine drainage (AMD) occurs when mined, disturbed, and crushed sulfide minerals are exposed to air and water, leading to a chemical reaction to create sulfuric acid. The sulfuric acid may then seep into groundwater and dissolve and mobilize heavy metals such as lead and cadmium, potentially impacting springs, seeps, and wells (Church et al. 2007).

Beginning about 25 years ago, the U.S. Bureau of Land Management Abandoned Mine Lands program and the California Department of Conservation Office of Mine Reclamation began a survey to determine the number of abandoned mines in California, and the results indicated approximately 47,000 abandoned mines in

PUBLIC DRAFT

California, including about 20,000 on federal lands, and about 1,000 identified as likely to affect surface and/or ground water quality (California Department of Conservation 2000; Abbott 2009). Contaminated runoff from abandoned mines impacts tens of thousands of acres of land, groundwater, and hundreds of streams, rivers, and lakes throughout the state (California Department of Conservation 2000). Although contamination is typically localized, abandoned mines pose long-term risks to groundwater quality in some areas of the Sierra Nevada foothills and throughout California.

5. Basin and Range Hydrogeologic Province

The Basin and Range Hydrogeologic Province includes 45 alluvial groundwater basins and 56 watersheds. The boundary with the Sierra Nevada province is defined by groundwater basin and watershed boundaries that, where possible, approximate geologic boundaries. Most of the boundary with the Desert province is defined by groundwater basin boundaries that approximate the Garlock Fault. The easternmost part of the boundary is defined by groundwater basin boundaries that approximate the geomorphic boundary between the north-south trending mountains of the Basin and Range province and the broader, more widely spaced mountains of the Desert province (Johnson and Belitz 2003; Belitz et al. 2003). These boundaries typically mark shifts from faulted, internally drained structural basins and intervening mountain ranges, hallmarks of Basin and Range tectonics, to regions with different geologic frameworks, such as the metamorphic and granitic terrains of the Sierra Nevada to the west or the lower-relief sedimentary formations of the Colorado River region to the southeast. The fractured bedrock of the non-basin area in the province covers approximately 7,000 square miles and accounts for about half of the total province area (Belitz et al. 2003). The province predominantly lies within northern portions of the South Lahontan Hydrologic Region, with portions also found in the Honey Lake area of the North Lahontan Hydrologic Region.

The province is predominantly composed of unconsolidated to consolidated alluvial and terrace deposits that form productive basin-fill alluvial aquifers, underlain by bedrock. Sequences of Mesozoic and Paleozoic carbonate rocks underlie most of the alluvial groundwater basins within the province in southeastern California; these rocks also extend into eastern Nevada, western Utah, northwestern Arizona, and southeastern Idaho. Other rock types within the province have low hydraulic conductivity and act as boundaries to the flow of groundwater (Johnson and Belitz 2003; Belitz et al. 2003). The fractured bedrock groundwater in the province's non-basin areas consists of carbonate rocks, such as limestone and dolomite, and

PUBLIC DRAFT

volcanic rocks, including welded tuffs, bedded tuffs, and lava flows. The carbonate rocks are deformed, faulted, and eroded, often forming isolated blocks and aquifers. The groundwater systems of the province approximate regional groundwater flow systems, as groundwater is transmitted along several valleys through the basin-fill and the carbonate-rock aquifers. While a complete description of the regional groundwater flow systems is unavailable, it has been noted that discharge from large springs in the alluvial basins is always in areas underlain by carbonate rocks (Planert and Williams 1995).

The province is part of the most arid area in the nation; the potential annual water loss through evapotranspiration exceeds the annual water gain from precipitation even at higher elevations. Clear skies and low humidity cause extreme daily and seasonal temperature ranges as the sparsely covered land surface is heated quickly by solar radiation and then rapidly cools at nightfall. The arid climate, combined with sparse vegetation and high temperature variability, further reduces soil moisture retention and increases surface water loss, limiting both surface and subsurface recharge (Musgrove and Belitz 2016). Recharge to the province's alluvial groundwater basins is primarily from infiltration of mountain streams and inflow from fractured bedrock, typically entering the subsurface along mountain fronts. As a result, groundwater in this province is often slow to replenish, highly dependent on infrequent storm events or mountain-front recharge, and vulnerable to overdraft or water quality degradation over time (Planert and Williams 1995). Between 2003 and 2023, the number of public supply wells in non-basin areas of the province increased from 20 to 63, growth of 215% (Belitz et al. 2003; California Department of Water Resources 2024).

Faults and springs in the province influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-43; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3). These features can enhance recharge or provide storage in otherwise low-yield settings.

Groundwater quality in the province varies significantly depending on whether it is drawn from alluvial basins or non-basin areas. In alluvial basins, groundwater often contains elevated levels of total dissolved solids (TDS) (Fram and Belitz 2012). In non-basin areas, groundwater quality is also variable, with naturally occurring constituents such as arsenic, fluoride, boron, and uranium sometimes exceeding drinking water standards. These exceedances are typically linked to prolonged water–rock interaction in volcanic terrains or geothermal systems (Fram and Belitz 2012; Belitz et al. 2003). Groundwater quality data from non-basin

PUBLIC DRAFT

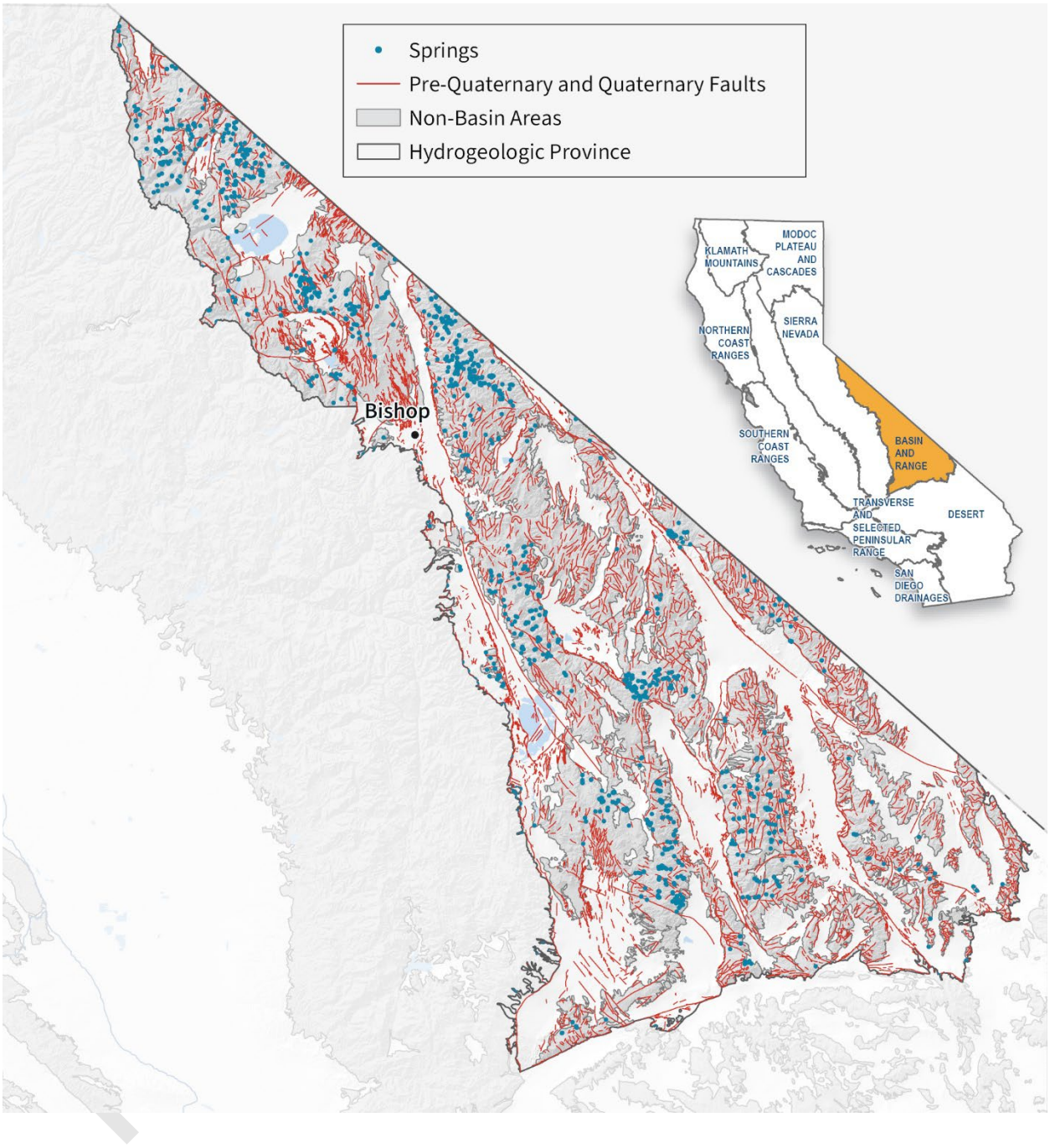
areas in the Basin and Range Province are limited. GAMA data focuses primarily on the alluvial Owens Valley and Indian Wells Valley. While taken from alluvial systems, these groundwater quality data may be indicative of conditions in the upgradient non-basin areas.

Within Owens Valley, trace elements with human-health benchmarks were present at high concentrations in 15% of the primary aquifers, on an areal basis, and at moderate concentrations in 13%. Of the 17 trace elements with human-health benchmarks analyzed in this study, four were detected at high concentrations: arsenic, boron, fluoride, and molybdenum. Radioactive constituents were found at concentrations above benchmarks in 10% of the primary aquifers, and at moderate concentrations in 15%. Six radioactive constituents were analyzed; of these, uranium and gross alpha radioactivity were detected at concentrations above human-health benchmarks. Inorganic constituents with non-health benchmarks were present at high concentrations in 15% of the primary aquifers, and at moderate concentrations in 8%. Of the seven constituents with non-health-based benchmarks that were analyzed, three (iron, manganese, and total dissolved solids) were detected at concentrations above benchmarks (Dawson and Belitz 2012a).

Within Indian Wells Valley, trace elements with human-health benchmarks were present at high concentrations in 54% of the primary aquifers, on an areal basis, and at moderate concentrations in 31%. Of the 17 trace elements with human-health benchmarks analyzed in this study, five were detected at high concentrations: arsenic, boron, molybdenum, strontium, and vanadium. Radioactive constituents were found at concentrations above benchmarks in 15% of the primary aquifers, and at moderate concentrations in 8%. Six radioactive constituents were analyzed; of these, uranium and gross alpha radioactivity were detected at concentrations above benchmarks. Inorganic constituents with non-health benchmarks were present at high concentrations in 23% of the primary aquifers, and at moderate concentrations in 31%. Of the seven constituents with non-health-based benchmarks that were analyzed, three (chloride, manganese, and total dissolved solids) were detected at concentrations above benchmarks (Dawson and Belitz 2012b).

PUBLIC DRAFT

Figure 3-43 Basin and Range Hydrogeologic Province Non-Basin Area – Faults and Springs



6. Southern Coast Ranges Hydrogeologic Province

The Southern Coast Ranges Hydrogeologic Province corresponds to the southern half of the Coast Ranges and includes 74 alluvial groundwater basins and 89 watersheds. The province is bounded to the west by the Pacific Ocean, to the north by San Francisco Bay, to the south by Transverse and Selected Peninsular Ranges Province, and to the east by the Central Valley Province. Specifically, the

western part of the boundary with the Transverse and selected Peninsular Ranges Province is defined by groundwater basin boundaries that approximate the Santa Ynez Fault; the eastern part of the boundary is defined by watershed boundaries that approximate the Santa Ynez and Big Pine faults. The boundary with the Central Valley Province is defined by the boundary of the San Joaquin groundwater basin. The non-basin area portion of the province covers approximately 11,200 square miles and accounts for about 70% of the total area (Johnson and Belitz 2003; Belitz et al. 2003). The province extends over the San Fransico Bay and Central Coast hydrologic regions primarily and covers very small portions of the Tulare Lake and South Coast hydrologic regions in the southeast.

The province is composed of a geologically diverse mix of marine sedimentary rocks, Franciscan Complex assemblages, localized volcanic rocks, and Quaternary alluvium. Marine sandstones, shales, and conglomerates from the Great Valley Sequence and younger Cenozoic deposits dominate much of the region. The Franciscan Complex, characterized by mélange, greywacke, chert, greenstone, and serpentinite, underlies much of the rugged terrain and has generally low permeability. Miocene volcanic rocks, including basalt and andesite, are present in scattered areas and can provide localized groundwater storage where fractured (Johnson and Belitz 2003; Belitz et al. 2003). Quaternary alluvial deposits fill structural valleys and basins and form the most productive aquifers. The non-basin area of the Santa Cruz Mountains is divided by faults associated with the San Andreas Fault Zone (United States Geological Survey 2014).

Faulting associated with the San Andreas system further influences groundwater occurrence and movement across the province. Faults and springs influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-44; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3).

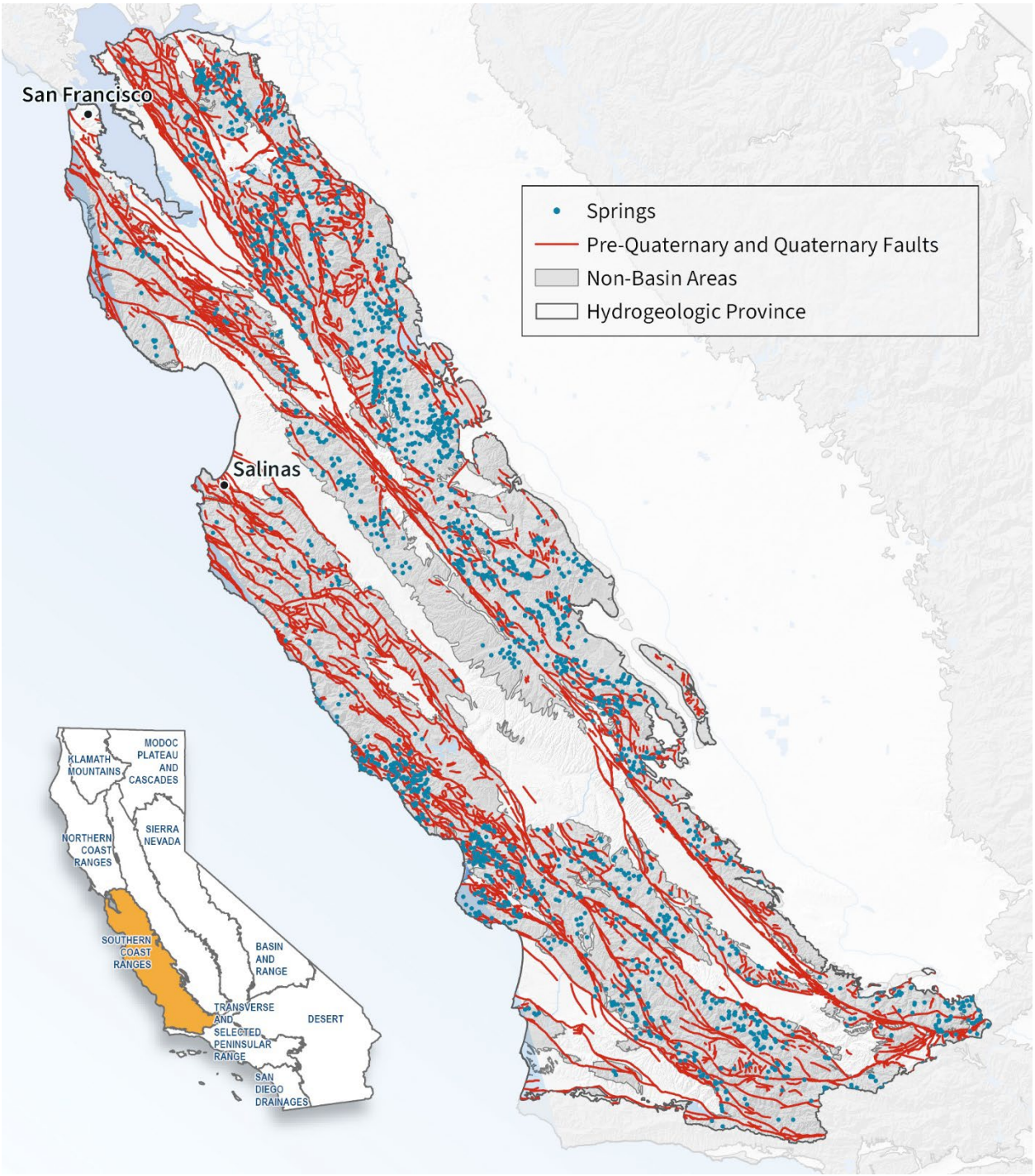
The climate in the province is mostly mediterranean, with wet winters and dry summers, characterized by coastal fog during the summer, and as a result, many of the streams and rivers run intermittently depending on the season. The coastal lowlands and valleys near the Pacific Ocean have a coastal climate, with warm, dry summers and cool, wet winters. The slopes of the coastal valleys and within the upland areas have a Mediterranean climate with hot, dry summers and cool, wet winters. Average annual rainfall ranges from 13 inches in the coastal lowlands to 20 inches in the uplands (Burton and Belitz 2013). Groundwater is heavily relied upon, especially during drought periods when the seasonal streams and rivers have reduced flows. Between 2003 and 2023, the number of public supply wells in

PUBLIC DRAFT

the non-basin area decreased from 480 to 439, a 9% reduction (Belitz et al. 2003; California Department of Water Resources 2024e).

PUBLIC DRAFT

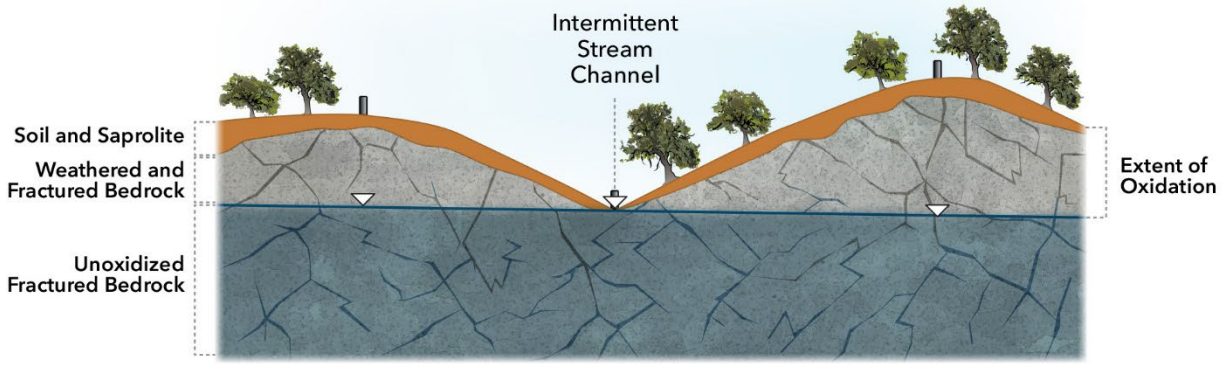
Figure 3-44 Southern Coast Ranges Hydrogeologic Province Non-Basin Area – Faults and Springs



The Franciscan Complex in non-basin areas of the province tends to be highly fractured and deeply weathered. A recent study on water flow in the Arbor Creek Experimental Catchment located in the Diablo Mountain Range in central coastal California demonstrated that subsurface fractures are due to the geologic and

tectonic setting, which encourages the infiltration of precipitation down to the water table and to the adjacent intermittent stream channel of Arbor Creek. The study coupled data from borehole drilling, groundwater monitoring, and seismic refraction, concluding that infiltrated precipitation and groundwater flow paths exploit and chemically weather the tectonically derived fractures in the bedrock, and hydraulic conductivity of the bedrock is enhanced by chemical weathering processes such as oxidation at depths above and at the water table (Callahan et al. 2024) (Figure 3-45). The results of the study have important implications for groundwater recharge, streamflow, inter-basin groundwater flow, and regional groundwater supplies in larger catchments within the upper watersheds within highly fractured and weathered zones of non-basin areas of the Central Coast Ranges (Callahan et al. 2024).

Figure 3-45 Conceptual Model Illustrating Interactions Between Fracturing, Chemical Weathering, and Hydrologic Processes Based on Field Measurements (after Callahan et al. 2024)



Water quality sampling of groundwater from 25 public drinking water supply wells showed elevated concentrations of arsenic, boron, molybdenum, fluoride, iron manganese, chloride, sulfate, and TDS. Iron and manganese and to some extent TDS were more significant in terms of number of wells. The observed groundwater quality issues are primarily the result of natural geologic sources and geochemical conditions, including water–rock interaction, redox processes, and mineral dissolution, common to the complex lithologies and slow-flowing groundwater systems of the Southern Coast Ranges Province (United States Geological Survey 2014).

7. Transverse and Selected Peninsular Ranges Hydrogeologic Province

The Transverse and Selected Peninsular Ranges Hydrogeologic Province includes 33 alluvial groundwater basins and 167 watersheds. The province is defined by the Pacific Ocean to the west and the boundaries with the Southern Coast Range, Sierra Nevada, and Desert provinces. Boundaries with these adjacent provinces are defined by groundwater basin and watershed boundaries, where possible, that approximate geologic boundaries, including the Santa Ynez, Big Pine, and San Andreas faults. The boundary with the San Diego Drainages province is defined by watersheds and groundwater basins, including the Santa Ana, Elsinore, and San Jacinto groundwater basins, which are included in the Transverse and Selected Peninsular Ranges Province.

The Transverse and Selected Peninsular Ranges Province is one of the smallest provinces by area but includes the heavily populated Southern California coastal plain and adjacent inland valleys. The province also includes the Santa Ynez, Santa Monica, San Gabriel, and San Bernardino mountains. The groundwater basins of the Transverse and Selected Peninsular Ranges Province contain the highest density of public-supply wells in California (number of wells divided by area). The mountain areas of the province also contain a disproportionately large number of public-supply wells. The non-basin area portion of the province covers approximately 5,400 square miles and accounts for about 65% of the total area (Johnson and Belitz 2003; Belitz et al. 2003). The majority of the province is within the South Coast Hydrologic Region; small portions can also be found in the Colorado River and Central Coast hydrologic regions to the east and north, respectfully.

The non-basin fractured-rock areas are highly variable due to extensive tectonic activity associated with the San Andreas Fault system and includes Eocene (34 to 56 million years ago) marine shale, sandstone, minor limestone, plutonic igneous rocks, metamorphic schists, and Cenozoic marine and nonmarine sedimentary rocks, along with noncarbonate shallow marine terranes (Dellinger 1989). The Transverse Ranges' east-west orientation and complex faulting from the San Andreas Fault system, along with the northwest displacement of the Peninsular Ranges, have created a fractured and geologically diverse bedrock framework. This tectonic history underlies the region's variable groundwater conditions, with limited storage and flow primarily through fractures in granitic, marine, and volcanic rocks (Dellinger 1989; Mathany et al. 2017).

PUBLIC DRAFT

The province features a Mediterranean climate with warm, dry summers and cool, wet winters. Most precipitation falls as rain from winter through early spring, with snowfall occurring in the higher elevations of the San Gabriel Mountains. Average annual temperature at the Mount Wilson station, located within the San Gabriel Mountains, is approximately 55 °F, and total annual precipitation averages about 14 inches. The highest peak in the area, Mount San Antonio, rises to about 10,000 feet. Groundwater recharge occurs primarily through infiltration from mountain runoff and streambed percolation, especially where the water table lies below stream levels (United States Geological Survey 2014).

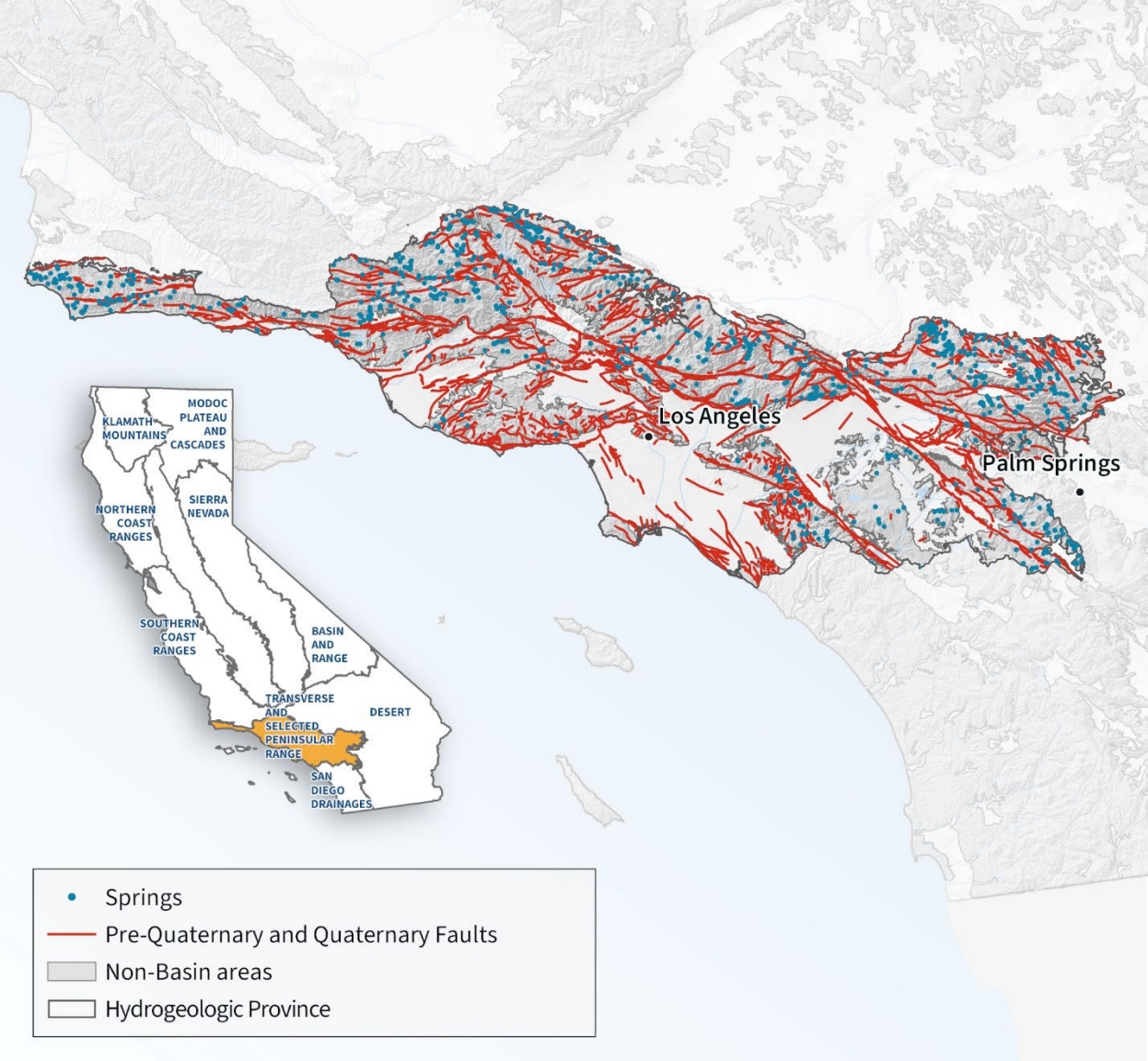
This province includes the Los Angeles metropolitan area, a global population hub with substantial water demands. Historically, groundwater flowed primarily from the inland non-basin area mountains to alluvial basins and on to the Pacific Ocean, but over time the hydraulic gradient has changed, directing flow inward toward groundwater extraction centers rather than the ocean. Structural features, such as faults and anticlines, significantly influence or restrict groundwater flow in various parts of the province (Planert and Williams 1995).

Faults and springs influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-46; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3).

Between 2003 and 2023, the number of public supply wells in the fractured rock non-basin areas of the province declined by 36%, from 800 to 510 (Belitz et al. 2003; California Department of Water Resources 2024e). As the most densely populated part of the state, the coastal plain and adjacent inland valleys have experienced extensive urbanization, prompting the consolidation of water supply systems and a shift away from small, decentralized public wells (Planert and Williams 1995; Johnson and Belitz 2003).

PUBLIC DRAFT

Figure 3-46 Transverse and selected Peninsular Ranges Hydrogeologic Province Non-Basin Area – Faults and Springs



Understanding groundwater quality in the province is essential for protecting public health and managing non-basin fractured-rock groundwater that supplies water to both urban and rural communities. These geologically complex areas often contain naturally occurring contaminants like arsenic, uranium, and radon that exceed health benchmarks. Limited aquifer connectivity, variable recharge, and long groundwater residence times contribute to elevated concentrations. Recent studies highlight the need for continued monitoring and site-specific management to ensure safe and sustainable groundwater use.

Groundwater quality data exists for several key non-basin fractured-rock areas. In the San Gabriel and Castaic mountains, primarily composed of granitic rocks, plutonic rocks, and schist, samples from 37 non-basin area wells, with 13 of the wells identified as springs, identified arsenic, boron, molybdenum, and fluoride with exceedances in human-health benchmarks in several wells. Iron, manganese, and TDS exceeded aesthetic benchmarks. Radioactive constituents were notable, with radon-222, gross alpha activity, and uranium exceeding human-health benchmarks. Since most radioactivity in groundwater arises from naturally occurring isotopes of uranium and thorium, management options for exceedances are limited, but routine monitoring is crucial to identify elevated concentrations and avoid groundwater use in areas hazardous to human health (United States Geological Survey 2014).

In the Lake Arrowhead non-basin area of the San Bernardino Mountains, wells are completed in granitic bedrock, and springs or horizontal wells provide more than half of the water supplies to the area, which features a mix of natural and urban land use, with forests dominating the natural landscape. Groundwater quality data from wells showed organic constituents with human-health benchmarks, such as VOCs, detected at high or moderate concentrations in about 8% of samples. Radioactive constituents, including uranium and adjusted gross alpha particle activity, were found at high levels in about 25% of samples also coming from the decay of uranium and thorium isotopes. Manganese and iron exceeded aesthetic benchmarks in 23% of samples. Radon-222, a constituent with proposed benchmarks, exceeded the proposed level in about 62% of samples (Mathany et al. 2017).

The USGS analyzed tritium, a radioactive isotope used to determine groundwater age. The results showed that some groundwater was recharged within the past 50 years, while other groundwater was recharged hundreds to thousands of years ago, indicating a mix of pre-modern and more recent groundwater (Mathany et al. 2017).

A recent groundwater investigation conducted in the non-basin area San Gabriel Mountains within the Angeles National Forest used continuous rock coring, in-situ hydraulic conductivity testing, groundwater sampling, and monitoring of boreholes using pressure transducers to characterize groundwater in the study area. The in-situ hydraulic conductivity testing showed a wide range of values, reflecting the rock's non-uniform nature due to varying degrees of fracturing and interconnectivity; however, the effective hydraulic conductivity values were relatively low, indicating limited potential for the fractured rock to yield large

PUBLIC DRAFT

quantities of water. Pressure transducer data from boreholes showed open vertical pathways for water flow and demonstrating connectivity near faults. In contrast, two deep boreholes within less fractured bedrock displayed multiple zones of isolated groundwater pressures, indicating limited hydraulic connectivity within the rock mass. Additionally, an abrupt increase in groundwater pressure was observed at several depths in boreholes near faults within one to two months of a rainfall event (California High-Speed Rail Authority and United States Department of Transportation 2019).

Water chemistry analysis from the USGS GAMA program identified a calcium carbonate (Ca-HCO_3) water type in shallow wells, while deeper groundwater from the geotechnical investigation exhibited a calcium sulfate (Ca-SO_4) type. This distinction suggests that the shallow wells sampled in the GAMA program are not connected to the deeper groundwater tested during the geotechnical investigation. Furthermore, carbon-14 age-dating revealed that deep groundwater within the mountains is approximately 4,500 years old, indicating it has not been replenished by recent rainfall (California High-Speed Rail Authority and United States Department of Transportation 2019).

Springs were also investigated for changes in discharges in the study area, and approximately 20 springs within a 25-square-mile area were identified. Those springs located on public lands were monitored from 2016 to 2020, and, during that time, some springs had dried up. Data collected indicate varied spring responses to seasonal conditions: some springs showed increased flow following winter rains, while others did not exhibit an immediate response. Additionally, several springs demonstrated a slight increase in discharge during summer months, despite the lack of rainfall (California High-Speed Rail Authority and United States Department of Transportation 2019).

8. San Diego Drainages Hydrogeologic Province

The San Diego Drainages Hydrogeologic Province includes 25 alluvial groundwater basins and 163 watersheds. The province is bounded to the west by the Pacific Ocean, to the north by the Transverse and Selected Peninsular Ranges Province, to the east by the Desert Province, and to the south by the Mexican border. The province includes the drainage areas of the Santa Margarita, San Luis Rey, San Dieguito, and San Diego rivers. In contrast to the Transverse and Selected Peninsular Ranges Province, the groundwater basins of the San Diego Drainages Province do not include a large number of public-supply wells. The non-basin fractured-rock area of the province covers approximately 3,500 square miles and

PUBLIC DRAFT

accounts for about 90% of the total area (Planert and Williams 1995; Johnson and Belitz 2003; Belitz et al. 2003). The province is nearly entirely within the South Coast Hydrologic Region, with a small portion extending into the Colorado River Hydrologic Region in the northeast.

The province consists of Mesozoic granitic and metamorphic rocks with small amounts of Mesozoic volcanic and Cenozoic marine sedimentary rocks. The coastal area features alluvium deposits and Tertiary sedimentary rocks, with some Eocene non-marine sandstone present (Planert and Williams 1995; Johnson and Belitz 2003; Belitz et al. 2003). In the western portion of the province, late Tertiary or Quaternary movement along northwest-trending normal faults shaped much of the present physiography. This landscape is broadly divided into three elevation belts: a low coastal belt covered primarily by sedimentary rocks; an intermediate belt resembling a dissected plateau; and the highlands, characterized by rugged relief but topped with surfaces of low relief (Figure 3-47). Fractured bedrock groundwater is most significant in the intermediate and highland belts (California Department of Natural Resources 1951).

The plateau-like surfaces are of particular interest because they appear to have undergone deeper weathering, leading to better fractured rock groundwater development, where hydraulic conductivity is influenced by structural features such as joints and faults, and chemical weathering. Intergranular openings created by weathering serve as the primary fractured rock groundwater reservoirs. While nearly all rocks in the region are deeply weathered, the extent of weathering varies based on factors like topographic position, temperature fluctuations, and moisture availability (California Department of Natural Resources 1951).

The highlands appear to be recently uplifted old surfaces of low relief that underwent significant weathering before uplift, contributing to variations in groundwater availability. Water yields in metamorphic rocks are highly variable, depending on local conditions and the specific type of rock; for instance, quartzite is massive with widely spaced joints, making it expensive to drill and yielding minimal water. Gabbro, on the other hand, is generally favorable for groundwater extraction, while tonalite, the most abundant rock in the area covering over half the region, is a moderately good water source except in bouldery areas. Granodiorite, with its prominent, widely spaced joints and clean-cut fractures, facilitates some water flow but is typically the poorest source of fractured bedrock water, rarely producing more than a few gallons per minute from domestic wells. Additionally, weathering in granodiorite results in tightly cemented grus (or decayed granite sand, where chemical weathering of the bedrock induces granular

PUBLIC DRAFT

disintegration), which does not improve its water-bearing properties, though small springs are occasionally found along brecciated zones (California Department of Natural Resources 1951).

Figure 3-47 Groundwater Monitoring Well in the Fractured Rock Non-Basin Area Near the San Pasqual Valley Alluvial Groundwater Basin, San Diego Drainages Hydrogeologic Province



Photo Credit — DWR, Southern Region Office 2012.

The province experiences a mediterranean climate characterized by warm, dry summers with abundant sunshine and mild winters with modest precipitation. Precipitation patterns are influenced by elevation, with the highest amounts occurring in mountainous non-basin areas. The non-basin areas serve as surface water sources for alluvial groundwater basins, and surface runoff from the mountains that infiltrates the permeable sediments of alluvial basins, primarily through basin margins and streambeds, significantly contributes to groundwater recharge. The majority of land in the non-basin areas is undeveloped, which

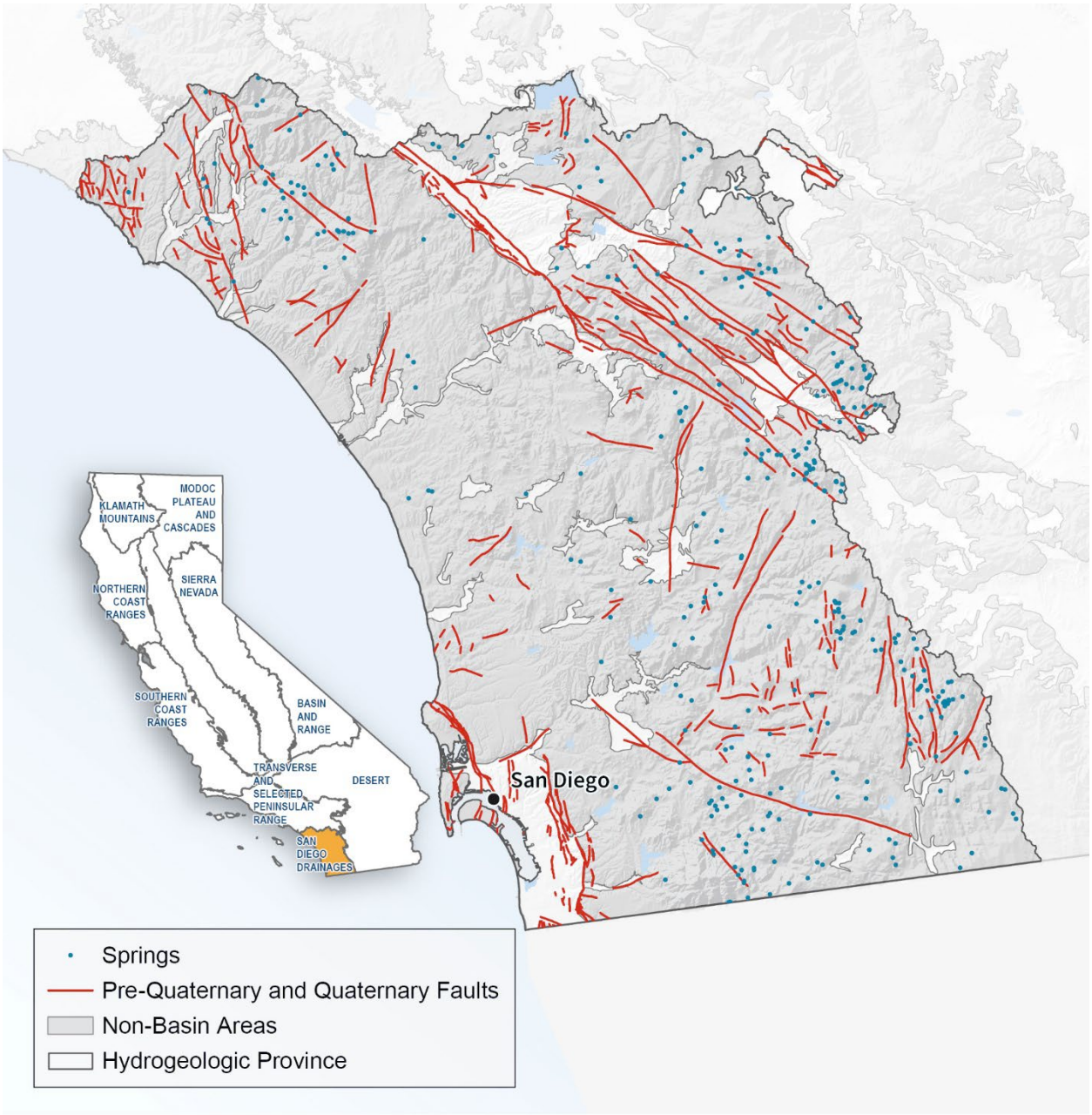
facilitates the natural recharge process by allowing precipitation to percolate into the fractured rock groundwater system.

Faults and springs influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-48; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see Section 3.2.3).

The non-basin areas are important for groundwater sustainability of the province as a whole. (Planert and Williams 1995). Between 2003 and 2023, the number of public supply wells in the non-basin area increased from 120 to 224, growth of 87% (Belitz et al. 2003; California Department of Water Resources 2024e), likely due to expansion of residential growth creating an increased reliance on fractured rock sources to meet local water demand in areas without access to larger municipal supply systems.

PUBLIC DRAFT

Figure 3-48 San Diego Drainages Hydrogeologic Province Non-Basin Area – Faults and Springs



Groundwater quality in the fractured rock non-basin area of the province was characterized by sampling from selected wells completed in hard rock within an 850 square mile area (Wright and Belitz 2011). Concentrations compared to health-based benchmarks were high in 25% of the study area wells and constituents including vanadium, arsenic, and boron appear to be correlated to pH, where alkaline groundwater inhibits these constituents from adsorbing to particle surfaces. High relative concentrations of manganese were detected in 33% of the

study area wells, with higher TDS in 17% of the study area wells. High relative concentrations of radioactive Radon-222, a naturally occurring radioactive gas common in groundwater, were observed in 25% of the study area wells, with the highest detections occurring in the crystalline rock aquifers. Additionally, herbicides were present in 40% of the study area wells, reflecting potential surface-level influences. (Wright and Belitz 2011; United States Geologic Survey 2011).

9. Desert Hydrogeologic Province

The Desert Hydrogeologic Province corresponds to the Mojave Desert and Colorado Desert geomorphic provinces. The province is the largest hydrogeologic province in the state and includes 96 alluvial groundwater basins and 110 watersheds. The boundaries of the province are based on alluvial groundwater basins, watersheds and faults, and the borders of Nevada, Arizona, and Mexico. The boundary with the Transverse and Selected Peninsular Ranges Province is primarily defined by groundwater basin boundaries that delineate the San Gabriel and San Bernardino mountains, which are part of the Transverse and Selected Peninsular Ranges Province. Groundwater basins along the boundary include the Antelope, Mojave, and Coachella basins. The boundary with the Basin and Range Province is defined by groundwater basin boundaries. The boundary with the San Diego Province is defined by a major watershed divide demarcating the South Coastal and Colorado River hydrologic regions. The non-basin area portion of the province covers approximately 9,600 square miles or 30% of the total province area (Johnson and Belitz 2003; Belitz et al. 2003). The province is within the Colorado Hydrologic Region and the southern portion of the South Lahontan Hydrologic Region.

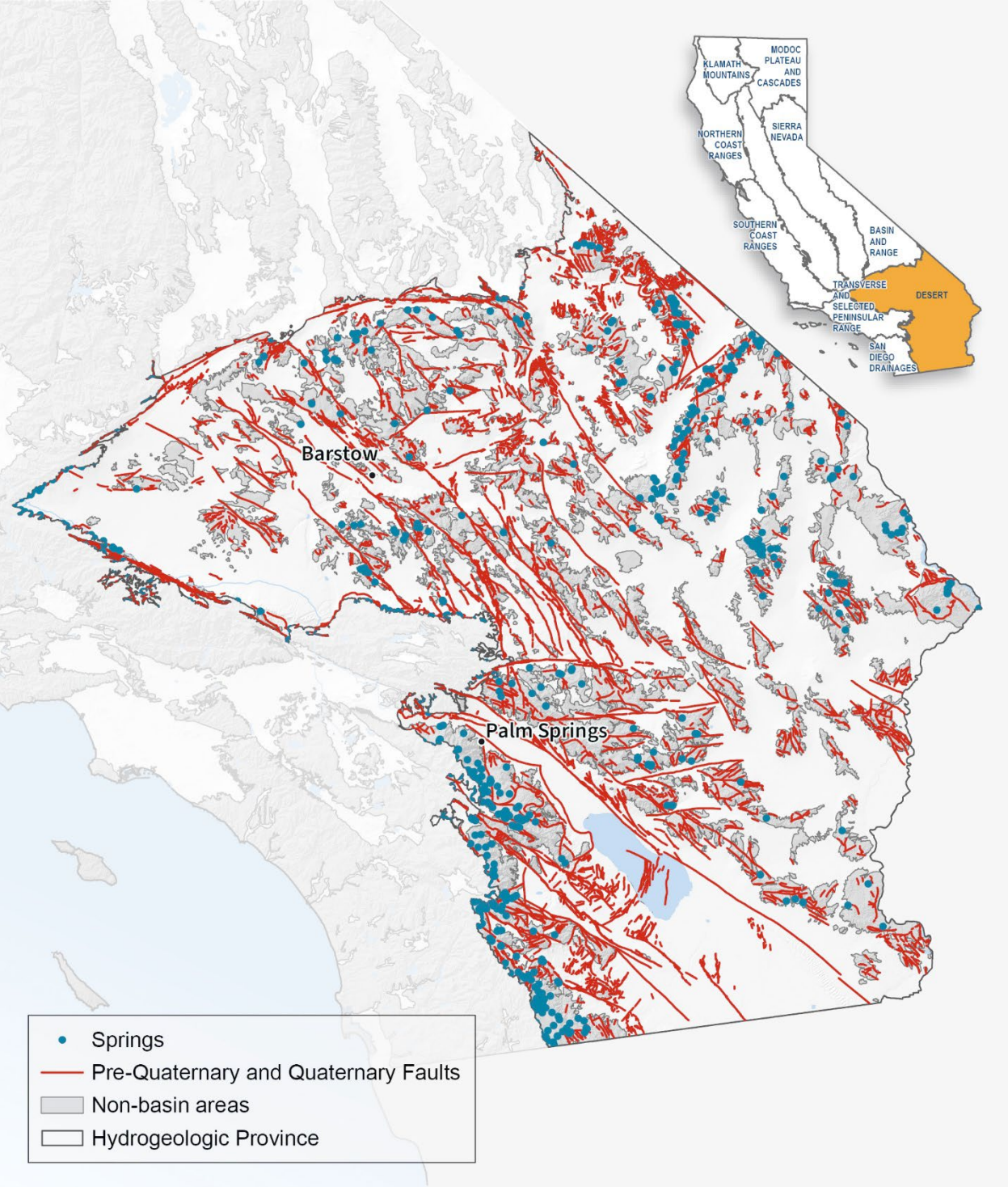
The province is composed of alluvial deposits, with scattered zones of volcanic rocks, plutonic rocks, and nonmarine sandstone. Rocks in the province range from 1.7 billion to 1,800 years old and have undergone significant tectonic uplift, extension, faulting, and volcanism, resulting in a landscape where groundwater occupies very old to relatively new spaces within an almost chaotic framework of structure and rock types. In the late Cenozoic, uplift and crustal extension gave rise to numerous closed drainage basins, resulting in extensive evaporite deposits, including borates (Dellinger 1989). The province is crisscrossed by numerous active faults, such as the Garlock Fault, the Eastern California Shear Zone, and the San Andreas Fault Zone, associated with ongoing crustal extension, strike-slip tectonics, and frequent earthquakes. Faulting in this area has led to the formation of extensive fault blocks and numerous pull-apart basins, including the Salton Trough (Wallace 1990).

PUBLIC DRAFT

Faults and springs influence and indicate, respectively, the occurrence of non-basin area groundwater and are shown in Figure 3-49; meadows, which indicate the occurrence of non-basin area groundwater, are shown in Figure 3-4 (see section 3.2.3).

PUBLIC DRAFT

Figure 3-49 Desert Hydrogeologic Province Non-Basin Area – Faults and Springs



The province receives little precipitation, making it the most arid area in the U.S.; evapotranspiration exceeds the annual water gain from precipitation, even at the higher elevations. As a result, almost all the rainfall is lost back to the atmosphere through evapotranspiration, either through plants, the soil, or by evaporation from

lakes and dry flats in the lower areas, leaving no water available to flow into surface water bodies. Because of the scarcity of both the surface water and groundwater, the province faces significant water supply challenges. Despite the scarcity of water, with the help of imported water, this province has some of the largest desert irrigation areas in the state, such as Imperial and Coachella Valleys (Planert and Williams 1995). The non-basin fractured-rock areas of the province host about 2,500 wells, including monitoring, domestic, and production wells. While public supply wells make up a small portion of this total, their number increased modestly from 60 to 64 between 2003 and 2023, a 7% increase, reflecting limited but growing use of local fractured rock sources in areas not served by imported water or larger distribution systems (Belitz et al. 2003, United States Geologic Survey 2003; California Department of Water Resources 2024e).

One notable aspect of the province is the Salton Buttes, a group of volcanic rhyolite domes located within the Salton Sea Geothermal Field on the south shore of the Salton Sea. The most recent eruptions from the Salton Buttes, approximately 1,800 years ago, formed dense obsidian lava domes following an initial explosive phase (United States Geologic Survey 2019). Volcanic and geothermal activity in this area is driven by a shallow magmatic heat source that heats groundwater, forming thermal springs, mud pots, and a high-temperature geothermal reservoir about one mile below the surface (Griscom and Muffler 1971). Developed for energy production in the 1980s, the field currently supports 10 geothermal power plants with 437 megawatts of capacity, with a total estimated potential of 2,000 megawatts (California State Lands Commission 2015). The geothermal brine also contains some of the highest concentrations of lithium in geothermal fluids worldwide (Blue Ribbon Commission 2022). This activity is significant for groundwater resources as it alters subsurface temperatures, water chemistry, and aquifer conditions. Interactions with geothermal brines can lead to elevated concentrations of naturally occurring constituents, and sustainable groundwater management is critical to maintaining energy production and protecting water quality in the region.

The diversity of California's nine non-basin hydrogeologic provinces reflects the state's complex geologic history and presents a wide range of groundwater conditions across fractured rock terrains. Each province varies in its lithology, faulting, climate, and presence of natural features like springs and meadows — all of which influence groundwater occurrence, flow paths, and storage potential. This variability underscores the importance of region-specific approaches to groundwater assessment and management in non-basin areas. While these fractured systems may not store water as predictably as alluvial basins, they are

PUBLIC DRAFT

vital to sustaining ecosystems, headwater streams, and communities throughout the state. Building on this hydrogeologic foundation, the next section explores how these non-basin areas contribute to groundwater recharge, both locally and across connected watershed systems.

3.5.3 Recharge Areas in Non-Basin Areas

Recharge occurring in non-basin areas is critical for groundwater resources both in non-basin and alluvial basin areas. Much of this recharge begins as precipitation. The rainfall, or frozen precipitation after melting, in non-basin areas may travel several paths in the natural system:

- Flow over the ground surface to join streams and rivers.
- Percolate into fractured rock to become groundwater.
- As groundwater, be taken up by vegetation and trees.
- As groundwater, flow through fractured rock to a meadow or emerge as a spring.
- As groundwater, flow through fractured rock to mountain range front alluvial fans, eventually merging with valley floor alluvial aquifers.

These interconnected processes play a crucial role in California's hydrology, influencing both surface water and groundwater recharge. Recent studies and models show that California's non-basin area mountain-valley groundwater systems serve as a primary source of groundwater recharge for valley alluvial groundwater basins (Meles et al. 2024; Armengol et al. 2024). A mountain-valley system allows groundwater to flow laterally from mountain blocks to valley alluvial basins. In these systems, rainfall and snowmelt infiltrate into mountain block aquifers, primarily through deep joints, fractures, and faults, while seepage from streams and lakes also contributes to groundwater recharge.

In a representative non-basin area headwater of the Colorado River, Carroll et al. 2024, demonstrate that groundwater contributions have historically been an important and stable contribution to stream water (approximately 26%), and groundwater recharge occurs through the percolation of infiltrated water below the soil zone (areal recharge) and via streamflow loss into the groundwater system (seepage recharge) (Carroll et al. 2024).

Non-basin hillslope areas can be important sources of water for the aquifers that communities rely on in California's valleys. A recent study found that water seeping into the ground from hillsides along lineaments can provide between 15

PUBLIC DRAFT

and 50% of the water that refills these valley aquifers. Lineaments are geologic structures, such as faults, cleavages, fractures, and joints — that are arranged in a straight line or slight curve, and allow infiltration of rainfall, snowmelt, and streams to groundwater in the hillslopes, which in turn flows through the subsurface to recharge adjacent valley aquifers. For non-basin areas with natural lineaments, increased recharge may be possible by using existing roadways and drainages to direct surface runoff into naturally occurring or constructed runoff retention areas (Meles et al. 2024).

Recent simulations of deep groundwater flow and flow paths across the continental United States (Yang et al. 2025) suggest that deep, upper watershed, non-basin area groundwater may travel underground much farther than previously thought — ranging from more than 30 miles to approximately 150 miles, depending on the region. The study also indicates that deep groundwater flow can contribute more than half of stream baseflow, and that lateral groundwater flow between watersheds and alluvial basins is significant. Recent studies, modeling efforts, and simulations highlight the importance of deep lateral groundwater flow across both alluvial and non-basin areas, reinforcing the need to view streams and aquifers as interconnected systems, even at very large scales.

Headwaters

California's headwaters and streams primarily originate in the upper portions of non-basin areas, fed by melting snow or ice or by streams overflowing from aquifers (Water Education Foundation 2024). These headwaters provide a source of clean water supply to downstream users, serve as essential habitat for native species, and offer recreational opportunities for nature lovers (American Rivers 2023). Healthy headwaters and ecosystems play a crucial role in enhancing groundwater recharge in non-basin and alluvial groundwater basin aquifers, while also contributing to the overall quality of groundwater and surface water.

Highland Areas

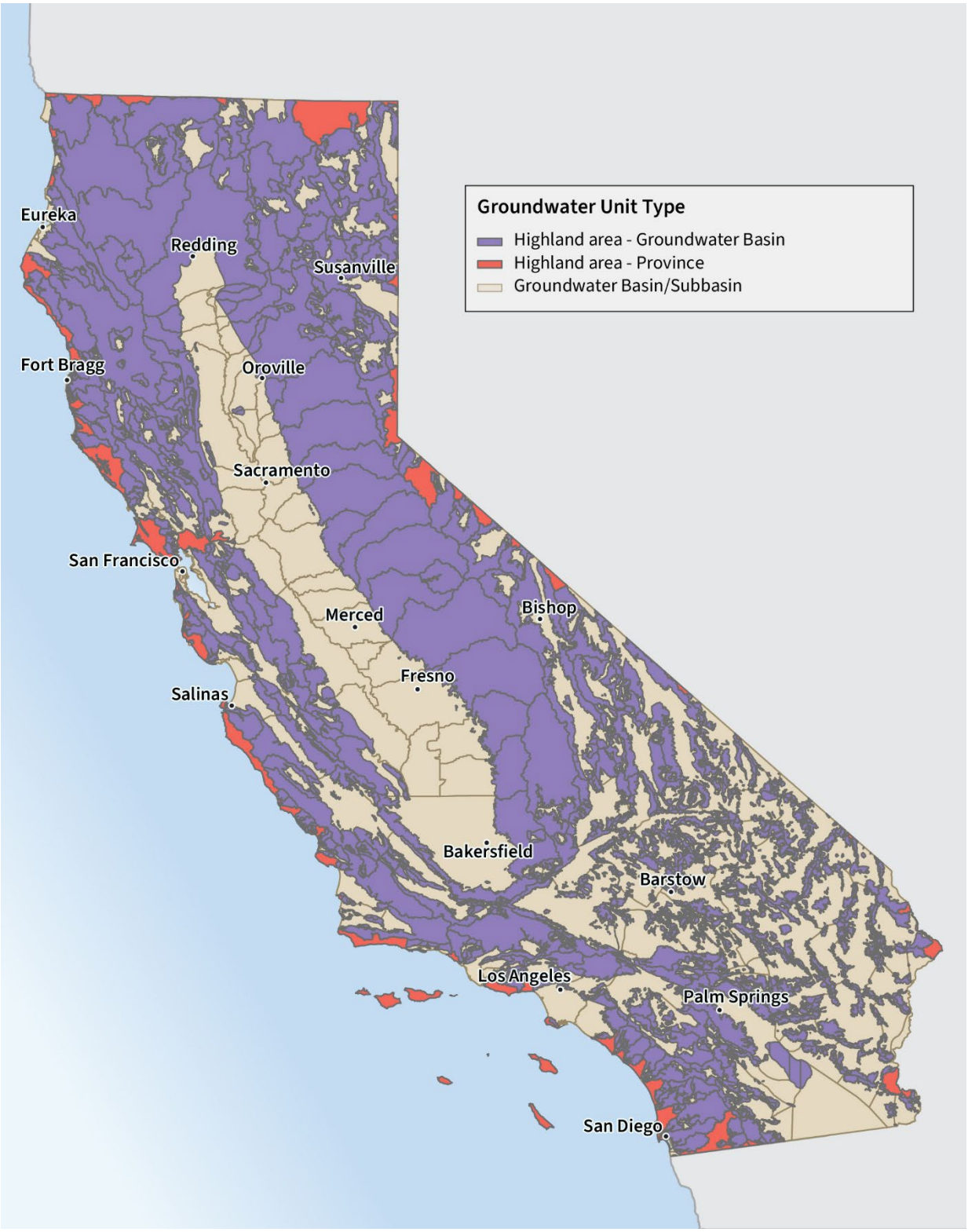
Groundwater recharge is part of the natural infrastructure of non-basin area groundwater systems. Highland areas, particularly those adjacent to or upstream of groundwater basins, play a critical role in this process by serving as important sources of precipitation, runoff, snowmelt, and subsurface flow that contribute to recharge in nearby alluvial basins. Future work is planned to analyze the potential groundwater recharge that may originate specifically from non-basin highland areas and flow into adjacent groundwater basins. USGS's California Groundwater Units dataset classifies and delineates these areas across California. The dataset

PUBLIC DRAFT

includes the following three categories: (1) areas previously defined as alluvial groundwater basins or subbasins, (2) highland areas that are adjacent to and topographically upgradient of groundwater basins, and (3) highland areas not associated with a specific groundwater basin but instead delineated by hydrogeologic province (Figure 3-50) (Johnson and Belitz 2014).

PUBLIC DRAFT

Figure 3-50 California Highland Areas Adjacent to Groundwater Basins and Province-Based Highland Areas (from Johnson and Belitz 2014)



Meadows

Previously discussed as a critical component of natural infrastructure in Section 0, meadows are generally located in upper watersheds of non-basin areas at elevations between 4,000 and 8,000 feet. Meadows act as local reservoirs to absorb high-elevation precipitation and snowmelt, which is stored in the meadow as groundwater and then slowly released to provide baseflow to streams during dry periods. Meadows are a key component of non-basin area recharge, providing an essential source of surface water and groundwater in the upper watersheds and also providing a natural buffer against floods (Purdy and Moyle 2006).

Meadow groundwater helps buffer streamflow fluctuation during dry years and promotes recovery of baseline streamflow conditions (Carroll et al. 2023). A 2012 meadow restoration project in Indian Valley, part of the Mokelumne watershed near Lake Tahoe, documented that the meadow system was experiencing more inflow from spring runoff than outflow, meaning the meadow actively stored water in spring seasons that shifted to greater outflows during the summer. The meadow thus acted as a natural reservoir releasing flow to the lower watershed. Before restoration, the total summer outflow from the meadow was 5% more than the total summer inflow. After restoration, total summer outflow from the meadow was between 35% and 95% more than total summer inflow. In the worst year of the drought (2015), summer baseflow was at least five times greater than before restoration. The meadow stores water and naturally extends the release of water into the dry season, a notable benefit to lower elevation ecosystems and users (Hunt et al. 2018). This delayed release of stored water in the upper watersheds also helps to regulate stream temperatures, filter out sediment to improve stream water quality, and allows more water to recharge local and regional groundwater systems (National Park Service 2024). Such benefits are important to the state's water supplies, as there are approximately 191,000 acres of meadows in the Sierra Nevada alone (Kahn 2023).

3.5.4 Non-Basin Area Characterization Efforts

California's non-basin fractured-rock groundwater systems have long been recognized as essential but challenging components of the state's water infrastructure. Since 1975, the California Department of Water Resources (DWR) has documented groundwater in fractured rock through various publications, including California's Groundwater Updates and California Water Plan Updates, as well as a series of informational reports and Water Facts between 1991 and 2010.

PUBLIC DRAFT

Early reports described fractured rock groundwater as unpredictable and limited due to its reliance on cracks, fissures, and faults for water storage and movement. They also highlighted volcanic regions, such as the Modoc Plateau, Napa-Sonoma Highlands, and Clear Lake as having more permeable formations capable of storing and transmitting larger groundwater volumes. Over time, DWR's assessments expanded to identify the Sierra Nevada, Coast Ranges, and Peninsular Ranges as additional groundwater source areas, even though these have widely varying well yields.

California's Groundwater Update 2003 emphasized the growing reliance on non-basin fractured-rock groundwater, particularly in foothill communities, and raised concerns about the uncertainty of long-term supply, increased well drilling, and impacts on streamflow and habitat. It also outlined data gaps and recommended expanded groundwater studies, local groundwater management efforts, and potential legislative actions to improve oversight in these areas.

California's Groundwater Update 2013: A Compilation of Enhanced Content for California Water Plan Update 2013 provided the first statewide hydrologic region-based summary of non-basin area groundwater. It highlighted the lack of monitoring data, the critical reliance of domestic wells and small public systems on these sources, and the hydrogeologic complexities of fractured-rock aquifers. Further insights emerged in 2020, with *California's Groundwater Update 2020* offering the most comprehensive data to date, reinforcing previous concerns and calling for increased monitoring, improved understanding of groundwater-surface water interactions, and better assessments of non-basin area recharge contributions. Public comments from 2020 to 2023 further stressed the need for expanded groundwater data collection, improved local groundwater management, and watershed-scale approaches to water resource planning.

Recent studies have highlighted the vulnerabilities of isolated communities relying on fractured rock groundwater, such as the Chicken Ranch Rancheria of Me-Wuk Indians in Tuolumne County, where wells became unreliable during drought conditions. As climate change accelerates, non-basin area groundwater users face increasing risks of water shortages, making better data collection, resource planning, and infrastructure development critical for ensuring water resilience across California's fractured rock regions.

Given DWR's extensive efforts in groundwater basin characterization through the Basin Characterization Program, a parallel effort focused on non-basin areas is needed to close critical knowledge gaps. Improved data collection, monitoring, and

PUBLIC DRAFT

modeling of fractured rock groundwater would enhance understanding of groundwater availability, recharge dynamics, and groundwater-surface water interactions in these regions. Additionally, integrating non-basin area hydrogeologic assessments with statewide water planning efforts would help address long-term water supply reliability and inform climate adaptation strategies. As California continues to develop a more comprehensive understanding of its groundwater systems, characterizing non-basin fractured-rock groundwater should be prioritized to ensure sustainable water management for both rural communities and broader regional water systems.

The awareness of the importance and significance of groundwater in non-basin areas has been increasing in recent years. This increased awareness is linked to the improved understanding of how non-basin areas interact with and contribute groundwater to basin areas. USGS is involved in two non-basin area characterization mapping efforts within California as listed below:

- Geologic Mapping in the Southern Pacific Border and Sierra Provinces
- Klamath Dam Removal Studies

3.6 Built Groundwater Infrastructure

Built groundwater infrastructure consists of constructed facilities and conveyance systems used to extract, replenish, and transport groundwater. It is intricately connected to the natural groundwater infrastructure described in the previous sections and provides the means to access, utilize, manage, and benefit from California's aquifer systems. A comprehensive understanding of California's built groundwater infrastructure, including how it is used, its management strategies, components, locations, benefits, challenges, successes, opportunities, and required investments — is essential for enhancing the state's water resilience, climate change adaptation, and groundwater sustainability (see Chapter 1, "Vision and Context for Sustainable Groundwater Management"). This section discusses various methods and strategies for extracting, replenishing, and transporting groundwater via built groundwater infrastructure.

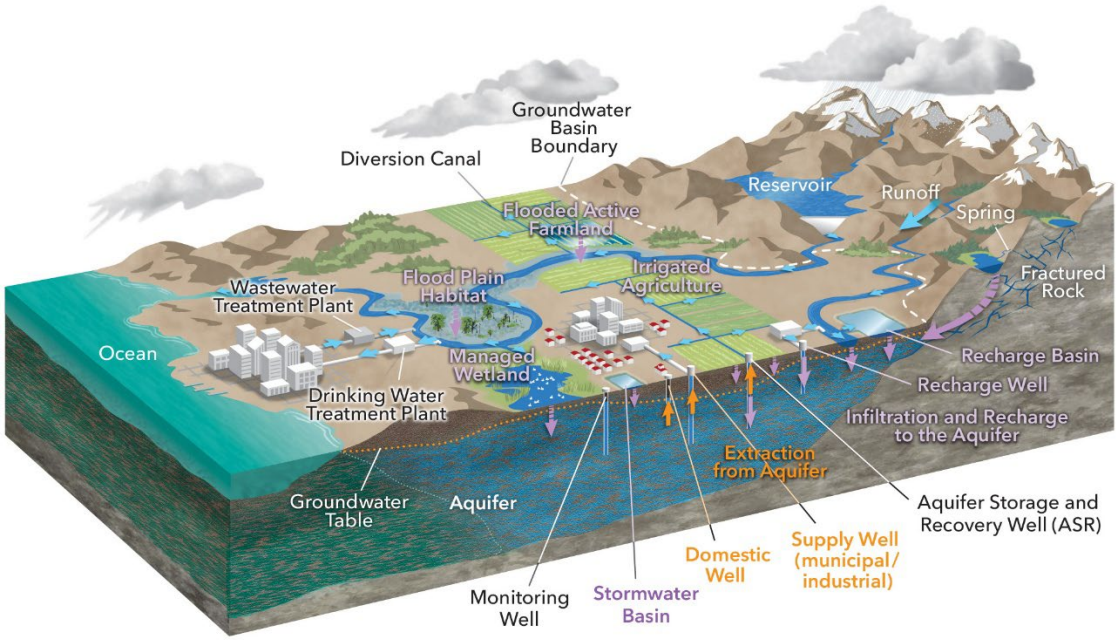
Groundwater extraction in both basin and non-basin areas is accomplished using wells that pump groundwater to the surface for use. Intentional recharge and replenishment of the aquifers, called managed aquifer recharge (MAR), is conducted using infrastructure that facilitates infiltration of water through the vadose zone to the underlying aquifer or through the injection of water directly into the aquifer using specialized wells. MAR projects are implemented across

PUBLIC DRAFT

multiple sectors and landscapes and include a variety of methods, such as recharge basins, on-farm recharge, aquifer storage and recovery (ASR) wells, stormwater capture and infiltration, recycled water recharge, multi-benefit projects (e.g., engineered wetlands and recreational areas with recharge ponds), and floodplain restoration.

In addition to extraction and recharge facilities, conveyance systems play an essential role in built groundwater infrastructure. They transport groundwater from extraction wells to the place of use, or from a surface water source to recharge facilities. This infrastructure primarily consists of canals, pipelines, unlined ditches, and water distribution systems. Figure
3-51 depicts various components of built groundwater infrastructure across a landscape.

Figure 3-51 Schematic of Built Groundwater Infrastructure Components Used to Extract, Convey, and Replenish Groundwater



Built groundwater infrastructure also enables conjunctive management, also referred to as conjunctive use. Conjunctive management is broadly defined as the coordinated and planned use and management of multiple sources of water in time and space, usually focused on surface water and groundwater resources to maximize the availability and reliability of water supplies in a region to meet various management objectives (California Department of Water Resources 2024f).

This management strategy can result in increased groundwater replenishment, either by MAR or by in-lieu recharge benefits. In-lieu recharge is defined in this document as recharge that occurs by providing surface water, or other alternative water supply, to users who would normally use groundwater to meet water demands. The reduced demand and extraction of groundwater leaves more water in the basin for replenishment and later use. Additional details on conjunctive management are provided in Chapter 2, "Progress Toward Sustainable Groundwater Management."

To better understand how California manages and benefits from its built groundwater infrastructure, a summary of the best available knowledge of California's built groundwater infrastructure and its usage is provided in the following sections, though many data gaps remain. With the passage of SGMA, the completion of GSPs and Alternatives, and ongoing SGMA annual reporting, DWR will continue to expand knowledge of existing built groundwater infrastructure and its usage. Each element described below plays a distinct role in supporting sustainable groundwater use and resilience across the state:

- **Groundwater Extraction Infrastructure:** Includes wells and pumping systems used to access groundwater for agricultural, municipal, industrial, and domestic use in both basin and non-basin areas.
- **Groundwater Recharge Infrastructure:** Refers to constructed facilities such as recharge basins, ASR wells, and infiltration systems designed to replenish aquifers through managed aquifer recharge.
- **Conveyance Infrastructure:** Comprises canals, pipelines, and ditches used to move water from extraction points or surface water sources to end users or recharge locations.
- **Groundwater Infrastructure Utilization:** Describes how built infrastructure is operated and managed to meet diverse water demands under changing hydrologic and regulatory conditions.
- **Groundwater Recharge Infrastructure Implementation:** Covers the planning, permitting, construction, and integration of recharge infrastructure into local and regional water management strategies.

3.6.1 Groundwater Extraction Infrastructure

Groundwater extraction infrastructure includes wells that pump groundwater to the surface for use, also called *production wells*. Production wells in this section are categorized by use type as domestic, irrigation, public supply, and industrial.

PUBLIC DRAFT

Wells constructed and identified for groundwater monitoring, such as monitoring for groundwater levels or water quality, are not included in the following analysis of production wells, since they are not typically used for groundwater extraction. However, monitoring wells play a crucial role in California as they provide valuable data on groundwater conditions, subsurface geology, water quality, land subsidence, and seawater intrusion. For more information about the monitoring well infrastructure in California, see Chapter 5, "Groundwater Monitoring."

This section is organized into two key topics:

- Statewide production wells.
- Statewide domestic and irrigation wells.

Statewide Production Wells Geographic Distribution

The section below describes the statewide distribution of production wells located within groundwater basins and non-basin areas, categorized by well type. Information on production wells is obtained from Well Completion Reports (WCRs) submitted to DWR's Online System of Well Completion Reports (OSWCR). WCR data is presented at both the statewide level and separately by groundwater basin and non-basin areas. Additional information on the use of WCRs in this chapter is provided in Appendix C, "Methods and Assumptions." This section only discusses the distribution of well types and does not include discussion of water use. Please see Chapter 4, "Groundwater Use, Extraction, and Water Budgets," for water use discussion.

LONG TERM (1977–2023) STATEWIDE PRODUCTION WELLS DISTRIBUTION

A total of 330,792 WCRs were submitted statewide from 1977 through 2023 for production wells. Figure 3-52 depicts the distribution of wells by well use type. Most production wells installed during this period were domestic wells (78%), followed by irrigation wells (18%), public supply wells (3%), and industrial wells (1%). Table 3-5 presents the statewide distribution of production wells by use type for each hydrologic region, including:

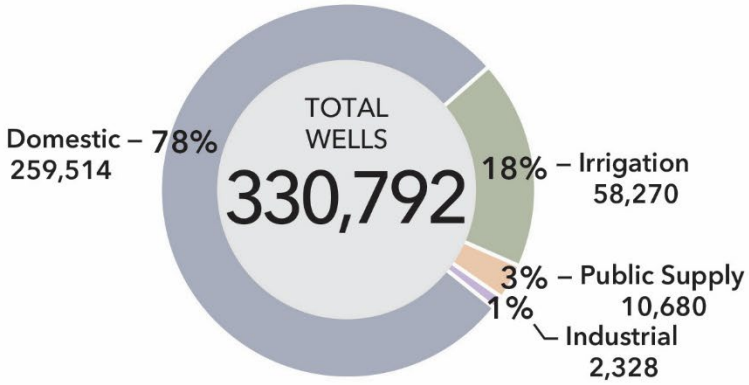
- All well types: The Sacramento River Hydrologic Region has the highest number of production wells with 100,467, and the North Lahontan Hydrologic Region has the least with 5,033.
- Domestic wells: The Sacramento River Hydrologic Region has the largest number of domestic wells at 88,295, and the North Lahontan Hydrologic Region has the least with 4,336. Domestic wells account for 88% and 86% of all production wells in the Sacramento and North Lahontan Hydrologic

PUBLIC DRAFT

Regions respectively. Statewide, domestic wells account for 78% of all production wells.

- Irrigation Wells: The Tulare Lake Hydrologic Region has the largest number of irrigation wells at 17,336, and North Lahontan has the least with 456. Irrigation wells make up 40% of all production wells in the Tulare Lake Hydrologic Region, a greater share than any other hydrologic region. In the North Lahontan Hydrologic Region, irrigation wells account for 9% of all production wells in the region. Statewide, 18% of all production wells are irrigation wells.
- Public supply wells: The South Coast Hydrologic Region has the largest number of public supply wells with 2,061, and North Lahontan Hydrologic Region has the least with 202. Public supply wells account for 9% and 7% of all production wells in the South Coast and North Lahontan Hydrologic Regions respectively, compared to 3% statewide.
- Industrial wells: The Sacramento River Hydrologic Region has the largest number of industrial wells with 436, and North Lahontan Hydrologic Region has the least with 39. In the Sacramento River Hydrologic Region, industrial wells account for less than 1% of all production wells. Within the North Lahontan Hydrologic Region, industrial wells account for 1% of production wells. Statewide, 1% of all production wells are industrial wells.

Figure 3-52 Statewide Production Well Completion Reports by Well Use Type (1977-2023)



DRAFT

Table 3-5 Statewide Production Well Completion Reports by Well Use Type and Hydrologic Region (1977–2023)

Hydrologic Region	Domestic	%	Irrigation	%	Public Supply	%	Industrial	%	Total
North Coast	28,942	87%	3,449	10%	763	2%	180	1%	33,334
San Francisco Bay	11,625	70%	4,338	26%	478	3%	188	1%	16,629
Central Coast	13,695	72%	4,595	24%	542	3%	135	1%	18,967
South Coast	18,395	66%	6,988	25%	2,061	7%	250	1%	27,694
Sacramento River	88,295	88%	9,946	10%	1,790	2%	436	0%	100,467
San Joaquin River	55,198	83%	9,544	14%	1,782	3%	313	0%	66,837
Tulare Lake	24,826	57%	17,336	40%	1,329	3%	383	1%	43,874
North Lahontan	4,336	86%	456	9%	202	4%	39	1%	5,033
South Lahontan	8,500	80%	788	7%	1,002	9%	270	3%	10,560
Colorado River	5,702	77%	830	11%	731	10%	134	2%	7,397
Total	**259,514**	**78%**	**58,270**	**18%**	**10,680**	**3%**	**2,328**	**1%**	**330,792**

RECENT (2019–2023) STATEWIDE PRODUCTION WELLS DISTRIBUTION

Of the total 330,792 wells completed between 1977 and 2023, 24,520 wells, approximately 7% of the total, were completed between 2019 and 2023. The 2019 through 2023 period included three drought years, which were bookended by two wet years. The statewide distribution of production wells by type as well as a breakdown by hydrologic region are presented in Figure 3-53 and Table 3-6. Compared to the long-term trends seen from 1977 through 2023, the more recent years show a greater percentage of irrigation wells installed (30% vs 18%) and a lower percentage of domestic wells (67% vs 78%). A summary of the well use type quantities for 2019 through 2023 for each hydrologic region is provided below:

- Between 2019 and 2023, the Tulare Lake Hydrologic Region had the highest number of production wells installed at 5,810, and the North Lahontan

PUBLIC DRAFT

Hydrologic Region had the least with 169. The North Lahontan Hydrologic Region also had the fewest new production wells installed in each of the individual categories.

- Between 2019 and 2023, the Sacramento River Hydrologic Region had the largest number of domestic wells installed at 4,058, and the North Lahontan Hydrologic Region had the least with 122. Domestic wells account for 78% and 72% of all new production wells in the Sacramento and North Lahontan Hydrologic Regions respectively. Both these percentages are down compared to the long-term distribution in these regions.
- The Tulare Lake Hydrologic Region had the largest number of irrigation wells at 2,693, and North Lahontan had the least with 42. Irrigation wells make up 46% of new production wells in the Tulare Lake Hydrologic Region, which is a greater percentage compared to the long-term average in the region. New irrigation wells still account for a greater percentage of production wells in the Tulare Lake Hydrologic Region than any other Hydrologic Region.
- The San Joaquin Hydrologic Region had the largest number of new public supply wells with 116, and North Lahontan Hydrologic Region had the least with 5. In both these Hydrologic Regions, public supply wells account for 3% of new production wells.
- The Tulare Lake Hydrologic Region had the largest number of industrial wells with 26, and North Lahontan Hydrologic Region had the least with 0. In the Tulare Lake Hydrologic Region, industrial wells account for less than 1% of new production wells.

PUBLIC DRAFT

Figure 3-53 Statewide Production Well Completion Reports by Well Use Type (2019-2023)

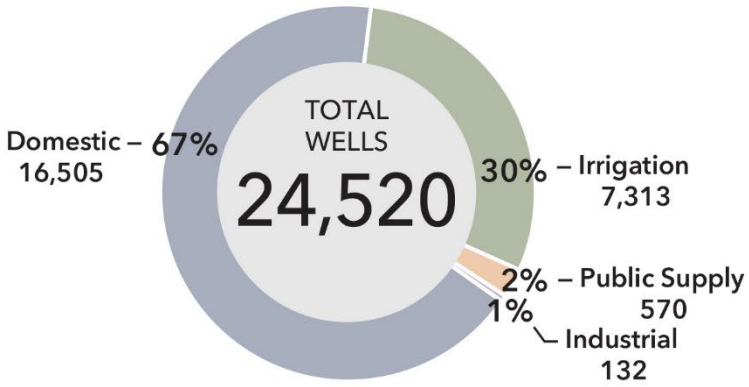


Table 3-6 Statewide Production Well Completion Reports by Well Use Type and Hydrologic Region (2019–2023)

Hydrologic Region	Domestic	%	Irrigation	%	Public Supply	%	Industrial	%	Total
North Coast	1,948	87%	857	10%	32	2%	23	1%	2,860
San Francisco Bay	716	70%	351	26%	21	3%	9	1%	1,097
Central Coast	1,041	72%	668	24%	43	3%	8	1%	1,760
South Coast	984	66%	475	25%	104	7%	8	1%	1,571
Sacramento River	4,058	88%	1,002	10%	95	2%	16	0%	5,171
San Joaquin River	3,413	83%	1,069	14%	116	3%	22	0%	4,620
Tulare Lake	3,006	57%	2,693	40%	85	3%	26	1%	5,810
North Lahontan	122	86%	42	9%	5	4%	0	1%	169
South Lahontan	546	80%	79	7%	33	9%	11	3%	669
Colorado River	671	77%	77	11%	36	10%	9	2%	793
Total	**16,505**	**67%**	**7,313**	**30%**	**570**	**2%**	**132**	**1%**	**24,520**

PUBLIC DRAFT

GROUNDWATER BASINS PRODUCTION WELLS DISTRIBUTION

A total of 179,239 production WCRs were submitted within groundwater basins from 1977 through 2023, which represents 54% of the statewide total WCRs. Figure 3-54 depicts the distribution of wells by well use type in groundwater basin areas. The distribution of production well use types in groundwater basins closely mirrors the statewide distribution. Domestic wells account for 70% of total production wells, followed by irrigation wells (25%), public supply wells (4%), and industrial wells (1%).

Table 3-7 presents the distribution of production wells in groundwater basins by use type for each hydrologic region. A summary of the well use type quantities within groundwater basins across hydrologic regions is provided below:

- All production wells: The Sacramento River Hydrologic Region has the largest number of productions wells in groundwater basins with 40,893, and North Lahontan Hydrologic Region has the least with 3,081.
- Domestic wells: The Sacramento River Hydrologic Region has the largest number of domestic wells with 30,887, and North Lahontan Hydrologic Region has the least with 2,558.
- Irrigation wells: The Tulare Lake Hydrologic Region has the largest number of irrigation wells with 16,803, and North Lahontan Hydrologic Region has the least with 375.
- Public supply wells: The South Coast Hydrologic Region has the highest number of public supply wells with 1,428, and North Lahontan Hydrologic Region has the least with 116.
- Industrial wells: The Tulare Lake Hydrologic Region has the highest number of industrial wells with 371, and North Lahontan Hydrologic Region has the least with 32.

PUBLIC DRAFT

Figure 3-54 Production Well Completion Reports in Groundwater Basins by Well Use Type (1977–2023)

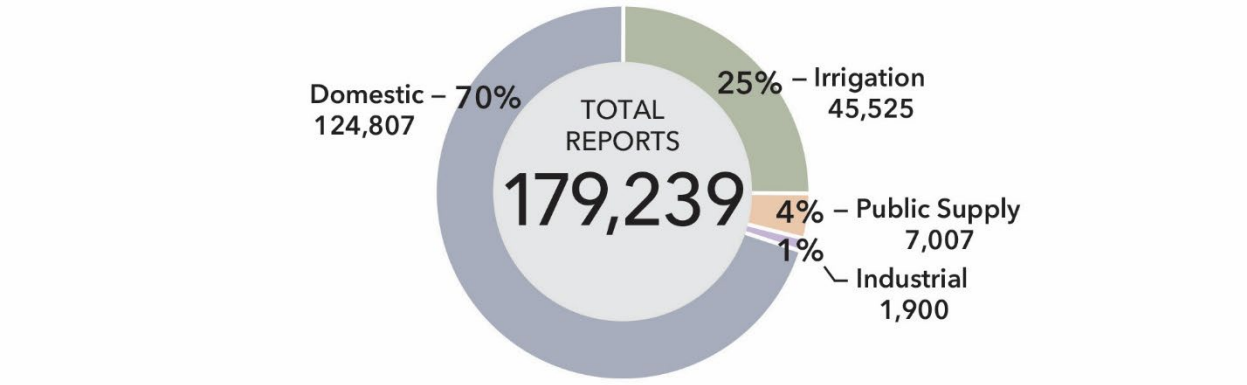


Table 3-7 Production Well Completion Reports in Groundwater Basins by Well Use Type and Hydrologic Region (1977–2023)

Hydrologic Region	Domestic	Irrigation	Public Supply	Industrial	Total
North Coast	13,907	1,877	410	136	16,330
San Francisco Bay	5,353	2,214	350	154	8,071
Central Coast	8,341	3,427	407	112	12,287
South Coast	5,163	1,937	1,428	147	8,675
Sacramento River	30,887	8,744	909	353	40,893
San Joaquin River	28,019	8,665	776	232	37,692
Tulare Lake	19,076	16,803	1,109	371	37,359
North Lahontan	2,558	375	116	32	3,081
South Lahontan	7,459	732	871	241	9,303
Colorado River	4,044	751	631	122	5,548
Total	**124,807**	**45,525**	**7,007**	**1,900**	**179,239**
Percent	**70%**	**25%**	**4%**	**1%**	**100%**

NON-BASIN AREA PRODUCTION WELLS DISTRIBUTION

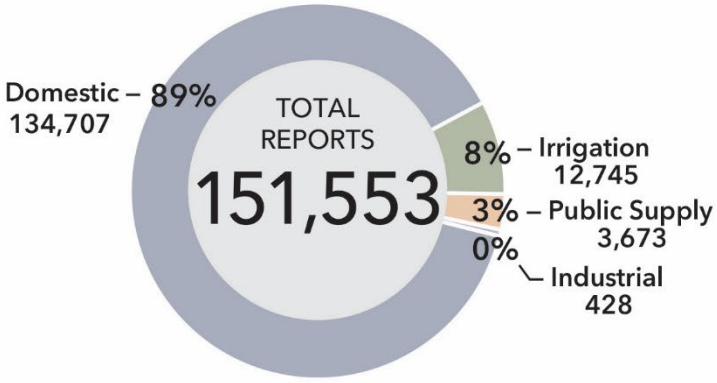
A total of 151,553 production wells were identified in non-basin areas, which represents 46% of the statewide total WCRs. Figure 3-55 depicts the number of WCRs submitted in non-basin areas for groundwater production wells from 1977 through 2023 by well use type. In non-basin areas, domestic wells notably dominate the distribution, accounting for 89% of total WCRs. Irrigation wells account for 8% of production wells, followed by public supply wells (3%), and industrial wells (less than 1%).

PUBLIC DRAFT

Table 3-8 presents the distribution of production wells in non-basin area by use type for each HR. A summary of the well use type quantities within non-basin areas for each HR is provided below:

- All production wells: The Sacramento River Hydrologic Region has the largest number of production wells in non-basin area with 59,574 wells, and the South Lahontan Hydrologic Region has the least with 1,257.
- Domestic wells: The Sacramento River Hydrologic Region has the largest number of domestic wells with 57,408 wells, and South Lahontan Hydrologic Region has the least with 1,041.
- Irrigation wells: The South Coast Hydrologic Region has the largest number of irrigation wells with 5,051, and South Lahontan Hydrologic Region has the least with 56.
- Public supply wells: The San Joaquin River Hydrologic Region has the highest number of public supply wells with 1,006, and North Lahontan Hydrologic Region had the least at 86 wells.
- Industrial wells: The South Coast Hydrologic Region has the highest number of industrial wells with 103, and North Lahontan Hydrologic Region has the least with 7.

Figure 3-55 Production Well Completion Reports in Non-basin Areas by Well Use Type (1977-2023)



PUBLIC DRAFT

Table 3-8 Production Well Completion Reports in Non-basin Areas by Well Use Type and Hydrologic Region (1977–2023)

Hydrologic Region	Domestic	Irrigation	Public Supply	Industrial	Total
North Coast	15,035	1,572	353	44	17,004
San Francisco Bay	6,272	2,124	128	34	8,558
Central Coast	5,354	1,168	135	23	6,680
South Coast	13,232	5,051	633	103	19,019
Sacramento River	57,408	1,202	881	83	59,574
San Joaquin River	27,179	879	1,006	81	29,145
Tulare Lake	5,750	533	220	12	6,515
North Lahontan	1,778	81	86	7	1,952
South Lahontan	1,041	56	131	29	1,257
Colorado River	1,658	79	100	12	1,849
Total	**134,707**	**12,745**	**3,673**	**428**	**151,553**
Percent	**89%**	**8%**	**2%**	**<1%**	**100%**

Statewide Domestic and Irrigation Wells

Domestic and irrigation wells together account for approximately 96% of all production WCRs submitted to DWR from 1977 through 2023. This section provides a detailed analysis of domestic and irrigation WCRs with figures showing statewide well density, well depths, and installation timelines. Although the statewide ratio of domestic well to irrigation well installations from 1977 through 2023 is approximately 4 to 1, irrigation wells account for approximately 79% of the groundwater extracted in the state on average (see Chapter 4, "Groundwater Use, Extraction, and Water Budgets").

DOMESTIC AND IRRIGATION WELLS GEOGRAPHIC DISTRIBUTION

Figures 3-56 and 3-57 show the estimated statewide density and spatial distribution of domestic and irrigation well WCRs, respectively, per square mile. Statewide, domestic wells are generally more densely concentrated in rural residential areas located away from larger population centers, in both basin and non-basin areas. This reflects the prevalence of private domestic wells used by residences in areas without access to public water systems. The highest densities of domestic wells are generally observed in non-basin areas across the state, which is consistent with the greater number of domestic WCRs located in non-basin areas (134,707 wells) compared to basin areas (124,807 wells). It is estimated that 3.7% of California's population relies on domestic wells for their water supply (Johnson et al. 2019). Based on the state's 2020 estimated

PUBLIC DRAFT

population of 40.8 million, this equates to approximately 1.5 million people relying on domestic wells. Urban groundwater use in basin versus non-basin areas is described in Chapter 4, "Groundwater Use, Extraction, and Water Budgets."

Irrigation wells are largely concentrated within groundwater basins, with 45,525 WCRs recorded in basin areas (Figure 3-54) and 12,745 WCRs in non-basin areas (Figure 3-55). Irrigation wells are generally designed to be higher-capacity wells than domestic wells. Most of the state's agricultural groundwater production occurs within the Central Valley, which is consistent with the high concentration of irrigation wells shown in Figure 3-57. The distribution of agricultural water use in basin versus non-basin areas is documented in Chapter 4, "Groundwater Use, Extraction, and Water Budgets."

PUBLIC DRAFT

Figure 3-56 Density and Spatial Distribution of Domestic Wells Estimated from Well Completion Reports (1977–2023)

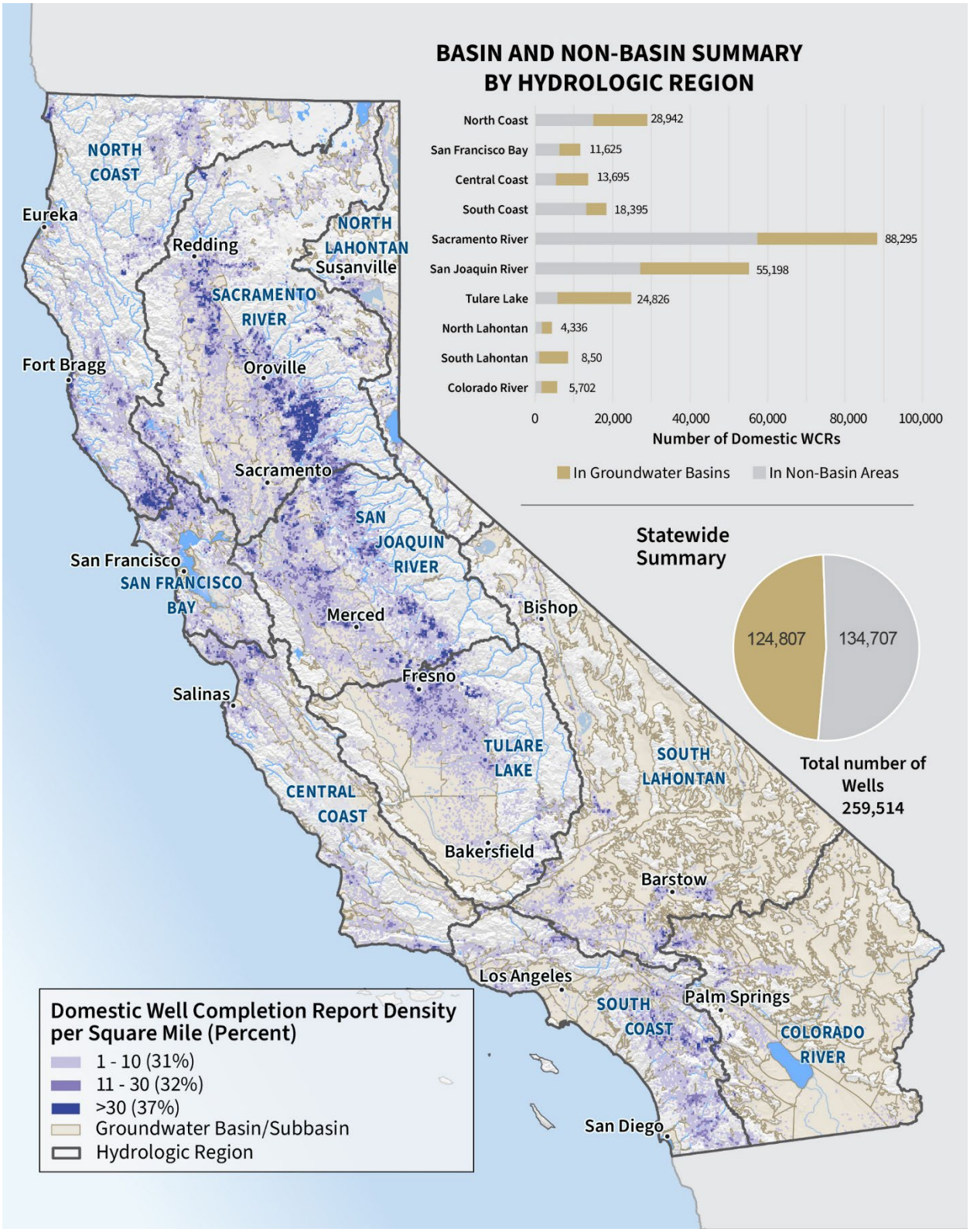
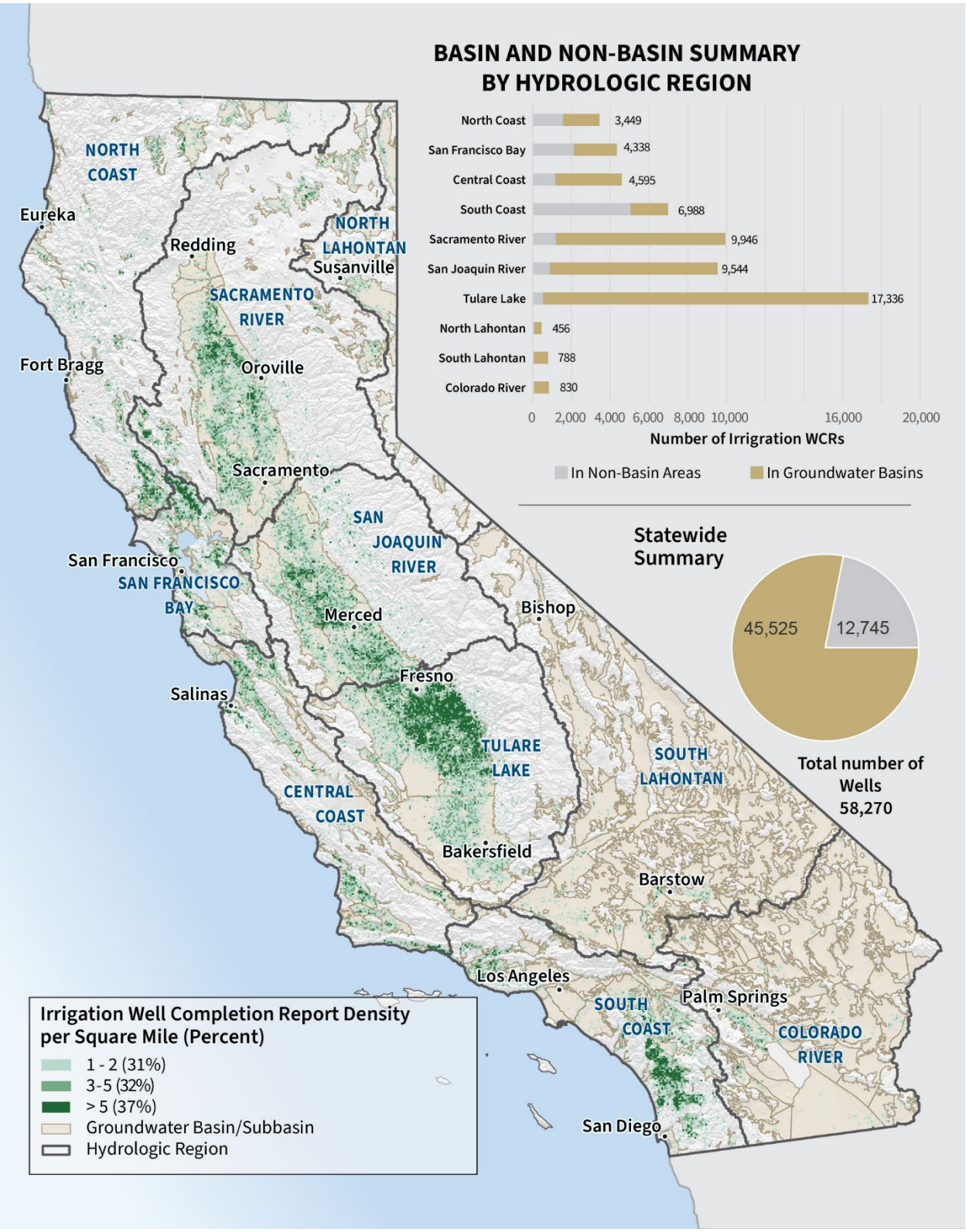


Figure 3-57 Density and Spatial Distribution of Irrigation Wells Estimated from Well Completion Reports (1977–2023)



DOMESTIC AND IRRIGATION WELLS DEPTH DISTRIBUTION

Figures 3-58 and 3-59 depict the well-depth distribution and cumulative totals of domestic wells and irrigation wells across the state based on WCR data. The bars in these figures represent the number of wells (vertical axis) that fall within a given depth interval (horizontal axis), while the line represents the cumulative number of wells that are equal to or shallower than a given depth interval. Depth distributions are shown in discrete intervals up to 1,000 feet. Beyond this, there are 1,218 domestic wells and 3,711 irrigation wells that exceed 1,000 feet deep, which are not reflected in the figures. However, when compared to wells within the first 1,000 feet, the distribution curve for wells deeper than 1,000 feet provides little additional insight into variations across depth intervals.

The distribution of domestic wells (Figure 3-58) shows a strong concentration in the shallower depth intervals, particularly between 75 and 325 feet. The peak number of domestic wells occurs in the 150–175-foot range, with over 25,000 wells in that interval. The cumulative curve rises steeply within the first 300 feet, indicating that the majority of domestic wells are relatively shallow. Beyond approximately 500 feet, the curve begins to flatten, reflecting a sharp decline in the number of deeper wells. Irrigation wells (Figure 3-59) show a broader and deeper distribution. While there is a concentration of wells between 125 and 325 feet — similar to domestic wells — the depth range for irrigation wells extends much farther. Substantial numbers of irrigation wells are constructed beyond 500 feet, with a noticeable tail reaching up to 1,000 feet. The cumulative curve climbs steadily across the full depth range, with a more gradual slope than that of domestic wells, reflecting a wider and deeper spread in construction. Additionally, irrigation wells show a higher concentration in basin areas (blue bars), particularly at greater depths, likely reflecting access to deeper, higher-capacity aquifers. In contrast, domestic wells have a stronger presence in non-basin areas at shallower depths.

PUBLIC DRAFT

Figure 3-58 Total Domestic Wells by Well Depth (in ft) with a Cumulative Curve Based on Well Completion Reports (1977–2023)

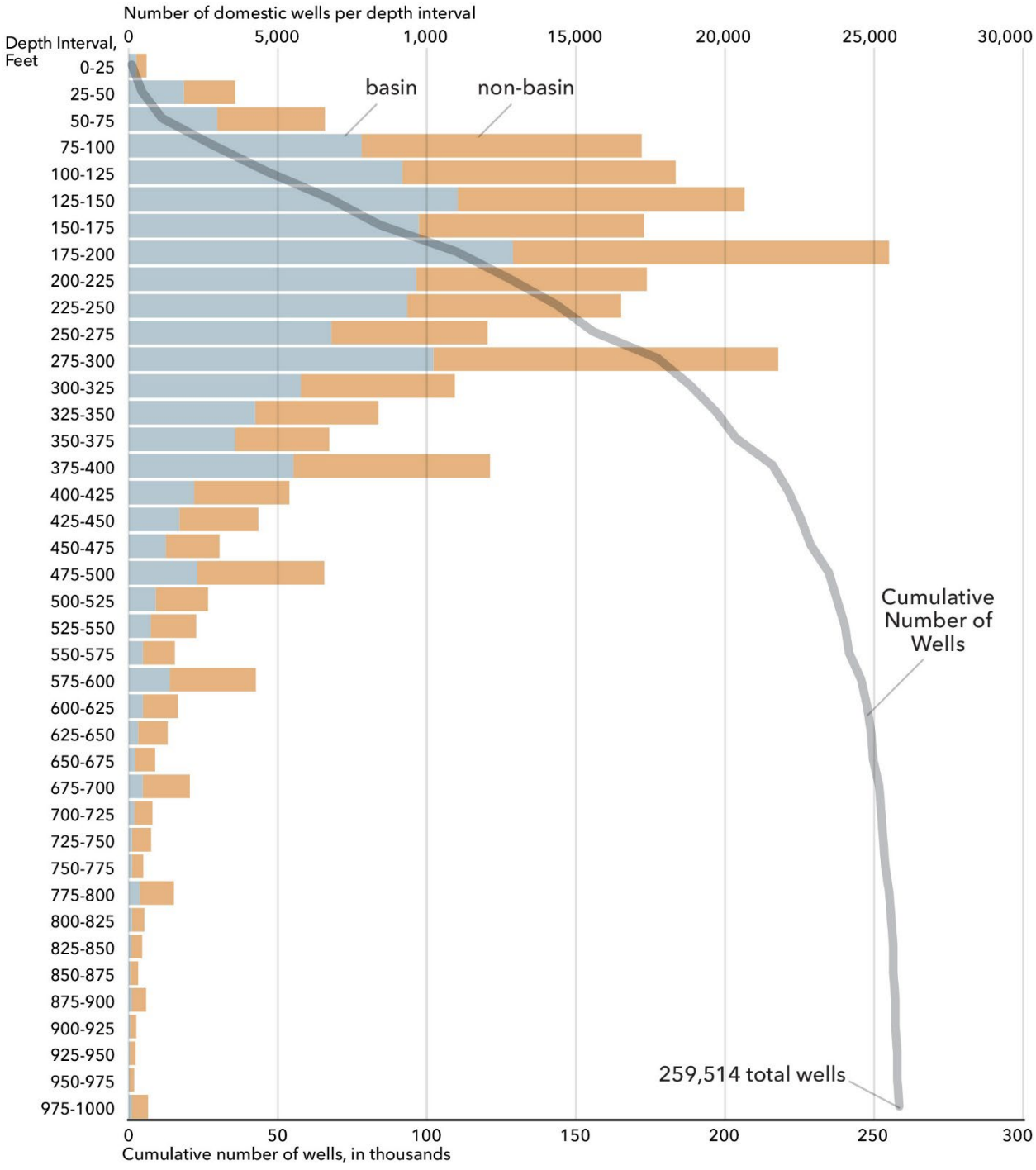


Figure 3-58 Note: There are an additional 1,218 domestic wells throughout California that exceed 1,000 feet.

Figure 3-59 Total Irrigation Wells by Well Depth (in ft) with a Cumulative Curve Based on Well Completion Reports (1977–2023)

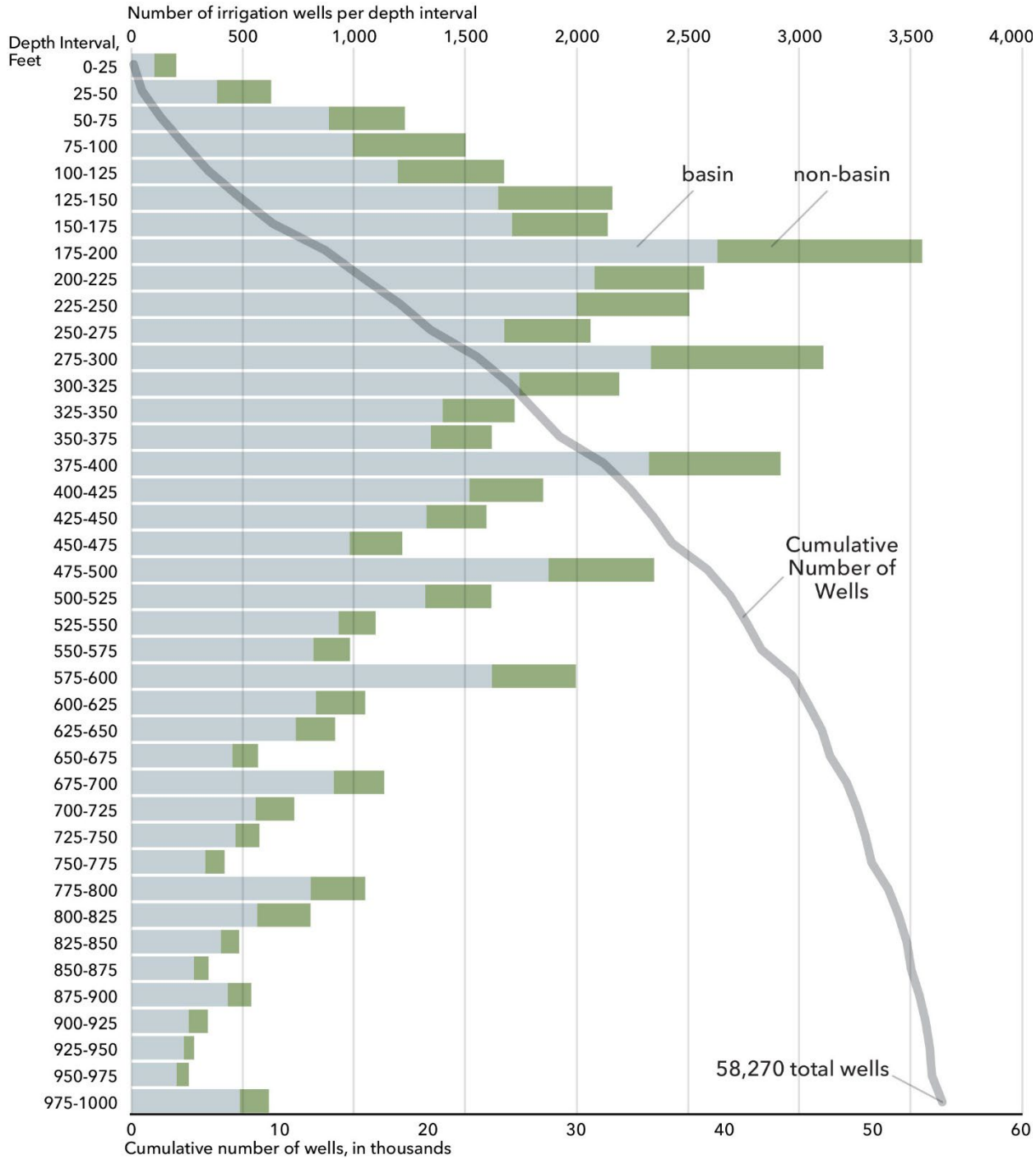


Figure 3-59 Note: There are an additional 3,711 irrigation wells throughout California that exceed 1,000 feet.

DOMESTIC AND IRRIGATION WELLS INSTALLATION TIMELINE DISTRIBUTION

Figures 3-60 and 3-61 depict the annual and cumulative installation quantities of domestic and irrigation wells, respectively, based on WCR data from 1977 to 2023. The number of WCRs submitted for domestic wells is typically influenced by population growth and new home construction, which are strongly affected by economic cycles. Housing booms in the 1970s and late 1980s resulted in peak years with more than 10,000 wells installed annually. However, the end of the Cold War (1991) caused a significant decline in the aerospace industry, contributing to a statewide slowdown in housing construction, particularly in the Los Angeles area. This downturn ultimately resulted in a statewide housing recession in the early 1990s (Construction Industry Research Board 2019). Similarly, the decline in domestic well installations between 2008 and 2010 corresponding with the Great Recession led to a reduction in housing construction and, in turn, fewer domestic well installations. Construction levels slowly increased from 2019 through 2020 before gradually leveling off since then (California State Library 2023). During the 2012 to 2016 drought, the reduced availability in surface water forced many rural residents to rely more heavily on groundwater, leading to a small increase in the installation of domestic wells as households sought more reliable water sources. Similar trends were seen during the 2020 to 2022 drought.

PUBLIC DRAFT

Figure 3-60 Domestic Well Installations by Year with Cumulative Curve (1977–2023)

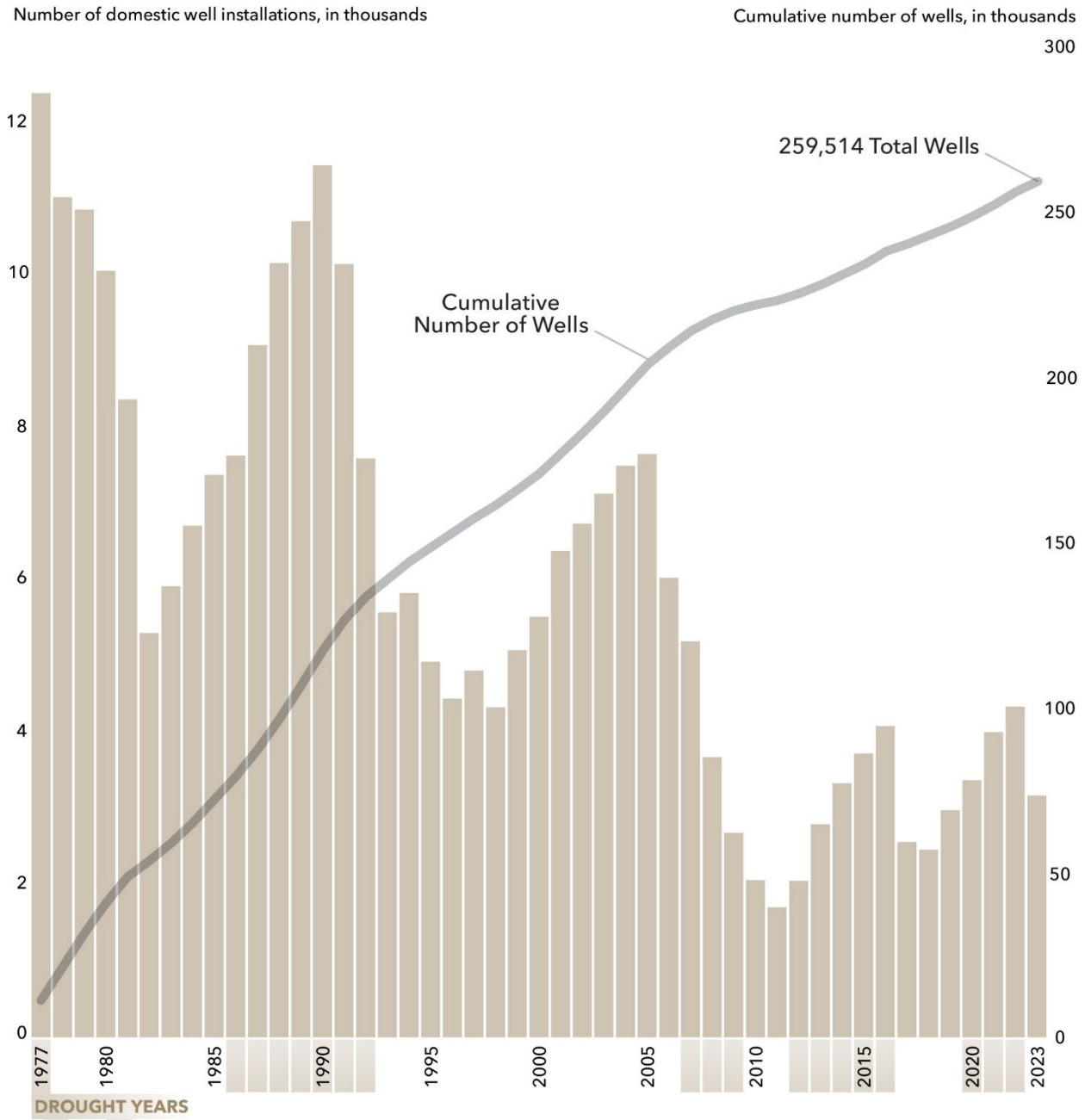


Figure 3-60 Note: Based on well completion reports submitted to DWR.

The number of irrigation wells installed reflect changes in annual precipitation patterns but may also be influenced by other factors such as cropping trends, irrigation methods, and the availability of alternative agricultural water supplies. The number of WCRs submitted for irrigation wells ranged from a high of approximately 4,300 in 1977 during the 1976–1977 drought to a low of 398 during the wet year of 1983. The number of newly constructed irrigation wells generally

correlates with regional water-year types, with considerable increases observed during dry to critical water years, such as 2012 through 2016. As surface water supplies were reduced and groundwater elevations in many parts of the state dropped to historical lows during the 2012 to 2016 drought, many new irrigation wells were installed to maintain crop production.

Figure 3-61 Irrigation Well Installations by Year with Cumulative Curve (1977-2023)

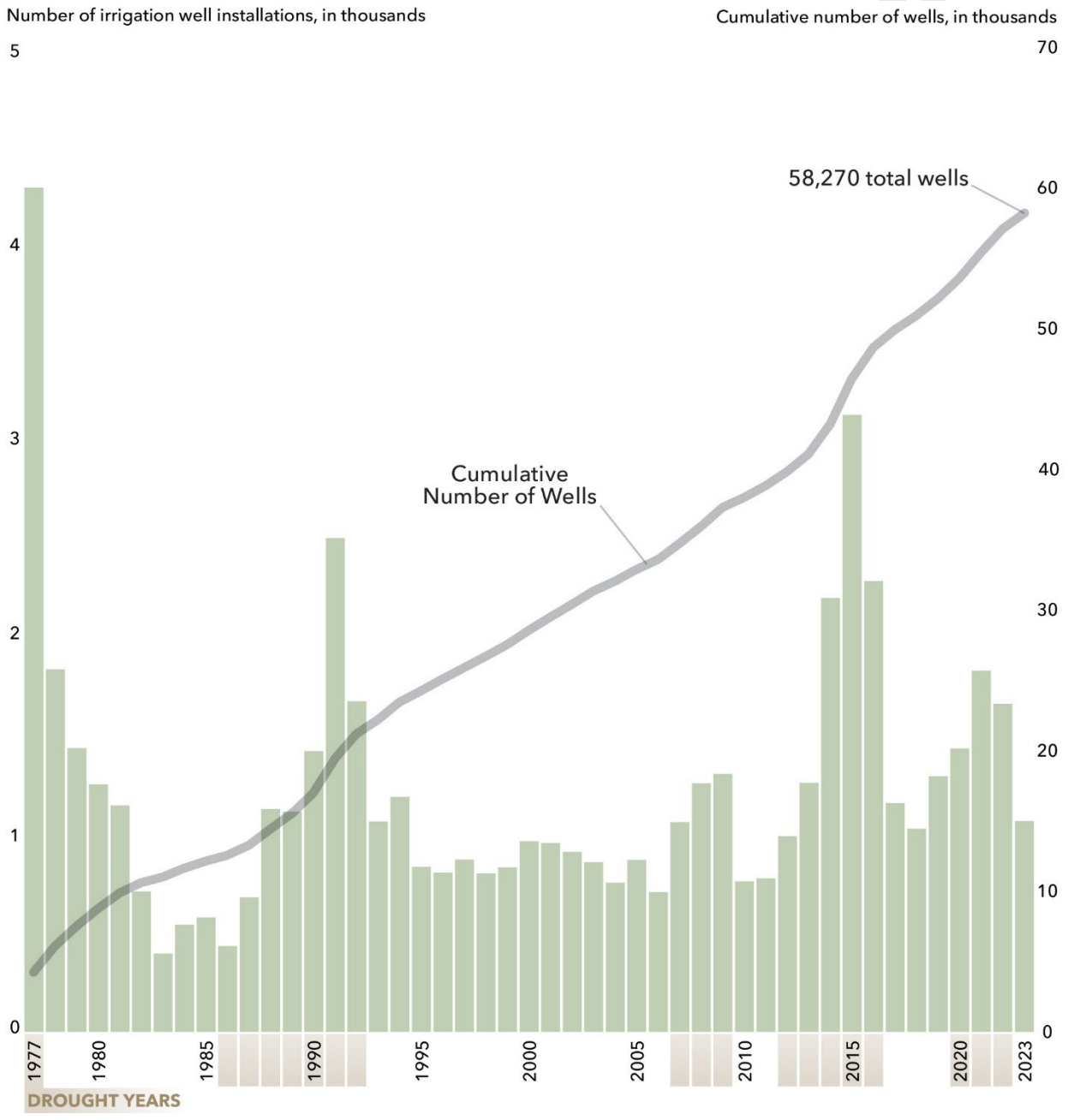


Figure 3-61 Note: Based on well completion reports submitted to DWR.

3.6.2 Groundwater Recharge Infrastructure

Groundwater recharge infrastructure includes built infrastructure, such as facilities and conveyance systems designed to capture, transport, and store surface water in an aquifer, as well as the natural infrastructure previously discussed in Section 3.2, such as waterways, wetlands, meadows, and floodplains. Built groundwater infrastructure enables common conjunctive management strategies such as MAR and in-lieu recharge.

Identifying areas that are suitable and feasible for groundwater recharge (see Section 3.4.1 earlier in this chapter) is an important step toward the expansion of groundwater recharge infrastructure and activities. The location of recharge infrastructure can have a significant impact on the effectiveness of the infiltration of water into the underlying aquifer. Areas best suited for recharge by infiltration typically have a hydraulic connection between the ground surface and aquifer. This connection can be defined as an infiltration and percolation pathway characterized by predominantly coarse-grained materials that extend from the surface downward into the aquifer (California Department of Water Resources 2023b). For areas that are less suitable for recharge by infiltration, direct injection of water into the aquifer may be feasible.

For a more detailed discussion about identifying, utilizing, and protecting recharge areas in California, see the Recharge Area Identification, Utilization, and Protection Resource Management Strategy Memorandum of the California Water Plan Update 2023 (California Department of Water Resources 2023a) as well as the Basin Characterization Program's Aquifer Recharge Potential Mapping Process Document (described in Section 3.4.2).

The following subsections describe common MAR infrastructure and methods, providing brief descriptions, benefits, challenges, and spotlights. See Chapter 4, "Groundwater Use, Extraction, and Water Budgets," for information on the historical data on volume of water recharged using built groundwater infrastructure in California.

Recharge methods and infrastructure discussed in this section include:

- Recharge basins/Spreading Basins.
- On-Farm Recharge.
- Temporary Dams, Unlined Canals, and Trickle Flow.
- Injection Wells and Aquifer Storage and Recovery Wells.

PUBLIC DRAFT

- Stormwater Basins.
- Dry Wells.
- Green Infrastructure and Low Impact Development.
- Flood Management Infrastructure.
- In-Lieu Recharge.
- Incidental Recharge.

Recharge Basins/Spreading Basins

Recharge basins, also sometimes referred to as *spreading basins*, are essential surface-spreading mechanisms for recharging unconfined aquifers through infiltration and percolation of surface water (Maliva 2019). They are primarily designed as excavated areas positioned lower than the surrounding ground surface, and/or as an area surrounded by berms or levees to efficiently store and infiltrate water into aquifers. Locations for recharge basins are often selected in areas with high infiltration and percolation rates, to maximize aquifer recharge, and the necessary conveyance (canals, pipelines, and distribution systems) to transport the water to basins (Maliva 2019; California Department of Water Resources 2023b).

These basins are utilized in a variety of settings and with multiple water sources, including stormwater, recycled water, and surface water diversions (high flows or under appropriative/permitted water rights). The timing of water movement in these systems largely depends on source water availability. However, traditional recharge applications that rely on surface water or floodwaters are often influenced by precipitation patterns, reservoir operations, competing water use demands, and water right conditions.

Benefits of recharge basins include, but are not limited to, mitigation of drought and potential subsidence impacts, recreational opportunities, enhanced water supply and reliability, and flood risk reduction. Recharge basins can also be designed to provide temporary habitat for shorebirds, waterfowl, and pollinators, by considering timing and depth of applied water and planting vegetation along the sides of the basin.

Recharge basins can be a part of an engineered, large-scale recharge facility, or as temporary infrastructure to more quickly expand local flood risk reduction and recharge capacity in the short-term. Temporary recharge basins, typically consisting of shallow levees or berms constructed around agricultural fields,

PUBLIC DRAFT

idle/fallowed land, or other designated areas, are sometimes used as a cost-effective alternative to permanent recharge basins, which can be expensive and require significant time and effort for permitting and construction, to respond to local needs. Recharge basins require regular maintenance to address fine sediment buildup and maximize infiltration rates. Additionally, potential impacts on water quality should be carefully evaluated when identifying and selecting recharge basin locations, particularly near groundwater production wells.

The Indio Subbasin serves as an example of successful implementation and the benefits of ongoing, large-scale recharge activities using recharge basins. Here, three dedicated groundwater recharge basin facilities are operated by the Coachella Valley Water District: the Whitewater River Groundwater Replenishment Facility (WWR-GRF), the Palm Desert Groundwater Replenishment Facility (PD-GRF), and the Thomas E. Levy Groundwater Replenishment Facility (TEL-GRF). The WWR-GRF began operation in 1973 and has recharged nearly 4 million acre-feet of water to date. The TEL-GRF has recharged approximately 400,000 acre-feet since operations began in 2009 and the PD-GRF has recharged over 14,000 acre-feet since operations began in 2019. These three facilities collectively support the region's groundwater sustainability efforts. Groundwater levels have dramatically recovered in the vicinity of GRFs, with recovery reported to be as high as 200 feet between water years 2009 and 2019 (Indio Subbasin GSAs 2022).

Recharge basins are some of the most commonly used built infrastructure for managed aquifer recharge (California Department of Water Resources 2020). A 2023 survey conducted by the Public Policy Institute of California on groundwater recharge in the San Joaquin Valley indicated that more than half of all applied recharge water (water applied at the ground surface for infiltration) — approximately 2.8 million acre-feet — was directed to recharge basins in 2023 (Peterson et al. 2024). As GSAs continue to implement their GSPs and expand recharge infrastructure to help achieve sustainability goals, continued State support will be crucial to support expedited implementation and maximize benefits, particularly in identifying more suitable recharge areas based on hydrogeology, providing financial assistance, and streamlining regulations, including water rights.

On-Farm Recharge

On-farm recharge occurs when growers apply available water on farmland (e.g., active farm land, fallowed fields, or designated recharge basins) in excess of crop needs. For active farmland, recharge water is typically applied during the non-

PUBLIC DRAFT

irrigation season, using existing or additional irrigation equipment or conveyance facilities. Recharge is typically done by direct spreading. Agricultural infrastructure used for irrigation, such as conveyance facilities for flood irrigation, can facilitate recharge. Some farmers have installed, or are evaluating the installation of, dual drip and flood irrigation systems that allow for the flooding of land when water is plentiful, and the use of drip irrigation when water is scarce and needs to be conserved. Growers with only drip irrigation systems may use temporary pipes to convey water available in winter floods to irrigate their land. In other cases, growers may use wells or tile drains (subsurface drainage of excess water in the soil via piles or tiles) to increase the amount of recharge.

On-farm recharge requires willing landowners, access to surface water, suitable soils and geology, careful consideration of potential impacts to water quality, and crop suitability. Fields with high infiltration rates are most desirable for recharge as soil does not remain saturated for long and field inundation is less likely to cause harm to permanent crops. Potential impacts on water quality may be related to past and current land and agricultural practices including crop type and past and current nutrient and pesticide management.

Fields with permanent crops may be suitable for on-farm recharge, especially those that are dormant in winter. Crop tolerance varies by crop type, variety, rootstock, soil type, timing of water application, and other factors. Trees and vines are generally more tolerant of root zone saturation from dormancy up to bud-break. Growers have successfully implemented on-farm recharge on fields growing alfalfa, almonds, wine and raisin grapes, pistachios, and walnuts, as well as on fallowed or annual crop fields outside of cultivation. A grower's knowledge of their fields and crops is critical for planning on-farm recharge applications, as they best know how fields typically drain and the timing of crop development and growth stages. Grower field preparation (e.g., adding berms, furrows, or tilling) is also an important component for maximizing recharge, protecting crops and agricultural practices, and achieving additional benefits, such as temporary wildlife habitat. Fallowed fields can be used for recharge at any time of the year and can be readily adapted for recharge, especially if they are already equipped with irrigation systems from previous crop activities.

On-farm recharge in specific locations can also help to support ecosystems. For example, shallow flooding on idle or unvegetated fields can provide habitat for migratory shorebirds, and deeper flooding can provide habitat for waterfowl. Many pilot projects have illustrated the potential benefits of temporarily flooding agricultural fields to support habitat and species development, including The

PUBLIC DRAFT

Nature Conservancy's Bird Returns Program and the Sacramento Valley's Floodplain Forward Coalition.

Temporary Dams, Unlined Canals, and Trickle Flow

A temporary dam, or check dam, is a small, temporary structure constructed or placed across a drainage ditch, gully, swale, channel, or river to slow the movement of water and/or allow water to pond within the channel. The reduction in flow velocity (also called trickle flow) and ponding of water provides more opportunity for infiltration to the aquifer and reduces erosion in the channel. Temporary dams may be constructed from logs, rock fill, an inflatable diaphragm, or prefabricated barriers (California Department of Water Resources 2023b). Consultation with, and approval from, various regulatory agencies may be required before the installation of any temporary dam or alteration to streamflow. Temporary or check dams are a common stormwater runoff control strategy, and use to increase groundwater recharge is growing. In addition to temporary dams, unlined canals provide opportunities for recharge by running water through the canals when they would otherwise be unused. Unlined canals are a common piece of built infrastructure across much of California's agricultural areas, many of which cross coarse materials conducive to groundwater recharge.

An example of inflatable diaphragms (also known as rubber dams) used for groundwater recharge is by the Los Angeles Department of Water and Power (LADWP) in the South Coast Hydrologic Region. LADWP operates a system of rubber dams in the San Gabriel River system for multiple benefits, including flood control and groundwater recharge. When the dams are inflated, the unlined "soft bottom" portions of the San Gabriel River are used as spreading grounds allowing floodwater to percolate to the aquifer after storms and dam releases. The dams can then be deflated for high flow events to allow water to pass downstream unobstructed (Los Angeles County Department of Public Works 2006). LADWP also operates rubber dams to divert flows to off-channel spreading basins.

The planned *Yolo-Zamora Groundwater Recharge Pilot Project* in the Sacramento River Hydrologic Region is an example of using temporary dams to maintain a more constant and slower velocity trickle flow, increasing water residency time in the channel and enhancing recharge to the aquifer. The project is a partnership between the Yolo County Groundwater Sustainability Agency, Yolo County Flood Control and Water Conservation District (YCFC&WCD) and local landowners to divert excess storm flows from Cache Creek and convey it through an unlined irrigation canal (Yolo Subbasin Groundwater Agency 2025). The pilot project plans

PUBLIC DRAFT

to engineer a system with automated gates to control flows along conveyance and establish monitoring to quantify the benefits. These trickle flow conveyance "losses" along the canal are desirable and intentional to benefit the aquifer.

The pilot project expands YCFC&WCD's existing recharge and conjunctive use programs. The Capay Diversion Dam diverts surface water to 160 miles of unlined canals. YCFC&WCD estimates that approximately 25% of surface water diverted to the canal system percolates to groundwater via the unlined canals every irrigation season — on average, that is approximately 40,000 acre-feet of recharge per year (Yolo Subbasin Groundwater Agency 2022). This indicates that substantial recharge may occur in the unlined distribution canals, and these unlined canals can provide additional recharge outside of the irrigation season when water is available.

Unlined canals exist throughout the state and should be considered when developing district-scale recharge programs. Further illustration of this potential was provided in the Merced River Watershed Flood-MAR Reconnaissance study, which indicated that more than 70,000 acre-feet of new recharge could occur, on an annual average, if the irrigation district used its unlined canals and diverted when local waterbodies were greater than their 90th percentile daily flow (based on SWRCB's streamlined permitting guidance) (California Department of Water Resources 2024g).

Depending on the type of project and local conditions, benefits of using temporary dams for ponding and trickle flow include flood reduction, erosion and sediment control, habitat enhancement, and aquifer recharge for supply enhancement. Use of unlined canals provides greater opportunity for recharge without the need for significant additional infrastructure investment. Considerations for such projects include soil properties of unlined canals and creeks for trickle flow recharge, existing diversion and conveyance infrastructure, operations and maintenance to maintain adequate recharge capacity of the canals, timing and availability of water source, water quality, and permitting and regulatory concerns.

Interoperability and retrofit of various structures for non-traditional uses, such as flood control conveyance for groundwater supply enhancement, should be explored further at the local level as there is significant remaining potential across California.

PUBLIC DRAFT

Injection Wells for Recharge and Aquifer Storage and Recovery Wells

An injection well for recharge is a well installed and screened in an underlying aquifer to inject water directly into the aquifer for recharge, resulting in immediate volumetric changes in the aquifer. Injection wells are often used to increase aquifer water levels, prevent seawater intrusion, or slow declines due to over-pumping (California Department of Water Resources 2023b). This method of recharge can be advantageous in areas with less suitable soils for recharge by percolation, smaller footprints, or existing well infrastructure that can support injection. Injection well systems often use treated surface water for recharge that is conveyed to one or more injection wells via an existing distribution system but may also inject recycled water that has been treated to high standards, providing an additional source of recharge water to bolster groundwater supplies while supporting sustainability efforts by reusing water that would otherwise be discharged into the environment (California Department of Water Resources 2023b) (see Section 3.6.4). In addition to aquifer replenishment and long-term water management, the stored water via injection well systems may also be recovered elsewhere in the aquifer at points of demand, effectively using the aquifer to convey water from the point of recharge to the point of use (Maliva 2019).

Aquifer Storage and Recovery (ASR) projects also involve the direct injection of water into aquifers, resulting in immediate volumetric changes; however, the main characteristic of ASR is the local storage *and recovery* of water, typically at the same well (Maliva 2019). Like injection well systems, an ASR project typically involves conveying treated surface water or recycled water to one or more injection wells; however, ASR also involves later extraction of water from the aquifer as needed, treated again at the wellhead if necessary, and conveyed to water users through the same distribution system. Most ASR projects are expected to maximize the use of existing infrastructure such as surface water intake pumps, water treatment plants, and potable water distribution systems to avoid the costs and environmental impacts of building duplicate systems (California State Water Resources Control Board 2012). The performance of ASR systems is influenced by several key factors, including clogging of wells, which affects injection and recovery rates; geochemical reactions after recharge that can alter the quality of the stored water; the hydrogeological characteristics that determine the movement and mixing of recharged water and its recoverability; and the design and operation of wells and wellfields, which ultimately dictate how closely the system's performance approaches theoretical potentials given the hydrogeological setting (Maliva 2019).

PUBLIC DRAFT

In the Central Coast Hydrologic Region, following the successful ASR pilot effort in 2001 with one test well, four ASR wells now comprise the Monterey Peninsula Water Management District's (MPWMD) ASR Project, injecting and extracting water from the Seaside Groundwater Basin at different times of the year. Wells 1 and 2 were fully operational in 2009 and 2010, respectively, and the third and fourth wells became operational in 2016. The ASR Project was designed to produce up to 1,920 acre-feet per year. Long-term storage of water in the aquifer began in 2021, and as of 2024 MPWMD has over 3,600 acre-feet stored for future dry years, which is almost 40% of the Monterey Peninsula's annual use. MPWMD notes that managing the ASR Project takes close coordination and balance between extractions and injections to maximize capturing excess water for storage (Monterey Peninsula Water Management District).

California Water Code Section 13801 requires local agencies to adopt ordinances to establish standards for any type of water-related well, including injection wells. The State Water Resources Control Board's Water Quality Order 2012-0010 establishes comprehensive guidelines and requirements for ASR projects that inject treated drinking water into groundwater (California State Water Resources Control Board 2012). This order was intended to streamline the permitting process, ensure consistent regulatory standards, and protect groundwater quality across California. Additionally, injection wells are regulated for groundwater quality by the U.S. Environmental Protection Agency under the Underground Injection Control program (United States Environmental Protection Agency 2025a).

A growing application of ASR wells is the use of agricultural production wells for both extraction and water injection when surplus water is available, a process known as Ag-ASR. This method involves converting existing agricultural production wells to have the ability to also inject water into the aquifer. An example of active implementation of Ag-ASR is by Westlands Water District, which includes an Ag-ASR program to capture and store surface water, when available, to meet future irrigation demands. The program aims to incrementally convert wells, ultimately reaching a total of 400 operational Ag-ASR wells over the next 15 to 20 years by leveraging existing infrastructure (Westlands Water District 2019).

Injection and ASR wells are beneficial for groundwater storage recovery, increasing groundwater levels, protecting against seawater intrusion, and particularly for reducing subsidence. These wells provide an opportunity for expedited groundwater replenishment to deeper, confined aquifers, where subsidence is often occurring, that would otherwise not be possible or take many years to replenish via applied recharge at the ground surface. This expedited

PUBLIC DRAFT

recovery of groundwater storage can help to more quickly offset groundwater pumping and may eventually reduce subsidence rates.

Stormwater Basins

Stormwater basins are typically engineered low-lying areas or constructed depressions to temporarily store stormwater runoff, primarily for flood control (Maliva 2019). These basins are a common built infrastructure component of stormwater management known as a stormwater best management practice (BMP). Stormwater BMPs are designed to capture runoff for water quality improvement and/or hydrologic mitigation.

There are four main types of stormwater basins utilized for stormwater management: infiltration basins, detention basins, retention basins, and enhanced detention basins. Depending on the site-specific considerations and design of the basin, recharge to groundwater can be intentional and optimized, incidental, or inhibited:

- Infiltration basins (also called dry retention basins) provide temporary runoff storage and are primarily designed to infiltrate water for groundwater recharge. They are generally implemented on a smaller, site-level scale and do not have permanent standing water. Their design typically includes an inlet for water entry, an infiltration/ponding area where water is absorbed into the ground, and an overflow mechanism to handle excess water beyond the storage capacity of the basin during large storm events. The ponding area is typically placed over rapidly draining soils, or a gravel bed may be installed for supplemental subsurface storage (Southern California Coastal Research Project 2020a). In areas where land availability is less constrained, infiltration basins are commonly integrated into larger stormwater management systems. These systems may collect runoff from impervious surfaces, such as roads and parking lots, and may be intentionally designed to provide multiple benefits such as groundwater recharge, habitat enhancement, and stormwater retention (Maliva 2019).
- Detention basins temporarily capture runoff in engineered low-lying areas and slowly drain to a downstream location, thereby reducing peak discharge rates during storms. They are typically implemented for a larger drainage area (over 10 acres) than site-level scale, collecting runoff at the neighborhood or regional scale. For continued effectiveness during stormwater events, these basins empty completely via an outlet pipe at its base (Southern California Coastal Research Project 2020a).

PUBLIC DRAFT

- Retention basins (or ponds) also capture runoff in engineered low-lying areas or depressions though are designed to hold a specific amount of water indefinitely. They are also sometimes referred to as "wet" detention basins because they hold a permanent pool of water (Maliva 2019). Like infiltration basins, they have an overflow outlet pipe to handle water in excess of the permanent pool capacity. For continued effectiveness to manage stormwater, the retention basin's active storage above the permanent pool must be emptied between storm events (Southern California Coastal Research Project 2020a).
- Enhanced or extended detention basins are systems that aim to capture water for the minimum and maximum time frames (e.g., 24 to 72 hours) to allow for sediment and pollutants to settle, after which they are drained completely to avoid mosquito breeding and restore capacity for future storm events (United States Environmental Protection Agency 2021).

All four types of stormwater basins listed here can result in groundwater recharge depending on the design and hydraulic conductivity of the base and sides of the basin. The design, construction, and operational standards for these basins are regulated by various State and local stormwater management guidelines. These guidelines ensure that stormwater basins function effectively within their intended environmental and urban settings while collectively complying with federal pollutant discharge permit requirements.

Dry Wells

Dry wells are another type of stormwater BMP designed to capture and infiltrate stormwater and incidental dry weather runoff into the vadose zone. They are particularly effective in areas with limited space or where surface conditions are not conducive to surface or near-surface BMPs, as they can infiltrate water into deeper subsurface soil layers with higher infiltration capacities (California State Water Resources Control Board 2020).

Dry well systems typically consist of a perforated concrete chamber surrounded by gravel, equipped with a perforated pipe and often a pretreatment system or sedimentation chamber. During and after precipitation events, water enters the dry well through surface inlets, flows into the perforated chamber, and percolates through the gravel and perforated pipe into the surrounding soil (Maliva 2019). The pretreatment system or sediment chamber filters sediments and other targeted contaminants before the water reaches the infiltration zone, reducing clogging and maintaining the efficiency of the dry well.

PUBLIC DRAFT

In the United States, dry wells are federally regulated as Class V wells under the Underground Injection Control (UIC) program, authorized by the Safe Drinking Water Act (California State Water Resources Control Board 2020). The UIC program requires that dry wells do not endanger underground sources of drinking water and must be registered with the United States Environmental Protection Agency. Although the United States Environmental Protection Agency does not provide specific design requirements, State and local guidance often includes design standards for dry wells. In California, dry wells are subject to regulations under the Porter-Cologne Water Quality Control Act, which requires a report of waste discharge to be filed with the applicable Regional Water Quality Control Board for proposed injection wells. Local municipalities also regulate dry wells under Municipal Separate Storm Sewer System permits, which require BMPs for new development and significant redevelopment projects, including criteria for groundwater protection (California State Water Resources Control Board 2020). Permits may also be required for dry wells under county permitting processes.

Dry wells are best suited to relatively low-risk applications where surficial strategies are not practicable, such as in areas with severe space limitations. Permitting entities should consider adopting a risk-based permitting framework as outlined in the California Drywell Guidance Research and Recommendations, prepared for the California State Water Resources Control Board. As these systems bypass natural near-surface contaminant removal and reduction processes and may relatively quickly introduce potentially impacted water to aquifers used for drinking water and/or mobilize existing contaminants in the subsurface, a certain level of pre-treatment may be required to ensure that the system functions appropriately in each given context, with siting and permitting of these systems requiring careful consideration by local enforcement and land use planning agencies.

The use of dry wells for recharge depends on site-specific conditions, and careful consideration must be given to prevent potential contamination of the aquifer. In general, dry wells have relatively low costs compared to other MAR methods, such as injection wells. They generally have a small footprint and can be constructed relatively quickly (Interstate Technology and Regulatory Council 2023). In addition to serving as an important component to stormwater management, dry wells contribute to local groundwater sustainability and water resiliency.

PUBLIC DRAFT

Green Infrastructure and Low Impact Development (LID)

Green infrastructure is defined by the Water Infrastructure Improvement Act as "[t]he range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters" (United States Environmental Protection Agency 2025b). Green infrastructure can vary in scale. Large-scale green infrastructure typically involves the preservation of natural landscape features such as forests, floodplains, and wetlands, while small-scale green infrastructure includes features like rain gardens, porous pavements, green roofs, infiltration planters, trees, and rainwater harvesting for non-potable uses (Chau 2009).

Low Impact Development (LID) encompasses a range of practices aimed at managing stormwater by mimicking natural processes. LID is a decentralized approach to stormwater management, designed to treat small areas individually rather than relying on large, centralized structures (Watershed Conservation Authority). LID is implemented through small, discrete units distributed near the source of impacts, protecting surface and groundwater quality, and maintaining ecosystem integrity. LID strategies include the use of bioretention and infiltration landscape areas, reduced impervious surfaces, functional landscaping, and grading techniques that maintain natural hydrologic functions such as interception, shallow surface storage, infiltration, evapotranspiration, and groundwater recharge (Chau 2009).

LID can be seen as a subset of practices within green infrastructure, but a distinction can be made between the two regarding their scale. LID focuses on site-level interventions to control stormwater and replicate pre-development hydrology, where green infrastructure can encompass a broader, community or watershed-wide approach; however, this distinction is increasingly blurred as the terms are often used interchangeably (University of Connecticut 2013).

Benefits of Green Infrastructure and LID include (United States Environmental Protection Agency 2024a):

- Limited Pollutant Removal: LID and Green Infrastructure practices remove pollutants from stormwater, enhancing water quality.
- Protection of Downstream Water Resources: Managing stormwater close to its source helps protect downstream water bodies from erosion, sedimentation, and pollution.

PUBLIC DRAFT

- Groundwater Recharge: Restoring a site to pre-development hydrologic conditions promotes natural processes, replenishing aquifers and supporting sustainable water supplies.
- Habitat Improvement: Green infrastructure may provide critical habitat for wildlife, promoting biodiversity in urban environments.
- Real Estate Value: Properties with LID and green infrastructure features often see increased real estate values due to their aesthetic and environmental benefits.
- Aesthetic Benefits: These practices enhance the visual appeal of urban areas, contributing to greener, more attractive communities.
- Community Engagement: Implementing LID and green infrastructure can foster community involvement and stewardship, as residents participate in maintaining and enjoying these green spaces.

However, implementing LID presents certain challenges. Without careful planning, LID techniques might inadvertently allow polluted stormwater to infiltrate groundwater supplies, especially in areas with significant pollutant sources and permeable soils like sandy terrains with shallow water tables (Maliva 2019). While natural soil processes such as filtration and adsorption can mitigate some contaminants, they may not eliminate all pollutants. The potential for urban runoff to contaminate groundwater can be influenced by soil characteristics, urban runoff pollutants, the mobility of pollutants, and runoff pretreatment (Maliva 2019). It is essential to ensure that LID is properly designed and maintained to prevent groundwater degradation. While they offer numerous benefits, they also require careful planning and maintenance to be effective. Addressing the challenges associated with potential groundwater contamination is essential to maximize their positive impact.

Both Green Infrastructure and LID play pivotal roles in sustainable stormwater management by replicating natural hydrologic processes, providing benefits to groundwater, and enhancing environmental quality.

Flood Management Infrastructure

Throughout the state, high flows caused by large precipitation events and snowmelt are managed by thousands of miles of levees, bypasses, and temporary/seasonal flood storage to reduce flood risks to millions of Californians. While the primary purpose of flood infrastructure is to reduce flood risk, incidental recharge occurs when floodwater is stored, slowed, and spread. There are

PUBLIC DRAFT

opportunities to increase this incidental recharge through flood infrastructure or modifications to flood infrastructure that increase frequency, duration, area, and depth of inundation support recharge efforts.

For example, the Yolo Bypass in the Sacramento Valley is the state's biggest and best example of a flood risk reduction project providing multiple benefits. The Yolo Bypass is a 40-mile long, 59,000-acre federal flood management facility built in the early 20th century to protect lives and property in the Sacramento River Basin. The bypass is capable of conveying flood flows of more than 500,000 cubic feet per second (cfs) and relieves pressure from the Sacramento River during high flow events, dramatically reducing the risk of flooding in surrounding communities, including the greater Sacramento urban area. The Yolo Bypass is a natural and working landscape characterized by many land uses, including a productive and vibrant agricultural area, and important natural communities that provide critical habitat to numerous fish and wildlife species. While not managed specifically for recharge, the bypass slows and spreads floodwaters and allows for natural infiltration while water is spread across the landscape. Current efforts to modify the Yolo Bypass, like the Yolo Bypass Cache Slough Master Plan, are considering how actions within the bypass and the region can increase recharge and support local groundwater sustainability. Actions within and around the Yolo Bypass can be planned and implemented to increase groundwater recharge — either incidentally or intentionally — to support multi-benefit projects, including:

- Incidental recharge opportunities associated with other Yolo Bypass measures.
    - Actions that increase inundation frequency, such as weir lowering and restoring low flow channels.
    - Actions that increase inundation depth, such as floodplain lowering.
    - Actions that increase retention or decrease flow rate, such as small berms and checks.
    - Actions that increase inundated surface area, such as setback levees and flowage easements.
    - Actions that increase infiltration rate, such as targeting areas with high infiltration rates or planted area.
- Intentional recharge measures within the bypass.
    - Actions that increase inundation frequency, such as intake pipes to dedicated recharge areas.

PUBLIC DRAFT

    - Actions that increase inundation depth, such as installing higher berms.
    - Actions that increase retention, decrease flow rate, or increase inundated area, such grading and new detention basins.
    - Actions that increase infiltration, such as deep tilling or cover crops.
- Intentional recharge measures outside the bypass.
    - Actions that reduce flows to the bypass, such as implementing projects that divert high flows for recharge and increase recharge throughout the Yolo Subbasin, implementing district-scale recharge programs, and reoperating reservoirs.

The actions above could be considered and applied to other flood infrastructure projects, either new or existing, to increase recharge.

Additionally, DWR and local partners have evaluated the potential flood risk reduction, ecosystem, and recharge benefits of setback levees or implementing temporary flood storage through the Multi-Benefit Floodplain Restoration studies in the San Joaquin, Cosumnes, and Pajaro watersheds. These studies have indicated that there are great opportunities and locations where on-the-ground projects can provide all three benefits.

Incidental Recharge

Incidental recharge is an unintentional and unaccounted byproduct of a project where some water taken for a different use is lost to seepage and enters the groundwater system (California State Water Resources Control Board 2024a). A variety of mechanisms result in incidental recharge and are generally grouped here by typical sources in urban, agricultural, and rural areas.

Urban sources of incidental recharge to the local groundwater system may include leaking conveyance (sewer and potable water pipes), landscape and park irrigation return flows, flood management activities, and leakage from ornamental lakes losing water to groundwater (maintained by supplemental water that can be surface water or groundwater sources). Agricultural sources may include unintentional leakage from unlined canals and tile drains, leaking irrigation systems, irrigation return flows from applied water in excess of plant needs, leakage from settling ponds or wastewater lagoons, and flood management activities. Rural sources may include septic system leach fields and flood management activities.

PUBLIC DRAFT

In-Lieu Recharge

In-lieu recharge is an important management tool used by agencies throughout California and is a key component of traditional conjunctive management of surface water and groundwater resources. In contrast to direct groundwater recharge methods, such as injection wells or spreading, in-lieu recharge has an indirect effect on groundwater replenishment. Surface water is used "in-lieu of" or "in-place of" groundwater pumping that otherwise would have occurred. This activity indirectly results in groundwater recharge by leaving the groundwater in the aquifer. Typically, this management approach involves using surface water during wet periods and groundwater during dry periods. This requires necessary infrastructure to meet demands flexibly through groundwater wells and through surface water diversions.

In-lieu recharge is defined in the Sustainable Groundwater Management Act, California Water Code Section 10721, as the use of surface water by persons that could otherwise extract groundwater in order to leave groundwater in the basin. Conjunctive use can be more broadly defined as the coordinated use of all available water resources, including recycled water or desalinated water, with the objective of optimizing overall water management (Maliva 2021). Using multiple water supply sources allows for flexibility, fosters resilient water supply portfolios, and can allow for maximizing in-lieu recharge benefits.

In-lieu is particularly important in areas experiencing land subsidence caused by excessive groundwater pumping. By meeting water demands with alternative water supplies in-lieu of extracting groundwater from aquifers prone to land subsidence, the rate of subsidence can be reduced, and future impacts considerably mitigated. This method is one of the best options for groundwater recharge in places where surface soils or upper aquifer conditions are not conducive to surficial recharge methods, a common condition in areas of subsidence (Peterson et al. 2024).

As reported by the PPIC in *Replenishing Groundwater in the San Joaquin Valley: 2024 Update*, while the overall prevalence of this recharge method has not significantly changed in the San Joaquin Valley since 2017 (Peterson et al. 2024). The reported volumes of in-lieu were 0.8 maf during 2017 and 1.3 maf during 2023 (Peterson et al. 2024). The PPIC reports that, although in-lieu recharge is the most common reported recharge method, further work is needed to develop accounting frameworks for more accurate tracking, as agencies are less likely to monitor and report in-lieu recharge (Peterson et al. 2024). According to the PPIC,

19% of responding agencies in the San Joaquin Valley used surface water bill reductions to incentivize in-lieu recharge (Peterson et al. 2024). Agencies can continue to deliberately encourage further growth of this method through water pricing strategies or other incentives.

The conjunctive management of surface water and groundwater resources should be maximized across the state is a relatively straight-forward approach, providing much needed operational flexibility and resilience to water supply portfolios. Although traditional elements of conjunctive use are widely used statewide as a water management strategy, the coordinated and expanded use of non-traditional, alternative water supply sources to provide in-lieu recharge benefits should be considered and quantified. Despite alternative water supply sources being more costly than surface water or groundwater sources, the reliability afforded by these methods may outweigh cost concerns in certain applications (McCann et al. 2018).

Valley Water, located in the San Francisco Bay and Central Coast hydrologic regions, provides an example of both traditional and non-traditional conjunctive management approaches with in-lieu recharge benefits to groundwater. Since the 1930s, their water supply strategy has been to maximize conjunctive use to enhance water supply reliability and avoid undesirable results like chronic overdraft, land subsidence, and seawater intrusion (Gurdak and Cook 2021). Annual groundwater pumping far exceeds what is replenished naturally in its groundwater basins, and the agency ensures water supply reliability with its direct recharge and in-lieu recharge activities (Gurdak and Cook 2021). In 2022, Valley Water reported it was able to directly recharge 87,200 acre-feet of local and imported surface water, and reduce groundwater demands with in-lieu recharge of 106,000 acre-feet through treated and recycled water deliveries (Gurdak and Tick 2023). Valley Water plans to maintain existing conjunctive management programs and further expand in-lieu and direct recharge through recycled water and purified water projects (Gurdak and Tick 2023).

Depending on the water supply used to offset groundwater consumption, significant differences exist in timing, availability, quality, management methods and associated costs for capital development, all of which must be taken into consideration. A holistic water management approach that incorporates integrated resource planning on a watershed scale, utilizing both traditional and non-traditional water supplies, may benefit the groundwater resource and provide in-lieu recharge benefits to those willing to expand beyond the conventional water resources management paradigm.

PUBLIC DRAFT

3.6.3 Conveyance Infrastructure

Built conveyance infrastructure, a key element of the built groundwater infrastructure, is crucial for the successful implementation of many recharge and conjunctive use projects, and water management across the state. Conveyance, recharge, and extraction infrastructure collectively form the pillars of these projects, enabling the efficient movement, capture, and utilization of water resources. While recharge and extraction infrastructure facilitate capturing, replenishing, and retrieval of water to and from the groundwater system, the built conveyance system expands on California's natural conveyance systems (rivers, creeks, deltas, and aquifers) to ensure smooth transportation of water to and from the recharge and extraction facilities, facilitating its distribution for storage or use demand.

California Water Plan Update 2023 (Update 2023) recognized the importance, nature, and challenges of the "built backbone infrastructure," stating that the state's water resiliency depends on the effective management of the integrated natural and built backbone systems. The built backbone infrastructure is defined as "human-constructed infrastructure that provides water management benefits to communities, ecosystems, and economies across regional and watershed boundaries." (California Department of Water Resources 2023a). While Update 2023 recognized that there is considerable small locally- and regionally-managed built infrastructure, such as dams, diversions, levees and bypasses, groundwater wells and recharge basins, conveyance, pumping plants, drinking water and wastewater treatment plants, and recycled water systems, it defined major State, federal, and local water projects as "backbone" infrastructure in that it helps manage or move water across the state and from one watershed to another. Figure 3-62 depicts the major State, federal, and local water projects, as identified in Update 2023. Examples include the State Water Project, the federal Central Valley Project, and the Los Angeles Aqueduct. More than two-thirds of Californians receive water from backbone systems, which include major dams and reservoirs with more than 40 million acre-feet of storage; more than 1,000 miles of canals, levees, and aqueducts; and hundreds of pump stations to deliver water from source watersheds to areas of need.

Conveyance infrastructure, both at the watershed scale and local scale, is vital to the successful implementation and utilization of groundwater infrastructure projects and conjunctive management. Lacking or absent conveyance can be a major limitation to utilize suitable areas for recharge or benefit from conjunctive management, including in-lieu recharge. Existing conveyance capacities often fall

PUBLIC DRAFT

short in capturing available high flows during precipitation events resulting in missed opportunities. Continued and increased State investment in conveyance infrastructure protection, maintenance, improvement, expansion, and management is needed to maximize the potential benefits from these strategies.

Temporary conveyance and flood diversion equipment have been successfully used in the past to provide additional local flood risk reduction and recharge capacity; however, the operation of this equipment is often less cost effective than more permanent solutions, requires regular maintenance and troubleshooting, and equipment can be in limited supply during precipitation events due to high demand. The Merced River Watershed Flood-MAR Reconnaissance Study found that infrastructure investments, such as increased turnout capacities for fields and the removal of conveyance bottlenecks, optimized the existing conveyance system and vastly reduced the amount of on-farm acreage needed for recharge applications (California Department of Water Resources 2024g). By investing in and maintaining adequate infrastructure, water managers can optimize water resource management, enhance water availability, and support sustainable water use practices (California Department of Water Resources 2024f).

PUBLIC DRAFT

Figure 3-62 Major State, Federal, and Local Water Projects in California



3.6.4 Groundwater Infrastructure Utilization

It is becoming increasingly important for surface water and groundwater managers to utilize both built and natural groundwater infrastructure to effectively manage water resources, especially when preparing for climate variability. Just as surface reservoirs are used to increase water supplies and protect against flooding, groundwater aquifers can be utilized to provide similar benefits, in addition to providing a source of water during dry years when surface water availability is reduced.

The following sections highlight several integrated strategies and infrastructure approaches that combine built and natural systems to enhance groundwater sustainability and resilience across California. Each approach illustrates how floodwaters, stormwater, recycled water, and land use can be harnessed to support groundwater recharge and water supply reliability:

- **Flood-Managed Aquifer Recharge (Flood-MAR):** A voluntary, multi-benefit strategy that uses floodwater to recharge groundwater through farmland, floodplains, and managed natural lands and recharge basins.
- **Forecast-Informed Reservoir Operations and Recharge (FIRO-MAR):** Combines advanced weather forecasting with aquifer recharge to strategically release floodwaters for downstream recharge while reducing flood risk.
- **Water Banks:** Groundwater banking stores water during wet years for later recovery, improving drought resilience and optimizing use of aquifer storage space.
- **Multi-Benefit Areas:** Projects that integrate recharge with other land uses — such as habitat restoration, recreation, and agriculture — providing broad public and ecological benefits.
- **Protection of Recharge Areas and Land Use Considerations:** Ensures long-term recharge capacity through land use planning, urban development controls, and coordination between water and planning agencies.
- **Stormwater Management and Recharge:** Captures urban runoff through green infrastructure and best management practices to recharge aquifers and reduce pollution and flood impacts.
- **Recycled Water Use for Recharge:** Treats wastewater for beneficial reuse in aquifer recharge, expanding water supply options, and supporting groundwater sustainability.

PUBLIC DRAFT

- **Treated Wastewater Use for Recharge:** Involves indirect or direct potable reuse of highly treated municipal wastewater for groundwater replenishment, enhancing long-term supply reliability.

Flood-Managed Aquifer Recharge

As described in previous chapters, Flood-Managed Aquifer Recharge (Flood-MAR) is an integrated and voluntary resource management strategy that uses floodwater for groundwater recharge on agricultural lands, working landscapes, recharge basins, and managed natural lands, including but not limited to refuges, floodplains, and flood bypasses. Flood-MAR strategies may include many of the recharge methods and built and natural infrastructure already discussed in this chapter. For example, Flood-MAR projects can be implemented at various scales, ranging from individual landowners diverting floodwater onto their land (e.g., farmland, dedicated recharge basins) with existing or temporary infrastructure to large-scale projects involving extensive detention or recharge areas and the modernization of flood management infrastructure and operations (e.g., Forecast-Informed Reservoir Operations described in the following section). Flood-MAR is not "one size fits all" nor one solution fits all; rather, strategies can be adapted to local and regional needs and opportunities.

There are many important considerations when implementing Flood-MAR projects, such as site-specific conditions and local dynamics, coordination and cooperation between landowners, flood managers, and water management agencies, navigating regulatory requirements, securing necessary funding, complying with State orders related to flood diversions, site suitability, conveyance, and assessing potential adverse impacts on water quality. But when everything comes together, Flood-MAR provides multiple benefits to both public and private interests (California Department of Water Resources 2018). Flood-MAR is a climate adaptation strategy that uses one challenge — flood events — to solve another challenge — groundwater overdraft. By diverting floodwaters onto lands instead of flowing through constrained and overwhelmed channels, peak river flows and flood risks are reduced for downstream communities. Utilizing that flood water for aquifer recharge helps to offset groundwater pumping, may reduce land subsidence caused by over pumping of groundwater, and may improve water quality. Flood-MAR can also enhance ecosystems by reconnecting floodplains, creating habitats, and supporting groundwater-dependent ecosystems. Additionally, Flood-MAR supports the stewardship of working landscapes by keeping agricultural lands productive while allowing periodic flooding for recharge.

PUBLIC DRAFT

The McMullin On-Farm Flood Capture and Recharge Project at Terranova Ranch in the Kings Subbasin within the Tulare Lake Hydrologic Region is a longstanding example of a successful Flood-MAR project. Flood-MAR concepts have been explored and implemented at Terranova Ranch since the 1980s when groundwater level declines were observed by local landowners. The large pilot Flood-MAR project was initiated under a Natural Resources Conservation Service grant to investigate flooding agricultural lands to mitigate regional flood risks and offsetting groundwater overdraft. The 1,000-acre pilot project studied the infiltration rate of floodwater diverted from the Kings River, potential recharge of groundwater, and farm scale logistics. Based upon a 30-year historical record of Kings Subbasin surplus flood flows, the project estimated 30,000 acres operated for on-farm flood recharge would have had the capacity to capture 80% of available flood flows and potentially help offset overdraft rates in the Kings Subbasin. The project was expanded to a regional scale under a DWR Flood Corridor Grant to expand the project's flood diversion capacity. This project included approximately 5,000 acres and was the first phase of a three-phase project to eventually enroll approximately 20,000 acres to divert 500 cubic feet per second of flood flows from the Kings River when available. Terranova Ranch received a 2017 Governor's Environmental and Economic Leadership Award for the McMullin On-Farm Flood Capture and Recharge Project under Ecosystem and Land Use Stewardship (California Department of Water Resources 2018).

Forecast-Informed Reservoir Operations and Recharge

Forecast-Informed Reservoir Operations (FIRO) is a science-based reservoir operations strategy that utilizes advanced weather and hydrologic forecasts to inform the timing and volume of water releases and storage in existing infrastructure. By anticipating incoming precipitation and runoff, FIRO enables reservoir operators to make more informed decisions that balance the need to mitigate flood risk with the opportunity to retain water for drought preparedness and supply reliability. The strategy represents a major shift from static rule curves toward dynamic operations based on evolving conditions. FIRO is the result of a collaborative effort among DWR, U.S. Army Corps of Engineers' Center for Western Weather and Water Extremes, and numerous local water agencies and academic partners.

Over the past decade, FIRO has been tested and refined through multiple pilot projects across California. In the Russian River watershed, the application of FIRO at Lake Mendocino demonstrated increased water supply reliability without compromising flood protection (Jasperse et al. 2020). Similarly, in the Yuba-

PUBLIC DRAFT

Feather River systems, coordinated FIRO strategies at New Bullards Bar and Lake Oroville have provided a framework for integrating improved atmospheric river forecasts into reservoir operations (Ralph et al. 2025). These pilot efforts have proven the viability of using forecasts to support reservoir operation and water management flexibility. The successful outcomes from these efforts have helped catalyze additional interest and investment in expanding FIRO across California's watersheds.

FIRO-MAR, the integration of Forecast-Informed Reservoir Operations with Flood-Managed Aquifer Recharge, represents the next frontier in California's efforts to build water system resilience. FIRO-MAR enables the strategic release of floodwaters — guided by forecast confidence and reservoir risk thresholds — into recharge basins or designated floodplains, where water can percolate into underlying aquifers. This dual-purpose approach delivers co-benefits for flood mitigation and groundwater sustainability. DWR's reconnaissance study in the Merced River watershed showed that FIRO-MAR implementation could reduce peak flood flows by up to 50%, substantially lowering the risk of levee overtopping and downstream flood damages (California Department of Water Resources 2024g). In Southern California, water agencies along the Santa Ana River are already applying FIRO-MAR principles by adjusting Prado Dam operations based on forecast-informed strategies to enhance aquifer recharge during high-flow events (Ralph et al. 2023).

By strategically enabling more floodwaters to be redirected into groundwater basins rather than flowing unchecked downstream, FIRO-MAR supports multiple State priorities — safeguarding infrastructure, augmenting water supplies, enhancing ecosystem function, and building resilience to climate extremes. As climate variability increases the frequency of both prolonged droughts and extreme precipitation, integrating FIRO-MAR into broader water management strategies will be critical for sustaining California's water systems and communities.

Water Banks

Water banks, also referred to as *groundwater banks*, are systems that store water in natural aquifers during wet periods, allowing for retrieval during dry periods. These banks serve as a buffer against California's variable climate, providing a sustainable water source that can help mitigate the impacts of droughts, protect against groundwater depletion, and support environmental needs.

PUBLIC DRAFT

Groundwater banks can be seen as a combination of both natural and built groundwater infrastructure. Aquifers are used for water storage. The operational and built components include recharge basins, wells, pumps, and monitoring facilities which are necessary to manage the recharge and extraction processes effectively.

The managing entity of a groundwater bank facilitates in-lieu or direct recharge or extraction from a groundwater basin on behalf of other entities having rights over a specific volume of surface water or other water sources such as recycled water. These "deposits" and "withdrawals" of surface water into the basin are accounted for by the managing entity, which is typically the same entity responsible for monitoring groundwater conditions within the basin. In this way, surplus surface water that may be available in a wet year can be "banked" by the owner for future use when needed, such as during a dry year. The managing entity, as a banking partner, may receive a percentage of the banking entity's deposit in exchange for the use of the aquifer storage space (California Department of Water Resources 2024f). Banking projects generally cannot incorporate "native groundwater," defined as existing groundwater volume in excess of banked water volumes, and must be operated to protect native groundwater.

Several groundwater banks have been established in California, especially in the San Joaquin Valley, where years of overdraft have created available aquifer space for storage of banked groundwater. Groundwater banking can only occur in areas where space in the basin has already been created. Unlike the San Joaquin Valley, many areas in the Sacramento Valley are less suitable for groundwater banking because of a lack of storage capacity and known interconnection with creeks and streams.

In California, groundwater banking is a critical component of the State's water strategy, especially given its variable climate and frequent drought conditions. California hosts several groundwater banks, varying in size and capacity. Notable large-scale operations include:

- Kern Water Bank: Located in Kern County, this bank has a storage capacity of approximately 1.5 maf and can recharge up to 460 thousand acre-feet (taf) annually.
- Semitropic Water Storage District: Also in Kern County, it offers significant storage (approximately 1.65 maf) and recovery capabilities, serving multiple banking partners.

PUBLIC DRAFT

In addition to these large facilities, numerous smaller groundwater banks operate throughout the state, often managed by local water districts or municipalities, such as Arvin-Edison Water Storage District (350 taf), Madera Ranch Water Bank (250 taf), Cawelo Water District Groundwater Bank (100 taf), Tulare Irrigation District Groundwater Bank (50 taf), Yolo County Water Bank (20–30 taf), and Santa Clara Valley Water Bank (100 taf), among others. These smaller banks collectively enhance the state's resilience to droughts and climate variability.

The exact number of groundwater banks in California is unknown. However, DWR recognizes the importance of expanding banking efforts to meet future water demands and adapt to climate change. By investing in infrastructure, refining management practices, and enhancing data collection, California can continue to leverage groundwater banking as a tool for sustainable water management. Overall, groundwater banking in California represents a strategic integration of natural and built infrastructure, leveraging the state's aquifers to enhance water resilience and sustainability.

Multi-Benefit Areas

The implementation of groundwater infrastructure can provide opportunities to maximize use of available landscapes for projects that serve multiple purposes, such as areas that simultaneously facilitate groundwater recharge, create habitat, and provide recreational spaces. These projects in turn provide multiple benefits for the local communities such as water supply, water resiliency, and socio-economic benefits. Common multi-benefit areas that incorporate recharge benefits include parks and managed wetlands and floodplain restoration as briefly described below.

PARKS

Parks inherently serve as valuable green or open spaces with aesthetic appeal and recreational value, but traditional park infrastructure often includes impervious surfaces that can lead to increased stormwater runoff. By integrating components of green infrastructure and low impact development principles, parks can be transformed into multi-benefit areas that provide recreational, environmental, and water supply benefits (United States Environmental Protection Agency 2017). For example, natural areas along stream channels within parks can be preserved or enhanced to support stormwater management and wildlife habitat. Constructed wetlands can be created in existing drainage areas to filter and infiltrate stormwater, support biodiversity, and offer recreational and educational opportunities for park visitors. Temporary infiltration, detention or retention basins

PUBLIC DRAFT

can be incorporated into playing-field designs, allowing these areas to hold excess water during heavy rainfall events and gradually infiltrate or release it back into the environment. Additionally, paved trails, walkways, and roads within parks can be retrofitted with permeable pavement, which allows water to infiltrate and reduces surface runoff. Trees planted along roadsides and pathways not only provide shade and improve the park's aesthetic but also contribute to stormwater management and recharge by intercepting rainfall and promoting infiltration.

In the San Joaquin Valley, Dos Rios State Park, recently opened, exemplifies how parks can serve as multi-benefit areas in groundwater management. Developed over 14 years through a collaboration of 11 partners, including DWR, the 1,603-acre park was transformed from former farmland into a restored natural landscape. The park included the restoration of the natural floodplain at the confluence of the Tuolumne and San Joaquin rivers to enhance groundwater recharge by allowing floodwaters to spread across the land, promoting infiltration into aquifers. This process not only replenishes groundwater supplies but also reduces flood risk for surrounding communities. In addition to groundwater benefits, the restoration efforts have created vital habitats for fish and wildlife, including juvenile salmon and migratory birds along the Pacific Flyway. The park also provides a refuge during extreme heat events, contributing to climate resilience and public health. Dos Rios State Park demonstrates how integrating park development and design with groundwater management strategies can yield multiple benefits: enhancing water resources, mitigating flood risks, restoring ecosystems, and supporting biodiversity (California Department of Water Resources 2024h).

MANAGED WETLANDS AND FLOODPLAIN RESTORATION

Managed wetlands are integral to groundwater management in California, providing a range of ecosystem services and socio-economic benefits. These wetlands enhance water quality by trapping sediments and breaking down pollutants and bacteria while also recharging groundwater aquifers and contributing to groundwater replenishment (California Department of Fish and Wildlife 2019). Additionally, they play a role in flood control by reducing peak water flows during storm events and support biodiversity by offering habitats for numerous species, including those that are State and federally listed. From a socio-economic perspective, wetlands support migrating waterfowl and fisheries, provide recreational opportunities such as bird watching, hiking, and fishing, and protect agricultural lands by preventing streambank erosion. They also maintain cultural and aesthetic values, including those important to Tribal communities.

PUBLIC DRAFT

Water resources for wetlands originate from precipitation, surface water, groundwater, and occasionally recycled water. Managed wetlands often depend on surface water diversions and groundwater extraction to replicate natural flooding regimes, particularly in regions like the Central Valley where historical flooding patterns have been disrupted. California's regulatory framework, including the Wetlands Conservation Policy (Executive Order W-59-3) and SGMA, provide guidelines for the protection and management of wetlands (California Department of Fish and Wildlife 2019). Despite these policies, wetlands encounter challenges such as development pressures, increased operational costs, and constraints on water delivery. Groundwater and watershed planning processes address these issues by identifying hydraulically connected wetlands, incorporating wetland contributions into water budgets, and monitoring wetland coverage to assess trends related to groundwater management.

Floodplains, especially expanded and restored floodplains, provide excellent opportunities for multi-benefit projects, like the Dos Rios example provided above in the Parks Section. Rivers and creeks throughout the state have experienced significant modifications to natural processes due to the construction of dams, levees, canals, and other infrastructure, aggregate mining, development, and altered flow and sediment regimes. Most of the state's natural floodplains and riverine habitats have been degraded or lost. Restoring and expanding floodplains provides a unique opportunity to achieve multiple benefits and restore system resilience. Increased and seasonal inundation will provide physical opportunities for spreading and slowing high flows, improving riverine and floodplain habitat, and infiltrating water into the ground.

DWR has been working with partners to develop a systematic approach to identify floodplain restoration and expansion opportunities that provide high-quality salmonid habitat and enhance naturally occurring floodplain recharge. This approach also progresses several California Natural Resources Agency initiatives, including expanding nature-based solutions and cutting green tape, by utilizing floodplains to achieve statewide climate change and biodiversity goals and promoting partnerships and coordination to more efficiently implement ecological restoration opportunities. The Ecological Floodplain Inundation Potential (EcoFIP) toolkit facilitates the identification, analysis, and prioritization of multiple floodplain restoration opportunities at the reach or project scale. DWR is currently piloting this approach and toolkit in the Upper San Joaquin, Pajaro, and Cosumnes watersheds in partnership with local flood and groundwater managers and non-governmental organizations. The pilot study tools help visualize and compare conceptual restoration designs for potential habitat and recharge benefits and

PUBLIC DRAFT

quantify potential benefits and implementation costs (California Department of Water Resources 2024i).

Protection of Recharge Areas and Land Use Considerations

Protection of recharge areas is necessary to benefit and preserve quantity and quality of groundwater in the aquifer. Recharge areas need protection in two primary ways: (1) protection from urban infrastructure expansion, and (2) protection from pollutants from entering the recharge area and impacting groundwater. Regional and local initiatives across the state lay the groundwork for developing groundwater quality and recharge area protection strategies. While not all policies explicitly target groundwater recharge areas, they influence land use decisions and the quality of water used for recharging aquifers (California Department of Water Resources 2023b). For example, California Government Code Section 65302 mandates that cities and counties assess land use, conservation, and safety elements within their general plans, particularly concerning flood hazards and floodplains. This legislation requires the identification and conservation of rivers, creeks, streams, flood corridors, riparian habitats, and lands suitable for groundwater recharge and stormwater management within the context of conservation. The primary goal is to preserve these areas and limit urban development, aligning with broader strategies for protecting groundwater recharge zones.

Additionally, California Government Code Section 65352.5 emphasizes the need for coordination between water supply or management agencies and land use approval agencies (California Department of Water Resources 2023b). This section establishes a standardized process to evaluate the adequacy of existing and future water supplies in meeting demands and assesses the impact of land use decisions on water supply management. Such collaboration is essential for integrating groundwater recharge area protection into comprehensive land use planning and policies.

At the local level, every California city and county is required to develop a comprehensive, long-term general plan that outlines community vision, goals, and development objectives (California Department of Water Resources 2023b). These general plans consist of seven required elements and serve to define and protect existing resources while providing a blueprint for future growth. Groundwater recharge area protection policies are typically embedded within the Land Use, Conservation, Open-Space, or Safety elements of these plans. Although general plans recognize the importance of protecting groundwater recharge areas, the

PUBLIC DRAFT

specific methods and levels of action to achieve this protection can vary significantly among different jurisdictions. Addressing water quality issues associated with recharge areas necessitates effective land use management. Therefore, regulatory and water resources agencies, which may lack direct authority over land use decisions, collaborate with city and county planning departments to incorporate public policies that establish recharge area protection strategies through land management practices (California Department of Water Resources 2023b).

Land repurposing offers a strategic approach to improve groundwater management while reducing socioeconomic impacts of land fallowing, particularly for small, rural disadvantaged communities in the Central Valley (California Department of Water Resources 2023b). A 2023 study conducted by Fernandez-Bou et al. identified disadvantaged communities in the Sacramento Valley and the San Joaquin Valley regions and explored the potential for groundwater banking and managed aquifer recharge by repurposing retired agricultural land (Fernandez-Bou 2023). The study's findings indicate that aquifer recharge could substantially increase groundwater storage and reduce overdraft, especially in areas currently experiencing groundwater depletion. Additionally, the study provided policy recommendations and a proposed framework for conducting feasibility studies in collaboration with local interested parties to develop specific recharge projects (California Department of Water Resources 2023b). Land repurposing can provide additional benefits such as minimizing health impacts from dust and pests in fallowed fields and providing meaningful, connected habitat when strategically implemented.

Stormwater Management and Recharge

Stormwater capture and management involves the utilization of a variety of built and natural infrastructure to handle runoff from precipitation and dry-weather runoff (runoff from daily activities such as lawn irrigation, car washing, etc.) in the urban setting. Stormwater management techniques are categorized into best management practices (BMPs), which can be implemented at various scales. As described in previous Section 3.6.2, many of these BMPs include runoff infiltration (i.e., recharge) as part of the management strategy, such as stormwater basins, dry wells, and green infrastructure and low impact development. Small-scale or site-level BMPs include rain gardens, cisterns, rain barrels, permeable pavements, infiltration basins, trenches, and dry wells. Larger-scale, regional, or neighborhood-level BMPs encompass retention basins, detention basins, urban runoff diversions, and flood control impoundments (Southern California Coastal

PUBLIC DRAFT

Water Research Project 2020). In California, there is significant potential to harness stormwater to recharge groundwater supplies for direct non-potable uses. Estimates from the Pacific Institute suggest that urban stormwater capture could provide between 580,000 af/y in dry years and up to 3 million af/y in wet years in urban areas overlying public supply aquifers. This potential benefit spans multiple scales, from individual households and parcels to neighborhoods to entire communities, making it essential to implement stormwater capture solutions at all levels (Cooley et al. 2022).

Stormwater BMPs can provide multiple benefits, which may include enhanced water supply and community resiliency, reduced flood risks, increased water availability through groundwater recharge and storage, and support for community resilience by reducing pollution, supporting habitats, and potentially improving water quality (Southern California Coastal Water Research Project 2020). However, several challenges include securing funding for the design, construction, installation, and maintenance of BMPs; obtaining necessary permits to comply with local, State, and federal regulations; tailoring BMPs to specific site conditions, such as soil type, topography, and existing infrastructure; and gaining community buy-in and involvement. Additionally, there are many pollutants and associated sources that contribute to water quality degradation of urban stormwater and BMPs are often used and needed to help remove pollutants in stormwater (California Department of Water Resources 2024j).

Urban stormwater management has historically been undervalued compared to other water management types but can provide multiple benefits and should be considered a valuable water supply resource and critical element of local sustainability and resiliency. Capturing and using urban stormwater as a resource can offset drought-related impacts through additional groundwater recharge and aquifer storage, mitigating pollution of stormwater, creating green and open spaces, enhancing fish and wildlife habitat, supporting watershed processes, and improving water use efficiency while mitigating the adverse effects of flood flows (California Department of Water Resources 2024j). California's Water Supply Strategy, highlights the importance of capturing urban stormwater above and below ground to diversify water supplies and better prepare for drought. This strategy set a statewide goal to increase annual supply capacity by at least 250,000 af by 2030 and 500,000 af by 2040, through implementation of new local stormwater capture projects (California Department of Water Resources 2022).

DWR should continue to increase understanding of groundwater recharge implementation in urban stormwater management and track progress toward

PUBLIC DRAFT

statewide goals. For additional information on urban stormwater management, see Urban Stormwater Runoff Capture and Management Resource Management Strategy, Draft Memorandum of the California Water Plan Update 2023 (California Department of Water Resources 2023a).

Recycled Water Use for Recharge

Recycled water, water reuse, and water reclamation are terms that may be used interchangeably and is a process by which water from various sources is treated and reused for beneficial purposes (United States Environmental Protection Agency 2024b). According to the California Water Code Section 13050, recycled water is "water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore considered a valuable resource." Although groundwater recharge is not considered a beneficial use of water by the State Water Resources Control Board, the act of recharge can lead to beneficial uses, including maintaining water quality, supporting baseflows, and enhancing irrigation and municipal supplies (California State Water Resources Control Board 2024a). California's Water Supply Strategy recognizes recycled water as an underdeveloped new water supply and sets goals for recycling at least 800,000 af of water per year by 2030 and 1.8 maf by 2040, and cites it as a key resource for diversifying local water supplies and improving the state's long-term water resilience (California State Water Resources Control Board 2024b).

Recycled water is typically derived from wastewater that has been treated at a centralized municipal wastewater treatment plant but can also be derived from decentralized industrial sources. Recycled water has been used in California for more than 100 years for irrigation and since the 1960s for groundwater recharge (California Department of Water Resources 2024k). As treatment technologies have advanced, the application has expanded, and recycled water is now used statewide for irrigation, industrial, and potable water supply augmentation (California Department of Water Resources 2024k). The following subsections provide a general discussion of potable and non-potable reuse as it pertains to treated wastewater and treated industrial wastewater, along with their implications for groundwater.

Treated Wastewater Use for Recharge

Treated wastewater is typically derived from a centralized municipal treatment plant and the degree of treatment necessary depends on the end use, which are generally grouped and permitted as potable and non-potable reuses (California State Water Resources Control Board 2024b). Potable use is generally described

PUBLIC DRAFT

as water used for public consumptive uses (which include public supply, sanitary, and household uses), and non-potable water as inclusive of all other uses not included in the prior definition. According to the 2022 State Water Resources Control Board Volumetric Annual Report, there were 255 wastewater treatment plants that produced recycled water statewide (California State Water Resources Control Board 2023b).

Potable uses of treated wastewater include reservoir augmentation and groundwater storage, which is also known as indirect potable reuse, as the recycled water is introduced to an environmental buffer such as a reservoir or aquifer (California State Water Resources Control Board 2023c). These are additions of new water to existing sources. Recycled water may be introduced to the aquifer by injection wells or via surficial applications to waterbodies, wetlands, spreading basins, or via vadose zone injection wells.

The Orange County Water District located in the South Coast Hydrologic Region, in partnership with the Orange County Sanitation District, operates the world's largest system for indirect potable reuse using various technologies and applications to groundwater via the *Groundwater Replenishment System*. The system takes highly treated wastewater that previously would have been discharged to the Pacific Ocean, treats it in a three-stage advanced treatment process, and recharges it into the local groundwater basin. The project has a total production capacity of up to 130 million gallons per day (mgd). The project retains the flexibility to pump up to 100 mgd into percolation basins, up to 30 mgd into injection wells to create a seawater intrusion barrier along the coastline, and up to 10 mgd into injection wells within the City of Santa Ana as indirect potable reuse (Orange County Water District 2025).

In December 2023, the State Water Resources Control Board adopted direct potable reuse regulations (California State Water Resources Control Board 2024c) which are expected to greatly facilitate local, large-scale water recycling projects where recycled water is directly introduced into a public drinking water system, or into a raw water supply immediately upstream of a drinking water treatment plant. Direct potable reuse of wastewater may have in-lieu benefits to aquifers in areas where groundwater use is replaced with this new water source, freeing up the groundwater for other beneficial uses or replenishment to the aquifer (see the In-Lieu Recharge section).

Non-potable uses commonly include irrigation (landscape, cemeteries, golf courses, and agricultural) and industrial or commercial applications. In cases when

PUBLIC DRAFT

groundwater is no longer used or pumped for these purposes and replaced with recycled water there is an in-lieu benefit to groundwater aquifers. Examples of non-potable uses of recycled water can be found statewide as the current use of recycled water in California spans a large range of geographies and scales, where investments in new and expanded recycled water projects are occurring in nearly all hydrologic regions (Cooley et al. 2022).

The Pajaro Valley Water Management Agency in the Central Coast Hydrologic Region partnered with the City of Watsonville on the Watsonville Area Water Recycling Project. The project produces approximately 4,000 af/yr of recycled water that is blended with 2,000 af/yr of blend water, totaling 6,000 af/yr of water distributed to local farmland along the coast for irrigation uses. The project has multiple benefits including in-lieu benefits accruing to the groundwater basin to aid in halting seawater intrusion into the aquifer (Pajaro Valley Water Management Agency 2025).

Although there are structural and financial challenges to further adoption of recycled water for non-potable uses, the major challenges pertaining to the widespread adoption of recycled water as a potable water supply source include costs, concerns about safety, regulatory uncertainty, and general public acceptance. Groundwater recharge with reclaimed water for indirect potable reuse has become well accepted among the public as the reclaimed water undergoes advanced treatment prior to recharge and further natural treatment occurs as it moves through the aquifer system (Asano et al. 2007).

According to the Pacific Institute, although California has made considerable progress in expanding the reuse of high-quality treated wastewater, "large volumes of municipal wastewater continue to be discharged to local waterways, marine and estuarine environments, and land" (Cooley et al. 2022). Specifically, the Pacific Institute estimates that 728,000 af of municipal wastewater is already beneficially reused and that an additional 1.8 to 2.1 maf/y of municipal wastewater is available for reuse in California (Cooley et al. 2022). Although there were 255 out of 703 wastewater treatment plants producing recycled water as of 2022, there may be significant opportunity statewide to diversify water supply portfolios and offset the use of groundwater and augment groundwater supplies using recycled water supplies from the remaining 448 wastewater treatment plants that do not produce recycled water (California State Water Resources Control Board 2023b).

PUBLIC DRAFT

TREATED INDUSTRIAL WASTEWATER USE FOR RECHARGE

Industrial reuse of treated industrial wastewater is another form of recycled water produced from an industrial process, rather than derived from a municipal wastewater treatment plant. *Industrial reuse* refers to water that is used more than once in an industrial setting, with the water treated and used again. Generally, these facilities are referred to as *decentralized treatment systems*, since the recycled water is not created in a centralized municipal wastewater treatment plant. When this water originates in the same facility that captures, treats, and reuses it, it is known as *onsite reuse* (WateReuse 2025). Alternatively, water in excess of what can feasibly be reused on-site may present an opportunity for offsite or adjacent reuse, benefiting groundwater aquifers either directly or indirectly. Whether onsite or offsite, decentralized treatment systems can be employed to indirectly benefit the aquifer via incidental recharge such as when applied to wetlands, landscape and irrigation (cemeteries, golf courses, and agricultural), and ornamental lakes. Decentralized treatment systems can directly benefit an aquifer when using similar applications as described in the prior section where groundwater recharge is intentional (i.e., spreading basins, etc.). The use of decentralized treatment systems, and the necessary treatment processes, may be used to offset the depletion of groundwater resources (Asano et al. 2007). In both the onsite or offsite reuse scenarios, when groundwater is no longer used, pumped, or supplied for industrial use and is instead replaced with recycled water, an in-lieu benefit to groundwater aquifers may occur.

As with any recycled water use case, water quality considerations depend on the receiving waterbody or aquifer. Consideration of appropriate treatment technologies using a "fit-for-purpose" approach is important to protect groundwater resources while balancing costs. "Fit-for-purpose specifications" are the treatment requirements to bring water from a particular source to the quality needed, to ensure public health, environmental protection, or specific user needs (United States Environmental Protection Agency 2024b). Mechanisms for intentional groundwater recharge using reclaimed water from industrial facilities could mirror those described in the treated wastewater section. However, the regulatory framework differs, and there are unique challenges associated with operations and maintenance of decentralized systems.

The City of San Francisco, located in the San Francisco Bay Hydrologic Region, developed non-potable onsite reuse requirements for new, large development projects through its "Non-Potable Water Ordinance." Codified in Article 12C of the San Francisco Health Code, this ordinance currently requires development projects of 100,000 gross sq ft or more to install and operate an onsite non-potable water

PUBLIC DRAFT

reuse system (San Francisco Public Utilities Commission 2025). This ordinance, implemented via a collaboration between several city agencies, has resulted in numerous high-profile facilities being built in the city and has substantially offset potable water demands. One example is at the Chase Center, which captures rainwater, stormwater, graywater, and other wastewater for toilet and urinal flushing and spray irrigation, resulting in a 34% potable water use reduction equating to a savings of 3.8 mg/y (or 11.6 afy) (San Francisco Public Utilities Commission 2021).

There may be significant opportunities statewide to offset the use of groundwater supplies using recycled water supplies through treated industrial wastewater sources.

3.6.5 Groundwater Recharge Infrastructure Expansion

As described in the previous sections, a wide variety of methods and opportunities exist for implementing groundwater recharge infrastructure across California's diverse landscapes. This section expands upon those discussions by focusing on how GSAs are planning and implementing recharge projects under SGMA. It also considers the cost-effectiveness and implementation challenges associated with these projects. Understanding the scope, cost, and feasibility of recharge infrastructure is critical to expanding California's managed aquifer recharge capacity and meeting long-term water sustainability goals.

To support these goals, the following subsections provide key insights into the best available information on groundwater recharge infrastructure implementation, drawing primarily from GSPs, SGMA data modules, and other state and academic sources:

- **Groundwater Recharge Projects Proposed in Groundwater Sustainability Plans:** Describes the types, frequency, and estimated recharge benefits of proposed recharge projects documented in GSPs, as well as their costs and stages of development.
- **Groundwater Recharge Projects Costs Considerations:** Summarizes both capital and levelized costs for various recharge project types, offering comparisons between traditional and nature-based infrastructure.
- **Groundwater Recharge Projects Implementation Challenges:** Outlines technical, legal, and institutional barriers that must be addressed to increase recharge capacity, including permitting, landowner coordination, water rights, and access to funding.

PUBLIC DRAFT

Groundwater Recharge Projects Proposed in Groundwater Sustainability Plans

SGMA regulations require each GSP to include a description of the projects and management actions (PMAs) that the GSA has determined to be necessary for achieving the sustainability goal of the basin. GSPs must also provide detailed descriptions of how the PMAs would prevent undesirable results, avoid exceedance of minimum thresholds, and achieve measurable objectives and interim milestones. The PMA descriptions also outline the triggers for action implementation, the process for public and neighboring agency notifications, regulatory requirements, project status and schedule for initiation and completion, cost estimates, and funding sources. When known, estimated volumetric benefits associated with the PMAs are also provided. The statistics and analysis included below are based on information provided in the PMA Module (described in Chapter 2, "Progress Toward Sustainable Groundwater Management"). This represents the best available information regarding groundwater recharge PMAs being proposed and implemented by GSAs as of April 2025.

The PMA Module identifies over 1,500 PMAs. For the analysis presented here, recharge projects were identified as those PMAs that were designated as "Direct Aquifer Recharge" in the "Project or Management Action Type(s)." A total of 355 PMAS were designated as "Direct Aquifer Recharge." The PMA Module also includes a "PMA Subtype(s)" field that allows GSAs to further break down recharge projects into more specific categories such as *Recharge Basins, Injection Wells, FloodMAR, and Stormwater Capture*. Table 3-9 summarizes Direct Aquifer Recharge PMAs by subtype, identifying the number and percentage of recharge projects that include quantified benefit estimates, expressed in acre-feet per year (af/yr).

PUBLIC DRAFT

Table 3-9 Direct Aquifer Recharge PMAs with Estimated Benefits Data

PMA Type and Subtype	Number of PMAs	Number of Projects with Estimated Benefits Data	Percent of Projects with Estimated Benefits Data	Total Estimated Benefit (af/yr)
New or Expanded Recharge Basin/Spreading Grounds	129	101	78%	442,618
Multiple Categories	79	38	48%	93,089
Stormwater Capture	29	12	41%	2,962
Existing Recharge Basin/Spreading Grounds	28	17	61%	78,900
FloodMAR	23	18	78%	126,888
Injection Wells	22	14	64%	77,591
Riparian Floodplain Restoration or Managed Wetlands	22	8	36%	15,665
Other *	23	14	61%	316,225
Direct Aquifer Recharge Project (TOTAL)	**355**	**222**	**63%**	**1,153,938**

Table 3-9 Note: Other includes water rights, recycled water delivery, site investigations, and development of banking programs.

The most common project type was New or Expanded Recharge Basins/Spreading Grounds (129 projects) followed by Multiple Categories (79 projects). Less common approaches included Riparian Floodplain Restoration (22 projects), Stormwater Capture (29), and Direct Aquifer Recharge — Other (23). This distribution reflects the diverse range of recharge strategies being explored across the state, with many agencies proposing multiple recharge pathways or hybrid approaches. Figure 3-63 highlights the number of recharge projects reported for each groundwater basin.

Of the 355 projects, 222 (63%) included an estimate of the recharge benefit, totaling 1.15 maf/yr in recharge across the state. Project subtypes that most often included estimated benefit quantifications included FloodMAR (78%), New/Expanded Recharge Basins (78%), and Injection Wells (64%). The largest

PUBLIC DRAFT

estimated volumes of annual recharge benefits were associated with the following subtypes:

- New or Expanded Recharge Basins: 442,618 af/yr.
- Direct Aquifer Recharge — Other: 316,225 af/yr.
- FloodMAR: 126,888 af/yr.

In contrast, project subtypes such as Stormwater Capture (2,962 af/yr) and Riparian Floodplain Restoration or Managed Wetlands (15,667 af/yr) have both less frequent reporting rates and smaller total estimated volumetric benefits, suggesting that some project types are still in early stages of development or face greater challenges in quantifying their recharge benefit.

The PMA Module also includes estimates of project costs when available. Table 3-10 presents the number and percentage of projects with reported cost estimates, along with total estimated costs by subtype. 176 of the 355 Direct Aquifer Recharge projects in the PMA module provided estimates of costs, with the total reported costs exceeding $5.6 billion. The largest estimated costs were reported for New or Expanded Recharge Basins ($1.9 billion), Injection Wells ($1.78 billion), and Other ($1.09 billion). These three project types alone accounted for nearly 80% of the total reported costs of direct recharge projects.

PUBLIC DRAFT

Table 3-10 Direct Aquifer Recharge PMAs with Estimated Costs Data

	Number of PMAs	Number of Projects with Estimated Cost Data	Percent of Projects with Estimated Cost Data	Total Estimated Cost ($)
New or Expanded Recharge Basin/Spreading Grounds	129	79	61%	$1,898,381,579
Multiple Categories	79	30	38%	$546,936,355
Stormwater Capture	29	15	52%	$124,216,000
Existing Recharge Basin/Spreading Grounds	28	12	43%	$45,861,089
FloodMAR	23	8	35%	$75,279,400
Injection Wells	22	13	59%	$1,779,304,000
Riparian Floodplain Restoration or Managed Wetlands	22	8	36%	$81,246,050
Other	23	11	48%	$1,088,692,000
Direct Aquifer Recharge Project (TOTAL)	**355**	**176**	**50%**	**$5,639,916,473**

Table 3-11 identifies the subset of projects for which both benefit and cost estimates are available and includes estimated total benefits and total costs for each type of direct recharge projects.

PUBLIC DRAFT

Table 3-11 Direct Aquifer Recharge PMAs with Estimated Costs and Benefits Data

	Number of PMAs	Number of Projects with Both Estimated Costs and Benefits Data	Total Estimated Benefit (af/yr)	Total Estimated Cost ($)	Cost per af of yield* (not levelized) ($/af)
New or Expanded Recharge Basin/Spreading Grounds	129	71	307,699	1,774,127,503	$5,766
Multiple Categories	79	23	63,489	536,601,717	$8,452
Stormwater Capture	29	10	1,822	70,541,000	$38,716
Existing Recharge Basin/Spreading Grounds	28	10	35,200	42,851,089	$1,217
FloodMAR	23	7	40,068	73,279,400	$1,829
Injection Wells	22	12	76,911	1,758,304,000	$22,862
Riparian Floodplain Restoration or Managed Wetlands	22	5	8,455	70,196,050	$8,302
Other	23	9	305,015	1,057,412,000	$3,467
Direct Aquifer Recharge Project (TOTAL)	**355**	**147**	**838,659**	**5,383,312,759**	**$6,419**

Table 3-11 Notes: Costs per af of yield is not annualized cost over the life of the project, which is called levelized cost. Costs per af/yr can be calculated by dividing the numbers in this column by the life span of the projects. A typical water project can have a life span of about 30 years.

A total of 147 PMAs included both estimates of benefits and costs. These projects reported an estimated total of 839 taf/yr of recharge benefit at a combined cost of $5.38 billion. It is important to note that these cost estimates generally represent upfront capital costs, not levelized costs that consider total life-cycle expenses. Project lifespan and long-term yield are key factors when evaluating overall cost-effectiveness and return on investment. Data on the lifespan of these projects are

PUBLIC DRAFT

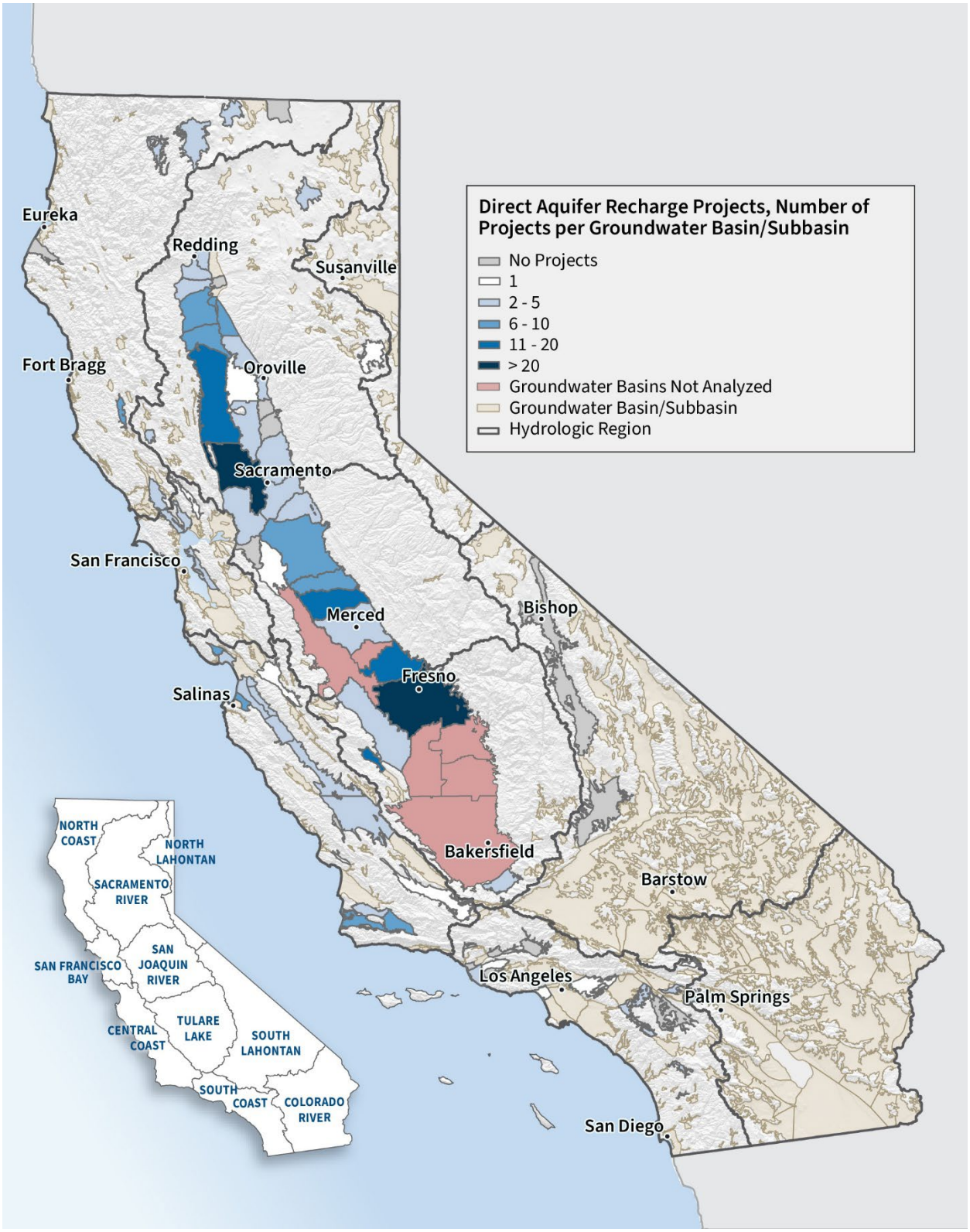
sporadic, and when available, are not consistent across all projects. In addition, annual operation and maintenance (O&M) cost data are not uniformly reported. If one assumes a uniform 30-year project lifespan, however, unit cost estimates could be developed using the reported capital costs and recharge benefits, which in this case would be $214/af/yr.

However, these results suggest that traditional and nature-based infrastructure (e.g., recharge basins and FloodMAR) may offer more cost-effective recharge opportunities than engineered systems like injection wells and stormwater projects, though site-specific needs and benefits (e.g., deep aquifer targeting) may justify their use in certain contexts. As with estimated recharge benefits, recharge project cost estimates should be reconciled with actual project costs for a more accurate analysis.

It is important to note that these projects represent potential recharge under SGMA, rather than actions that will necessarily occur or that currently exists. The data provided here are from approved GSPs only. Inadequate plans were excluded from the analysis, and therefore this analysis underrepresents the recharge potential, especially in the San Joaquin Valley. Additionally, the timeline and certainty of each PMA is subject to change. Some projects are in the process of being implemented while others are in early conceptual stages. PMAs for which recharge is one of their multiple benefits are also unable to separate out the specific volume associated with recharge. As implementation of PMAs progresses, estimated benefit quantification should be reconciled with actual project performance to obtain a more accurate and clear picture of the recharge activities under GSP implementation. For the most up-to-date PMAs, please refer to the basin's or subbasin's most recent GSP Annual Report.

PUBLIC DRAFT

Figure 3-63 Direct Aquifer Recharge Projects Identified in GSPs by Basin



Groundwater Recharge Projects Costs Considerations

The costs to build recharge infrastructure vary based on the recharge method, nature and size of the project, frequency of the use of recharge facility, sources of surface water supplies, and quality of surface water. As previously described, some recharge methods require relatively minor changes in operations or upgrades of existing infrastructure, such as pump upgrades or increasing releases of water from existing conveyance canals, while other recharge methods may require extensive new infrastructure. This infrastructure can include canal turnout structures, land preparation, new pipelines and pumps, injection or extraction wells, or construction of new recharge basins (California Department of Water Resources 2023b).

LEVELIZED COSTS

A metric for understanding the financial feasibility of MAR projects is the levelized cost. The levelized cost accounts for the total life-cycle expenses (including capital, operations and maintenance, and any additional associated costs) and provides a comprehensive view of the long-term financial sustainability of a project. Levelized costs provide implementing parties with a way to assess not just the immediate expenses, but the overall economic efficiency and return on investment of MAR projects over time.

For example, one study (Ross and Hasnain 2018) determined the following average approximate levelized costs for recharge basins and injection wells using natural and recycled water:

- Recharge basins.
    - Natural water: $234 per af.
    - Recycled water: $2,330 per af.
- Injection wells.
    - Natural water: $555 per af.
    - Recycled water: $1,431 per af.

Another study (Vanderzalm et al. 2022) estimated the following levelized costs (for the year 2020) for various recharge methods:

- Recharge releases (a release from an upstream dam for infiltration in downstream reach channel beds): $49 to $62 per af.
- Infiltration basins: $74 to $111 per af.

PUBLIC DRAFT

- ASR (depending on end use and post-treatment needs): $123 to $308 per af.
- Recharge weir/check dam: $160 to $209 per af.
- Seawater intrusion barrier: $444 per af.

A Flood-MAR pilot project in the Kings Subbasin consisting of capturing flood flows and applying it to agricultural lands, with the primary goal to reduce damages associated with 10- to 100-year flood events, was calculated at $36 per af, including costs for labor, land preparation, fuel, and farm-scale infrastructure improvements (Bachand et al. 2016). Flood-MAR projects that require the construction of recharge basins or changes to flood management infrastructure are likely to have higher costs.

The estimated recharge infrastructure levelized costs provided above range from $36 per af (minimum infrastructure investment needed) to $2,330 per af (significant infrastructure investment needed).

CAPITAL COSTS

GSAs have indicated in the PMA module that estimated capital (construction) costs for recharge projects range from $1,217 per af of yield (utilizing/enhancing existing recharge basins) to $38,716 per af of yield (stormwater capture); when a 30-year project lifespan is assumed, these cost figures translate to approximately $41 per af/yr and $1,290 per af/yr, respectively. These capital cost estimates only reflect the cost associated with recharging water into the ground and do not include cost for extraction and recovery. This approach is appropriate given the wide variability in operations and maintenance costs across different MAR projects. It is also important to recognize that not all MAR projects in GSPs are designed for subsequent groundwater extraction — some are intended to improve basin conditions or offset existing groundwater pumping without increasing future extraction needs.

A new reservoir underway in Northern California, Sites Reservoir, is estimated to cost about $4.5 billion and provide about 1.5 million acre-feet in capacity. An estimated annual average of 658,000 af of water is expected to be available for diversion and storage in the Sites Reservoir with an approximate cost of $6,800 per af of yield (Sites Reservoir 2024). Unlike MAR projects, surface storage projects like Sites Reservoir generally include capital costs for delivery and conveyance structures such as pumping to convey water into the reservoir. Assuming a typical 100-year life span of earthen embankment dam, the cost of

PUBLIC DRAFT

water per af/yr would be approximately $68. However, it is important to note that surface water storage also incurs higher O&M costs due to pumping and delivery requirements. Therefore, comparison of only capital costs between surface storage and MAR projects may not provide a complete picture of long-term economic performance.

Both levelized and capital costs for recharge project implementation vary widely depending on the scale of the project, type of recharge infrastructure needed, and site-specific conditions, but are often comparable to surface water storage costs. When also considering the scale of surface water reservoir projects, the decentralized nature of MAR projects may provide significant advantages. New reservoirs and reservoir expansions, while providing substantial new storage capacity, come with significant challenges such as lengthy construction timelines, the complexities of obtaining permits for large-scale projects, community impacts and buy-in, land acquisition and the inundation of additional land, which pose risks to existing ecosystems. In contrast, MAR offers a flexible, scalable, and less intrusive approach that can be implemented on a relatively short timeline. MAR projects are smaller in scale, allow for local management, often are implementation grant program priorities, and can often utilize existing spaces and infrastructure without the need for extensive new construction.

Additional information regarding costs of recharge projects, particularly as-built costs, is needed. As GSAs continue to provide annual reporting of project management action implementation, DWR will continue to compile, analyze, and disseminate information and insights related to recharge infrastructure costs. Given the complexity and variability in the costs associated with MAR, it is important to continue to assess how MAR projects compare with traditional water storage methods, particularly surface reservoir expansion. While expanding reservoirs has been a conventional solution for increasing water storage capacity, historical cost comparisons suggest that MAR may often present a favorable alternative, offering both economic and environmental advantages.

For additional information regarding recharge infrastructure cost considerations, see the Recharge Area Identification, Utilization, and Protection Resource Management Strategy Memorandum of the *California Water Plan Update 2023* (California Department of Water Resources 2023b).

PUBLIC DRAFT

State Assistance for Recharge Projects

As indicated in the previous sections, efforts to continue or expand recharge are identified in many GSPs as projects and management actions for achieving sustainability. DWR has supported the advancement of these local projects through financial and technical assistance. Some of the recharge projects described in the GSPs were at least partially, if not fully, funded by DWR grants or other state financial assistance programs. Since 2018, DWR has awarded almost $125 million to 70 groundwater recharge projects. Estimated recharge benefits for these projects are currently being compiled; however best available information indicates a total of almost 115,000 acre-feet per year of potential recharge capacity from these projects.

Groundwater Recharge Projects Implementation Challenges

Managed aquifer recharge has many benefits and is recognized as an important strategy for water supply management and resiliency, and groundwater sustainability in California. However, implementation of recharge projects presents a number of practical, regulatory, and systemic challenges.

In June 2018, DWR released a white paper on Flood-Managed Aquifer Recharge (Flood-MAR) to explore opportunities to use high flows for managed aquifer recharge (California Department of Water Resources 2018). The paper recognized the need to rehabilitate and modernize water and flood infrastructure in California, and noted that large-scale implementation of Flood-MAR could fundamentally transform how flood and groundwater management are integrated. The white paper also identified several barriers that hinder implementation of Flood-MAR at a larger scale.

These challenges were informed by the experiences of agencies that have successfully implemented long- or short-term groundwater recharge programs using floodwater. They identified several key issues, including:

- Determining the quantity and timing of flows available for diversion.
- Understanding crop suitability.
- Willingness of local landowners to participate.
- Accounting and reporting of replenished water.
- Developing explicit agreements for operations and use of water.
- Making funding available for studies, projects, and compensation of landowners.

PUBLIC DRAFT

- Collaboration between academia, the State Water Resources Control Board, and local agencies to provide proof-of concept and ease of permitting.

Building on these findings, a survey conducted in 2017 and updated in 2023 by the Public Policy Institute of California identified barriers to recharge project implementation that were very similar to the list above, but also included infrastructure constraints, regulatory complexities, challenges related to cropland recharge due to farming practices, and difficulty securing adequate funding (Hanak et al. 2018; Peterson et al. 2024).

The Flood-MAR white paper organized the barriers and challenges into four main themes, which continue to affect the planning and implementation of recharge projects more broadly:

- **Cooperation and Governance:** Landowner willingness; the multitude of agencies that own and operate infrastructure; the necessary, but lacking, integration and coordination of flood and groundwater management; leadership for multi-agency, regional or watershed scale efforts, and required cooperative agreements.
- **Policy:** Issues associated with recharge not being considered a beneficial use of water and State and local incentive programs
- **Legal:** New water rights for winter diversions and underground storage, permitting, and regulations, such as environmental laws.
- **Implementation:** Land use, crop suitability, water quality, water available for recharge, basin characterization, conveyance, reservoir operations, economics, environmental considerations, and data and capacity building.

While some barriers and challenges have been addressed through new information — such as data gathered from basin characterization, changing conditions including the historic wet year in 2023, evolving perspectives showing increased landowner willingness and reduced concern about crop impacts, and efforts to streamline processes for temporary and streamlined water rights — many challenges still remain. These include the lack of incentive programs and funding, limited availability of water for recharge, lack of underground storage rights, low risk tolerance for testing and learning, and the need to comply with environmental protection laws, such as fish screening requirements.

In response to some of these institutional challenges, Water Code Section 1242.1 was enacted in July 2023 to build upon Executive Orders issued earlier that year. This statute aimed to allow the diversion of floodwaters for recharge outside the

PUBLIC DRAFT

traditional water rights process if certain conditions were met. These conditions included defining flood flows, fulfilling local planning requirements, providing public notification, adhering to land-use restrictions for recharge, and considering Delta conditions, among others. However, implementation proved difficult. Few — if any — local agencies were able to meet the statute's local planning requirements, and many lacked a designated local flood agency or defined flood flow standards, both of which are prerequisites under Water Code Section 1242.1. As of January 2025, no diversions had been made under this statute. DWR is actively collaborating with local agencies to clarify requirements and facilitate compliance with Water Code Section 1242.1. In a more targeted effort to overcome procedural delays, Governor Newsom issued Executive Order N-16-25 in January 2025 to facilitate the capture and storage of water from atmospheric river storms in Northern California. This order streamlined the process for diverting flood flows for groundwater recharge by waiving compliance with local planning requirements under Water Code Section 1242.1, thereby enabling local agencies to act more rapidly in response to flood conditions. As a result, in February and March 2025, the Dunnigan Water District and Rancho Murieta Community Services District became the first local agencies to implement flood diversions under the streamlined provisions, effectively enhancing groundwater recharge efforts during the storm events.

While Executive Order N-16-25 demonstrates the potential for regulatory flexibility to accelerate recharge projects, it also underscores the continued existence of significant technical, legal, and institutional challenges that affect the planning and implementation of Flood-MAR and other recharge programs and projects. Addressing these barriers in a lasting and systematic way will require thoughtful strategy, open dialogue, strong leadership, robust public-private partnerships, sustained and adequate funding, and innovative research and pilot projects. As emphasized in the Flood-MAR white paper, ongoing local and regional collaboration and active support from State government are critical to advancing local- and system-level implementation and fully realizing the promise of managed aquifer recharge.

PUBLIC DRAFT

4 . Groundwater Use, Extraction, and Water Budgets

Chapter Summary

Chapter 4, "Groundwater Use, Extraction, and Water Budgets," of *California's Groundwater: Bulletin 118 — Update 2025* (CalGW Update 2025), examines California's groundwater usage patterns, extraction practices, and the crucial role of water budgeting in sustainable water management. This chapter begins by discussing recent and long-term trends in groundwater use across various sectors, such as agriculture, urban, managed wetlands, and forestry. It highlights the impacts of land-use changes, including shifts in crop types and the effects of fallowing agricultural land, on groundwater demand. This chapter also considers the distribution of groundwater use across basins, using data from groundwater sustainability plans (GSPs), alternatives to GSPs (Alternatives), and annual reports, submitted by groundwater sustainability agencies (GSAs). Non-basin areas are also analyzed using available datasets. Unless otherwise specified, the reference to GSAs includes the Alternatives managers.

On the supply side, this chapter addresses groundwater recharge, distinguishing between managed and natural recharge. This chapter provides reviews of data from GSPs, and outlines State-initiated programs and projects aimed at enhancing recharge potential to support sustainable water management.

This chapter also explores groundwater budgets and accounting practices, guided by California Department of Water Resources' (DWR's) water budget framework and pilot projects on water supply and balance. The role of sustainable yield is underscored, with an emphasis on aligning future water budgets with groundwater sustainability goals.

Integrated hydrologic models are essential tools for water resource management, supporting comprehensive water budgeting and addressing data gaps. The chapter outlines State- and federal-sponsored modeling tools and resources and describes how local agencies can apply these models to manage groundwater sustainably. It concludes by examining the role of climate change data and tools in groundwater sustainability planning, underscoring the importance of incorporating climate projections into water budget assessments to adapt to changing conditions and ensure long-term groundwater sustainability.

PUBLIC DRAFT

Chapter 4, "Groundwater Use, Extraction, and Water Budgets," connects with the themes of CalGW Update 2025, including Theme 2, "Accelerating Momentum for Sustainability," and Theme 4, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support," by emphasizing water budgeting, recharge initiatives, and hydrologic modeling as foundations for sustainable water management. Through detailed data on groundwater use, recharge projects, and future water budget planning, this chapter highlights both the urgency of sustainable practices and the role of advanced tools and climate projections in maintaining long-term groundwater reliability.

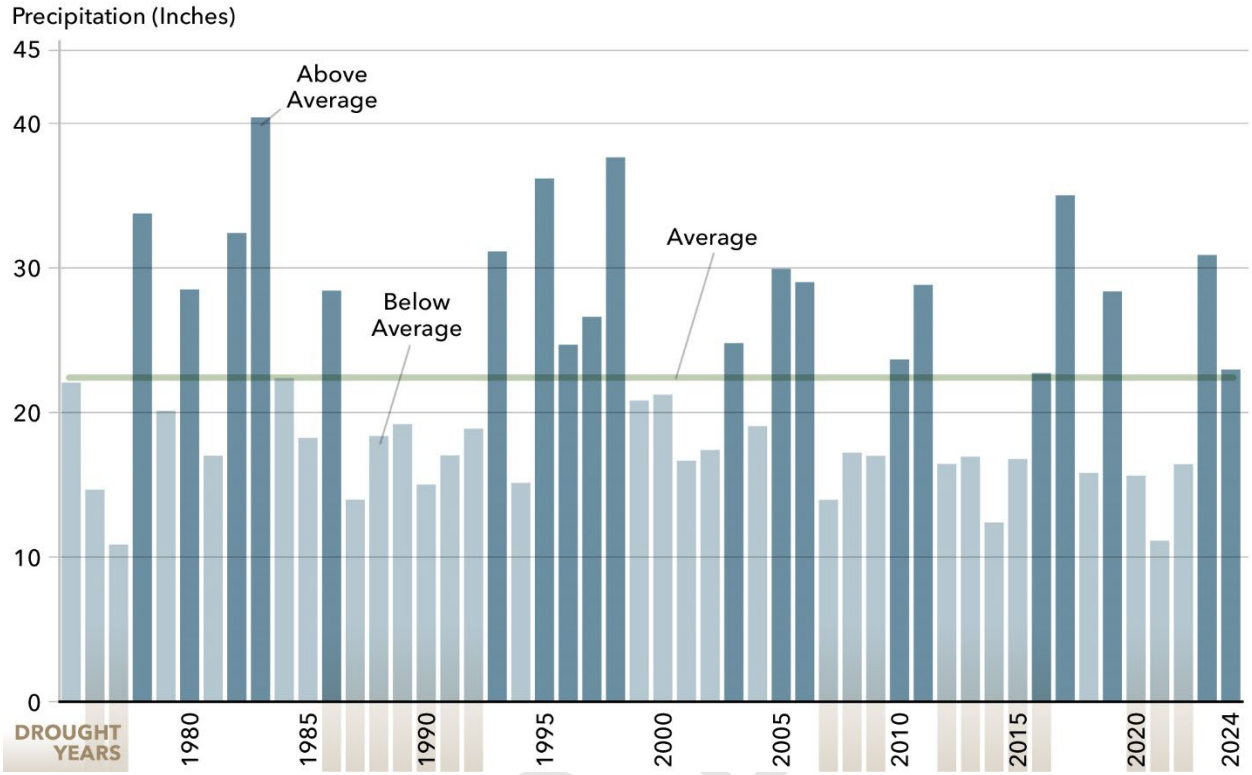
4.1 Introduction

Understanding how much groundwater is used and where is vital to ensuring the future health and well-being of California's people and economy. While surface water use can be measured and monitored with relative precision — in waterways, conveyance infrastructure, diversion points, and distribution systems — groundwater use in California has historically been estimated based on water demand. Outside of public water systems and some adjudicated areas, direct measurement and reporting of groundwater extraction has historically not been required in the state. Although groundwater use estimates have been presented in the California Water Plan, these estimates are generally high-level (limited to statewide or hydrologic region scales) and are based on demand estimates — using groundwater as a closure term. With the implementation of the Sustainable Groundwater Management Act (SGMA), regulatory requirements have resulted in more localized efforts to estimate and report groundwater use in recent years.

Understanding precipitation patterns is also critical, as precipitation is a major driver of both surface water availability and groundwater use. California's highly variable climate — marked by frequent droughts and occasional wet years — strongly influences groundwater extraction and recharge patterns. Figure 4-1 displays the annual statewide precipitation in California since 1972, highlighting this variability. Years with below-average precipitation typically lead to increased groundwater pumping, while above-average years offer opportunities for groundwater recharge through natural and managed means.

PUBLIC DRAFT

Figure 4-1 Statewide Annual Precipitation



Source: National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (Climate at a Glance: U.S. Time Series, Precipitation).

In addition to statewide precipitation patterns, regional water year classifications offer important context for evaluating hydrologic conditions and their influence on water supply. The Sacramento and San Joaquin Valley Water Year Indices, developed by the California Department of Water Resources, classify each year as Wet, Above Normal, Below Normal, Dry, or Critical based on unimpaired runoff forecasts and prior hydrologic conditions. Water Year Indices for 1977 through 2023 are presented in Table 4-1. While these indices are not statewide measures, they provide a consistent and practical gauge of water availability in two of California's largest watersheds. As such, they serve as a valuable proxy for understanding broader surface water conditions in the Central Valley, where much of the state's agricultural activity and groundwater use occurs.

These regional water year indices have significant implications for surface water availability, particularly in relation to the State Water Project (SWP) and Central Valley Project (CVP). During dry or critical years, reduced surface water deliveries often lead to increased reliance on groundwater pumping, which can strain local aquifers. Conversely, wet and above normal years improve surface water supply

PUBLIC

and support opportunities for recharge. The importance of these indices is underscored by their formal incorporation into State Water Resources Control Board (State Water Board) Water Right Decision 1641, which uses the Sacramento and San Joaquin classifications to trigger and scale regulatory flow and water quality requirements in the Sacramento-San Joaquin River Delta (Delta). Because SWP and CVP water supplies are conveyed to users throughout the state — including Southern California, the Bay Area, and the Central Coast — the hydrologic conditions they respond to have far-reaching implications beyond the Central Valley. As such, water year types not only reflect hydrologic variability but also shape how water is managed across the interconnected surface water and groundwater systems throughout much of California. When hydrology is discussed in this chapter, it broadly encompasses precipitation patterns, the occurrence of drought years, and regional water year indices, which together provide a comprehensive understanding of surface and groundwater availability.

Table 4-1 CDEC Water Year Indices

Water Year	Sacramento Valley Index	San Joaquin Valley Index
1977	Critical	Critical
1978	Above Normal	Wet
1979	Below Normal	Above Normal
1980	Above Normal	Wet
1981	Dry	Dry
1982	Wet	Wet
1983	Wet	Wet
1984	Wet	Above Normal
1985	Dry	Dry
1986	Wet	Wet
1987	Dry	Critical
1988	Critical	Critical
1989	Dry	Critical
1990	Critical	Critical
1991	Critical	Critical
1992	Critical	Critical
1993	Above Normal	Wet
1994	Critical	Critical

PUBLIC DRAFT

Water Year	Sacramento Valley Index	San Joaquin Valley Index
1995	Wet	Wet
1996	Wet	Wet
1997	Wet	Wet
1998	Wet	Wet
1999	Wet	Above Normal
2000	Above Normal	Above Normal
2001	Dry	Dry
2002	Dry	Dry
2003	Above Normal	Below Normal
2004	Below Normal	Dry
2005	Above Normal	Wet
2006	Wet	Wet
2007	Dry	Critical
2008	Critical	Critical
2009	Dry	Below Normal
2010	Below Normal	Above Normal
2011	Wet	Wet
2012	Below Normal	Dry
2013	Dry	Critical
2014	Critical	Critical
2015	Critical	Critical
2016	Below Normal	Dry
2017	Wet	Wet
2018	Below Normal	Below Normal
2019	Wet	Wet
2020	Dry	Dry
2021	Critical	Critical
2022	Critical	Critical
2023	Wet	Wet

While accurately tracking and estimating groundwater use is essential, preventing the long-term overdraft of California's groundwater basins is paramount. As described in Chapter 3, "California's Natural and Built Groundwater Infrastructure," groundwater recharge projects can offset groundwater extraction and support groundwater basins in achieving sustainability. Consequently, supporting implementation and tracking of managed aquifer recharge projects has become a key focus for the State in its efforts to enhance water resilience.

PUBLIC DRAFT

As more data are collected and reported, and as new datasets and technologies are developed, water accounting at the local, regional, and state levels will become increasingly more accurate, enabling better long-term water management planning. Understanding all the inputs and outputs of the groundwater system and utilizing the best available data and tools to develop water budgets are vital for effective long-term water management. Water budgets have played a critical role in the state's water management and will continue to be vital in the coming years, particularly in basins implementing groundwater sustainability plans.

This chapter presents data and information on groundwater use, groundwater recharge, and water accounting in California. Groundwater use and recharge data are organized by hydrologic region, groundwater basin area, and non-basin area. The chapter also provides information on water accounting, along with summaries of available datasets and tools that aid in the development of hydrologic models and water budgets.

4.2 Groundwater Use

This section provides a discussion on where groundwater is used in California, with an emphasis on identifying communities dependent on groundwater. It also describes how much groundwater is used, presenting historical groundwater use data and trends derived from the California Water Plan water portfolio. Data presented in Section 4.2.6 is based on information obtained from the SGMA annual reports.

The data in this chapter is presented by water year. Detailed information regarding how the California Water Plan water portfolio data was compiled is provided in Appendix C, "Methods and Assumptions." Additional water use data can be found in Appendix F, "Water Use Data."

4.2.1 Groundwater Use Across California

Groundwater is used across the state for irrigation, drinking water, and a variety of other domestic, industrial, and environmental purposes. Identifying areas where groundwater is used is an important part of managing and protecting the state's groundwater resources. A practical approach for determining where groundwater is used is to identify where water wells are constructed. DWR's Online System for Well Completion Reports (OSWCR) database provides information for wells constructed throughout the state, including construction date, general location, and well depth. This data can be useful for identifying areas of the state with

PUBLIC DRAFT

potentially high groundwater use, such as regions with high concentrations of water wells. The Well Completion Report Map Application — a web-based interactive mapping tool — accompanies OSWCR to help visualize the location and density of wells statewide. These tools and data help provide insights into where new wells are being constructed, helping to track the expansion of wells into previously untapped aquifers.

Generally, groundwater is used in nearly every part of California where people, business, or agriculture are present. Large areas with minimal groundwater use — often indicated by a low number of wells — are generally associated with state and federal public lands. In these areas, minimal groundwater use may support recreational facilities such as campgrounds and parks, agricultural purposes such as irrigation or grazing, or industrial uses such as supporting large scale energy projects (e.g., solar) built on public lands.

Communities Dependent on Groundwater

While groundwater is used throughout the state, with approximately 82% of Californians relying on it for at least a portion of their water supply, many communities depend solely on groundwater. Public water systems — those serving at least 15 service connections or 25 people — that rely solely on groundwater provide drinking water to nearly 8.5 million Californians (California State Water Resources Control Board 2024). These communities are potentially at a greater risk for water supply shortages because of changing hydrologic and environmental conditions, population or agricultural growth that may increase water demand, and aging infrastructure. With no alternative water sources, groundwater-dependent communities have limited options for managing their groundwater resources and must rely on natural recharge mechanisms to replenish their groundwater supply or install additional and deeper wells. In contrast, communities that utilize both surface water and groundwater have greater flexibility. They can shift to increased surface water use during wetter periods, enabling in-lieu recharge, and may also have surface water available for managed aquifer recharge projects, which can help supplement natural groundwater recharge.

SMALL WATER SUPPLIERS AND RURAL COMMUNITIES

Small water suppliers and rural communities that rely exclusively on groundwater are especially vulnerable to drought impacts and water shortages. This report identifies three categories of these communities: (1) domestic well users, (2) non-public state small water systems serving 5 to 14 connections, and (3) publicly regulated small community water systems with 15 to 2,999 service connections

PUBLIC DRAFT

and annual deliveries under 3,000 acre-feet. Senate Bill 552 identifies these users as potentially at risk and vulnerable to drought impacts and water shortages.

Figure 4-2 shows the general locations of domestic well users, state small water systems, and small community water systems throughout the state. Only state small water systems and small community water systems whose sole water supply is groundwater are depicted in Figure 4-2. As shown, these groundwater dependent communities are found throughout the state. In total, more than two million Californians served by small water suppliers or living in rural areas, rely entirely on groundwater. This includes roughly 740,000 people that use domestic wells, approximately 16,700 people that are part of the 1,200 state small water systems, and approximately 1.3 million people using the 1,800 small community water systems.

DRAFT

Figure 4-2 Communities Dependent on Groundwater

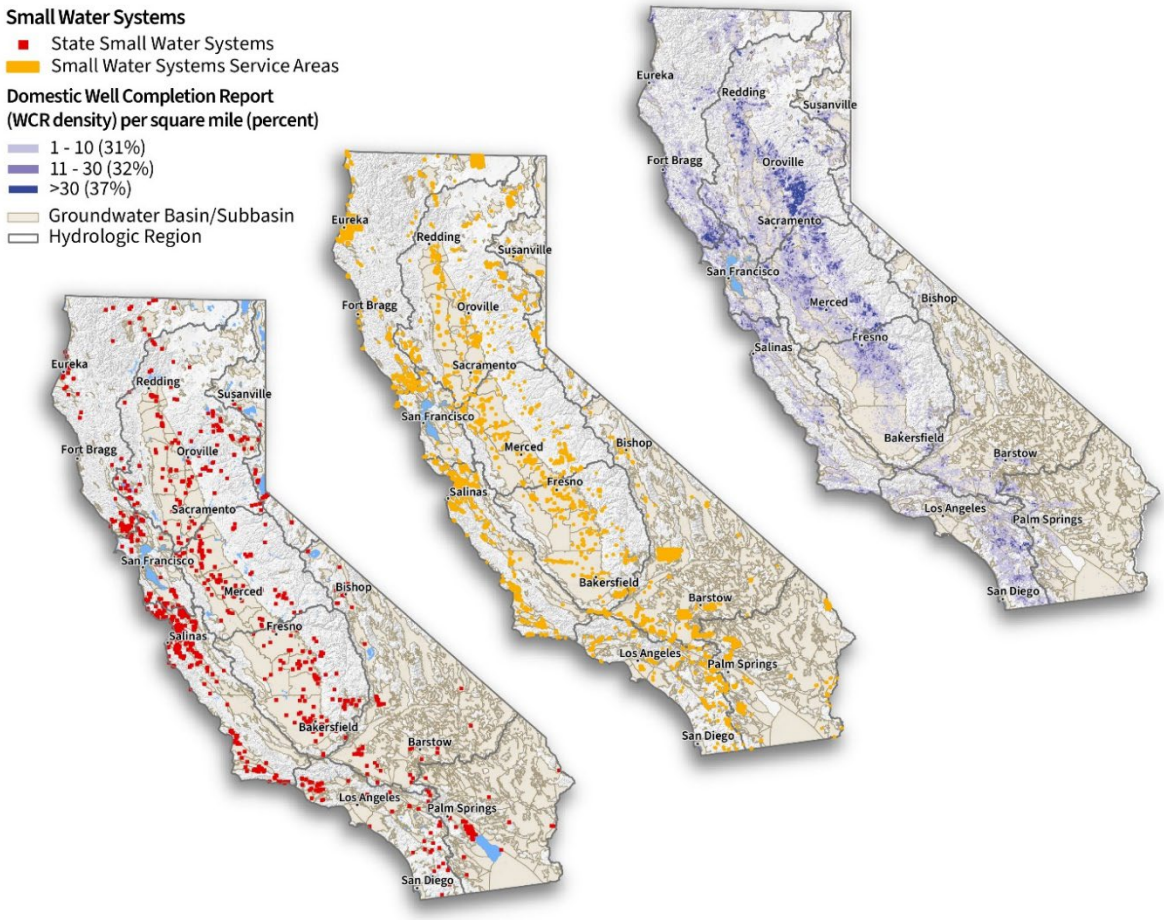


Figure 4-2 Notes: Domestic well heat map based on well completion reports submitted between 1977 and 2023. State small water systems data sourced from State Water Resources

Control Board 2025 Aquifer Risk Map and filtered to exclude systems with identified surface water supplies. Small community water systems data derived from the DWR Water Shortage Vulnerability Tool, filtered for "community" water systems whose sole water supply is groundwater.

4.2.2 Recent Trends in Groundwater Use (Water Years 2017–2021)

Between 2017 and 2021, the state's average annual groundwater extraction volume was approximately 15.8 million acre-feet (maf), accounting for 39% of the total water use in the state. The five-year average was 1.4 maf less than the long-term average of 17.2 maf from 2002 to 2021, reflecting improved hydrologic conditions. Table 4-2 presents statewide groundwater use, surface water use, reuse, and the total water use for 2017 through 2021. During this five-year period, groundwater use fluctuated, ranging from 31% of total water use during the wetter years of 2017 and 2019 to 51% of total water use during the 2021 drought year.

Table 4-2 Statewide Water Use by Source of Water in Million Acre-Feet (Water Years 2017–2021)

Year	Groundwater Use	Surface Water Use	Reuse	Total Water Use	Groundwater as Percentage of Total Water Use
2017	13.2	26.6	2.4	42.3	31%
2018	16.2	23.4	2.1	41.6	39%
2019	12.2	24.6	2.4	39.2	31%
2020	16.4	21.5	2.2	40.1	41%
2021	20.9	18.3	2.0	41.2	51%
5-Year Average	**15.8**	**22.9**	**2.2**	**40.9**	**39%**

Table 4-2 Notes: Numbers may not total precisely because of rounding. A statewide land use dataset for 2017 in spatial format comparable to those published by DWR is not available. As a result, agricultural water use and supply information for Water Year 2017 were calculated using land use data derived from the average of 2016, 2018, 2019, and 2020.

California experienced above average precipitation in 2017 and 2019, following a five-year drought from 2012 to 2016 during which groundwater was heavily relied upon to meet agricultural, urban, and managed wetland demands. The decrease in groundwater use from a high of 23 maf in 2015, at the peak of a prolonged drought, to lows of 13.2 maf and 12.2 maf in 2017 and 2019, respectively, was the result of hydrologic conditions that were in stark contrast to the preceding drought years. The wetter year of 2017 began to replenish many of the state's

PUBLIC DRAFT

surface water reservoirs after years of drought, and 2019 further eased drought conditions throughout California. This occurrence of two above-average precipitation years over a span of three years helped bolster the surface water storage and aided surface water deliveries which greatly reduced the reliance on groundwater. The surface water use increased from 14.7 maf in 2015 to 26.6 maf in 2017.

In contrast, much of the state experienced another dry period in 2020 and 2021, with 2021 classified as a dry or critically dry year in the Central Valley and many other regions. The variation in water supply distribution between surface water and groundwater during these hydrologically distinct years highlights California's dependence on conjunctive water management to meet demand. Compared to 2019, groundwater use in 2021 increased by nearly 9 maf.

Figure 4-3 illustrates the average annual groundwater use from 2017 to 2021 relative to total water use from all sources. It also shows the percentage of the total water use in each hydrologic region met by groundwater. Additionally, each region's percentage of statewide groundwater use is graphically shown for its portion of the average annual groundwater use of 15.8 maf for the 2017–2021 period.

PUBLIC DRAFT

Figure 4-3 Groundwater Use and Total Water Use by Hydrologic Region (Water Years 2017–2021)

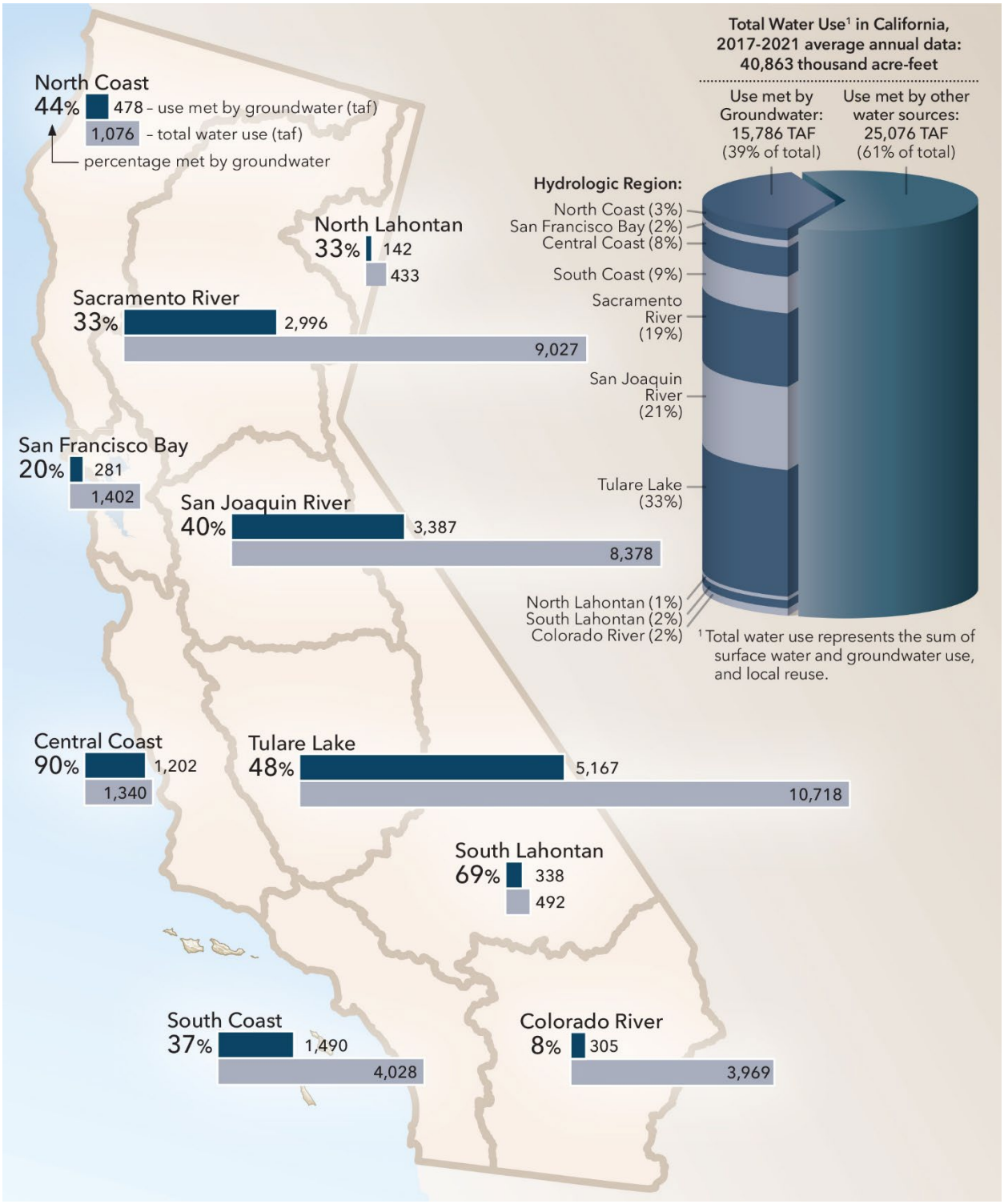


Figure 4-3 Note: taf = thousand acre-feet.

Table 4-3 shows the hydrologic region and statewide average annual groundwater use in thousand acre-feet (taf) and as a percentage of the total water use for 2017–2021. Groundwater use varies widely from one region to another, with groundwater representing as little as 8% of the total water use in the Colorado River Hydrologic Region and as much as 90% of the total water use in the Central Coast Hydrologic Region. Groundwater accounts for 39% of the statewide average annual total water use for the same five-year period.

Table 4-3 Average Annual Groundwater Use by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021)

Hydrologic Region	Groundwater Use	Groundwater as a Percentage of Total Water Use in Each Region
North Coast	478	44%
San Francisco Bay	281	20%
Central Coast	1,202	90%
South Coast	1,490	37%
Sacramento River	2,996	33%
San Joaquin River	3,387	40%
Tulare Lake	5,167	48%
North Lahontan	142	33%
South Lahontan	338	69%
Colorado River	305	8%
Statewide	**15,786**	**39%**

Table 4-3 Note: Numbers and percentages may not total precisely because of rounding.

4.2.3 Long Term Trends in Groundwater Use (Water Years 2002–2021)

Variation in average annual groundwater use may be related to several factors such as surface water availability, agricultural and urban growth or decline, changes in crop types, weather, drought, economic fluctuations, and water use efficiency practices. Hydrologic conditions can vary significantly across California from year to year, directly and indirectly impacting groundwater use. When surface or imported water supplies decrease, crops already reliant on groundwater may remain unaffected. However, irrigators who depend partially or entirely on surface water may need to adjust by reducing or changing crop types, fallowing fields, or increasing groundwater use to supplement shortfalls.

PUBLIC DRAFT

Figure 4-4 and Table 4-4 show statewide water use trends over a 20-year period, from 2002 to 2021, by source — groundwater, surface water, and reuse water. Figure 4-5 displays the percentage of total water use by source of supply. Drought years are included in the figures to highlight how groundwater use changes under the different hydrologic conditions.

Figure 4-4 Statewide Water Use by Source of Water (Water Years 2002-2021)

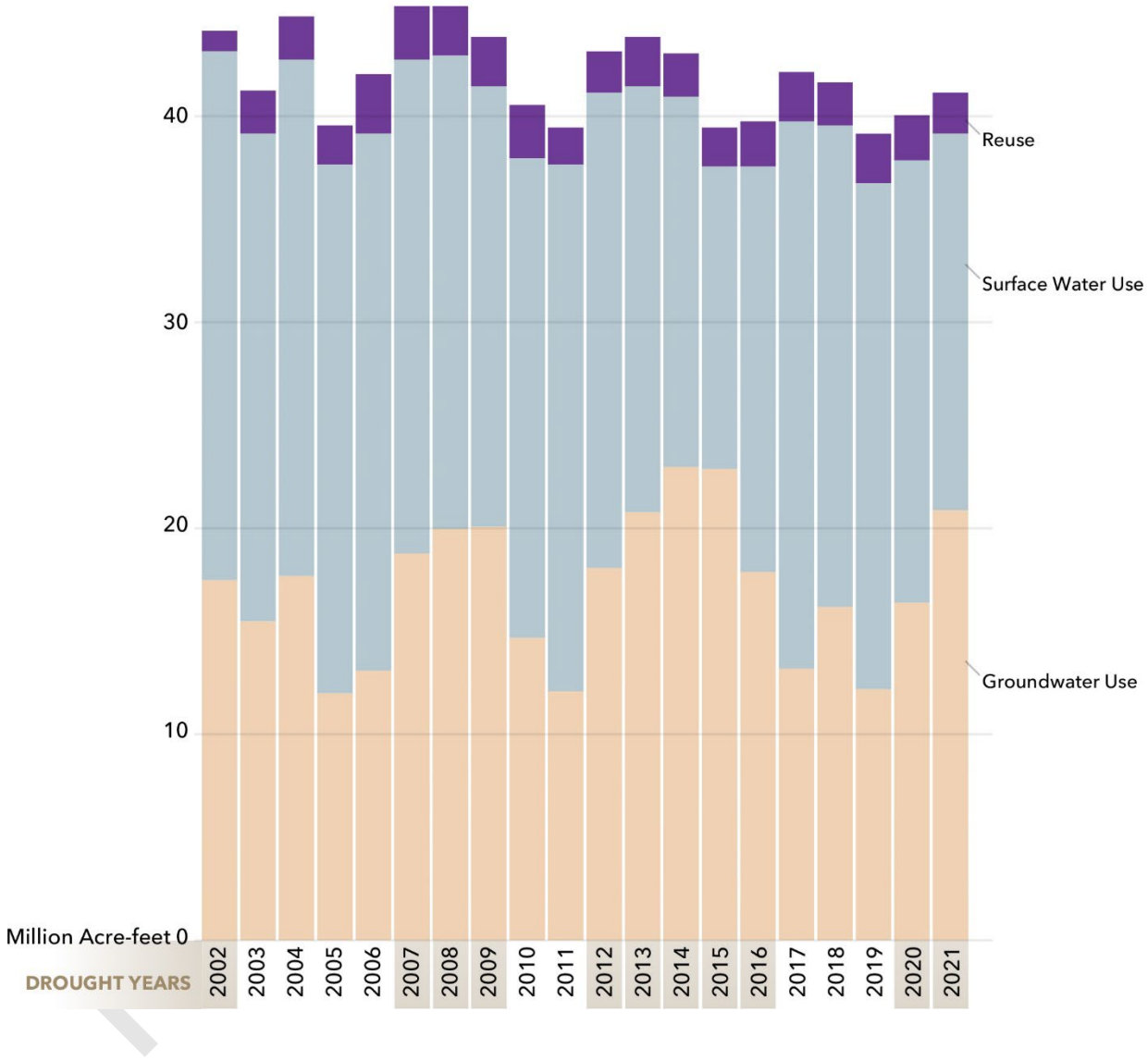


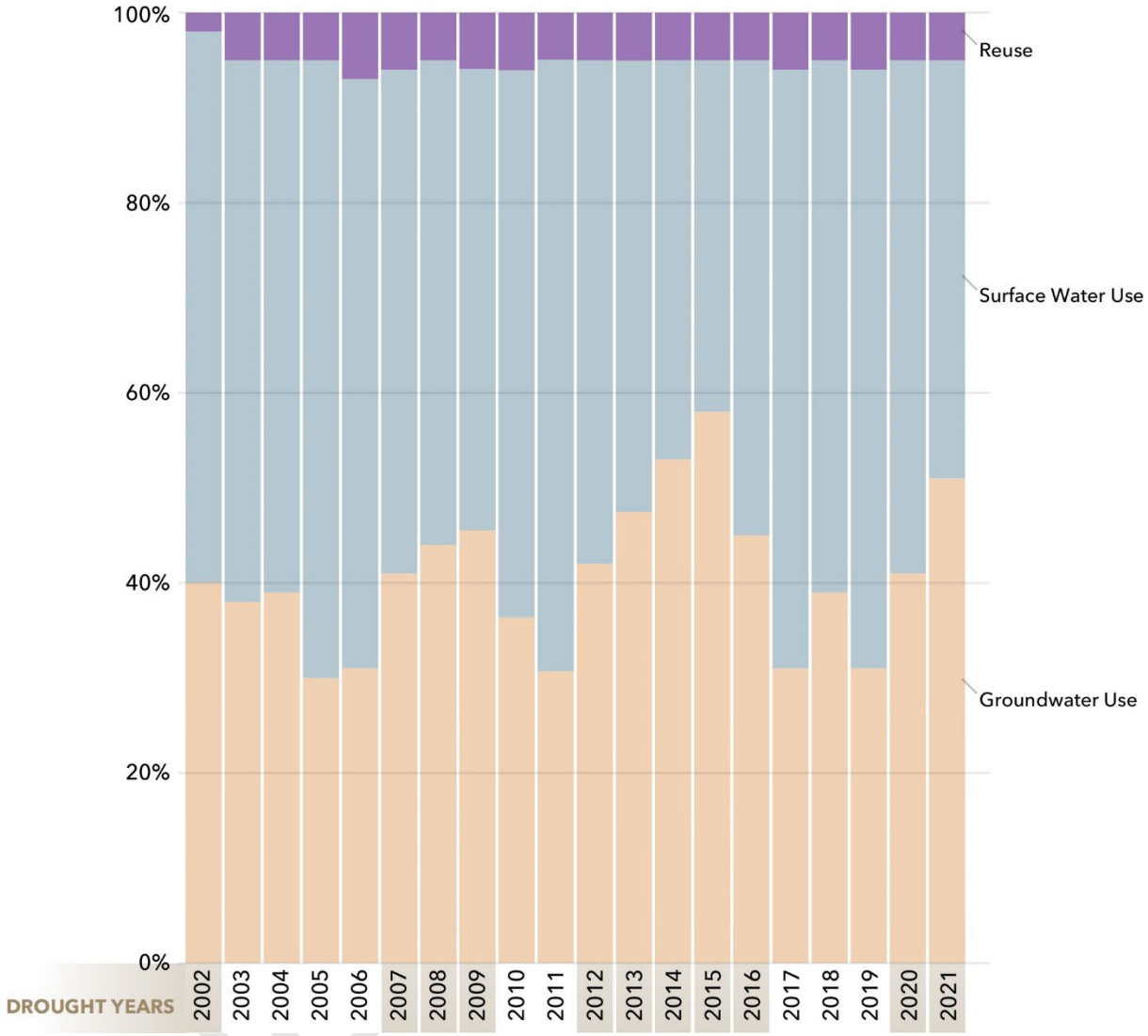
Table 4-4 Statewide Water Use by Source of Water in Million Acre-Feet (Water Years 2002–2021)

Year	Groundwater Use	Surface Water Use	Reuse	Total Water Use	Groundwater as a Percentage of Total Water Use
2002	17.5	25.7	1.0	44.2	40%
2003	15.5	23.7	2.1	41.4	38%
2004	17.7	25.1	2.1	44.9	39%
2005	12.0	25.7	1.9	39.7	30%
2006	13.1	26.1	2.9	42.2	31%
2007	18.8	24.0	2.6	45.5	41%
2008	20.0	23.0	2.4	45.3	44%
2009	20.1	21.4	2.4	43.9	46%
2010	14.7	23.3	2.6	40.6	36%
2011	12.1	25.7	1.8	39.6	31%
2012	18.1	23.1	2.0	43.2	42%
2013	20.8	20.7	2.4	43.9	47%
2014	23.0	18.0	2.1	43.0	53%
2015	22.9	14.7	1.9	39.4	58%
2016	17.9	19.7	2.2	39.8	45%
2017	13.2	26.6	2.4	42.3	31%
2018	16.2	23.4	2.1	41.6	39%
2019	12.2	24.6	2.4	39.2	31%
2020	16.4	21.5	2.2	40.1	41%
2021	20.9	18.3	2.0	41.2	51%
20-Year Average	**17.2**	**22.7**	**2.2**	**42.0**	**41%**

Table 4-4 Note: Numbers may not total precisely due to rounding.

PUBLIC DRAFT

Figure 4-5 Statewide Water Use by Source as a Percentage of Total Water Use (Water Years 2002–2021)



From 2002 through 2021, total annual water use for the state fluctuated between a high of 45.5 maf in 2007 and a low of 39.2 maf in 2019, with an annual average of 42 maf. The total water use fluctuates in response to the cycle of wet and dry years. Annual groundwater use during the 20-year period averaged 17.2 maf, accounting for 41% of state's total annual water use. There was a substantial decrease in groundwater reliance in 2017, a hydrologically wetter year compared to the preceding drought years; however, this reliance has since risen to 51% of total water use in 2021.

Also significant was the relatively rapid increase in groundwater reliance observed in 2020 and 2021. This highlights how quickly consecutive years of below average

precipitation can impact supply sources needed to meet agricultural, urban, and managed wetland demands when surface water availability becomes limited — even after years of seemingly abundant rain and snow.

Changes in groundwater use within the different hydrologic regions can have considerable variability. Figure 4-6 highlights the average, maximum, and minimum groundwater use over the 20-year period for California's hydrologic regions. Areas such as the San Francisco Bay Hydrologic Region show a difference of only 77 taf between the maximum and minimum annual groundwater use, which could indicate stable surface water supplies or less groundwater dependency. Groundwater use in the Tulare Lake Hydrologic Region, however, had a year-to-year variation of 7.6 maf, indicating that the reliance on groundwater in the region is highly variable.

PUBLIC DRAFT

Figure 4-6 Hydrologic Region Average, Minimum, and Maximum Groundwater Use (Water Years 2002–2021)

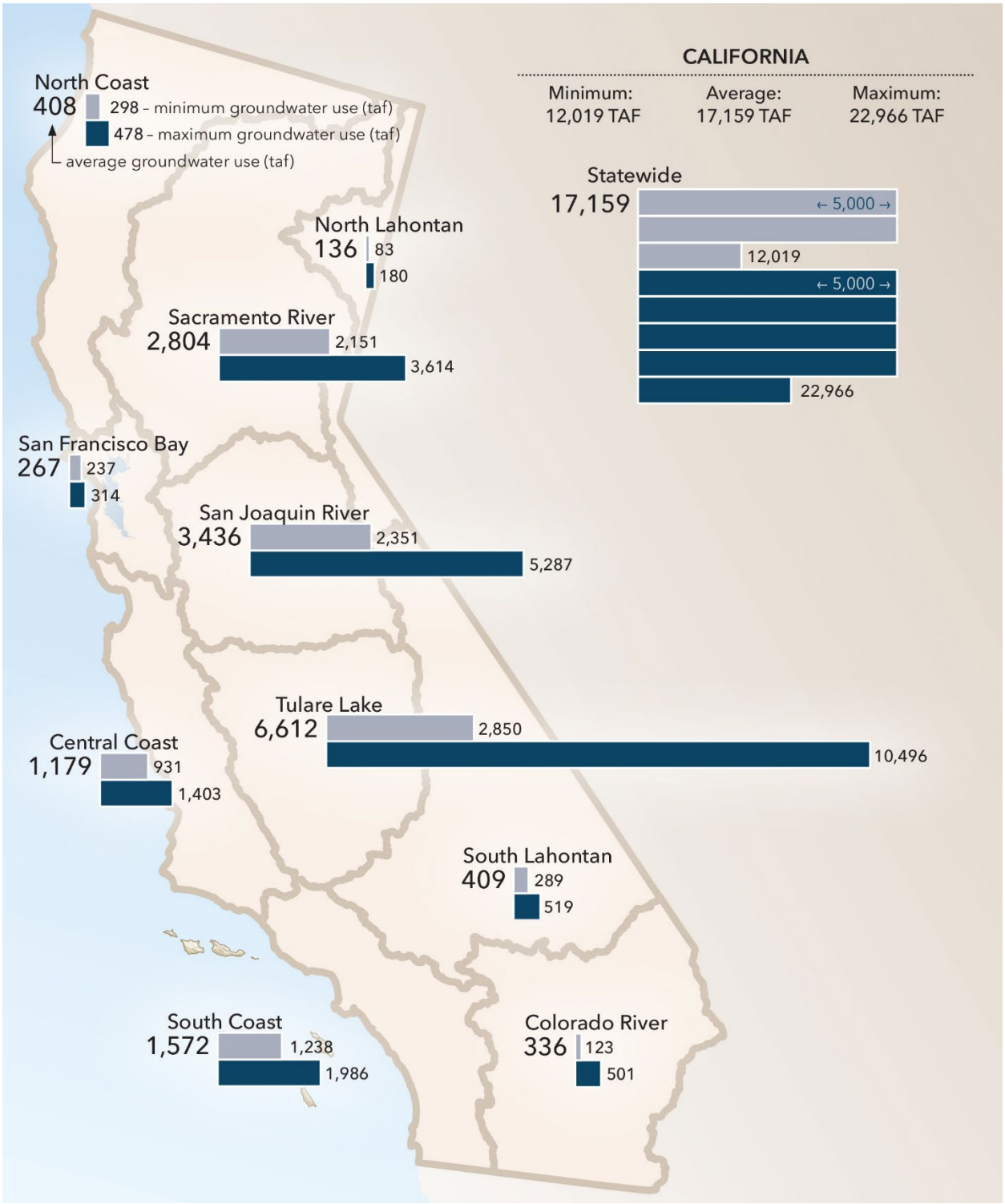


Figure 4-6 Note: taf = thousand acre-feet.

4.2.4 Groundwater Use by Sector

Groundwater is a crucial water source for various water use sectors because of the high spatial and temporal variability of surface water supplies. Using available land use data to estimate water use, this section summarizes data for three main sectors: Agriculture, Urban, and Managed Wetlands. Land use surveys, as well as remote sensing technologies using satellite imagery and other data, are used to identify the various crops grown across the state. Urban areas are identified using similar processes.

Table 4-5 provides the hydrologic regions' percentage distribution of average annual groundwater use between the agriculture, urban, and managed wetlands sectors for the 2017–2021 period. The last column in the table shows a given hydrologic region's groundwater use as a percentage of statewide total groundwater use. Overall statewide percentages are also provided.

Table 4-5 Percent of Average Annual Groundwater Use by Use Type and Hydrologic Region (Water Years 2017–2021)

Hydrologic Region	Agriculture	Urban	Managed Wetlands	Hydrologic Region Groundwater Use as a Percentage of Statewide Total Groundwater Use
North Coast	88%	12%	0%	3%
San Francisco Bay	45%	55%	0%	2%
Central Coast	86%	14%	0%	8%
South Coast	22%	78%	0%	9%
Sacramento River	89%	10%	1%	19%
San Joaquin River	84%	8%	7%	21%
Tulare Lake	92%	7%	1%	33%
North Lahontan	79%	18%	3%	1%
South Lahontan	62%	38%	0%	2%
Colorado River	21%	79%	0%	2%
Statewide	**80%**	**18%**	**2%**	**100%**

Table 4-5 Note: Percentages may not total precisely because of rounding.

Of the 10 hydrologic regions, Tulare Lake has the largest portion (33%) of the total groundwater use in the state and North Lahontan has the smallest portion at just 1%. The three hydrologic regions that cover the Central Valley (Sacramento River, San Joaquin River, and Tulare Lake) are responsible for 73% of the total groundwater used in the state.

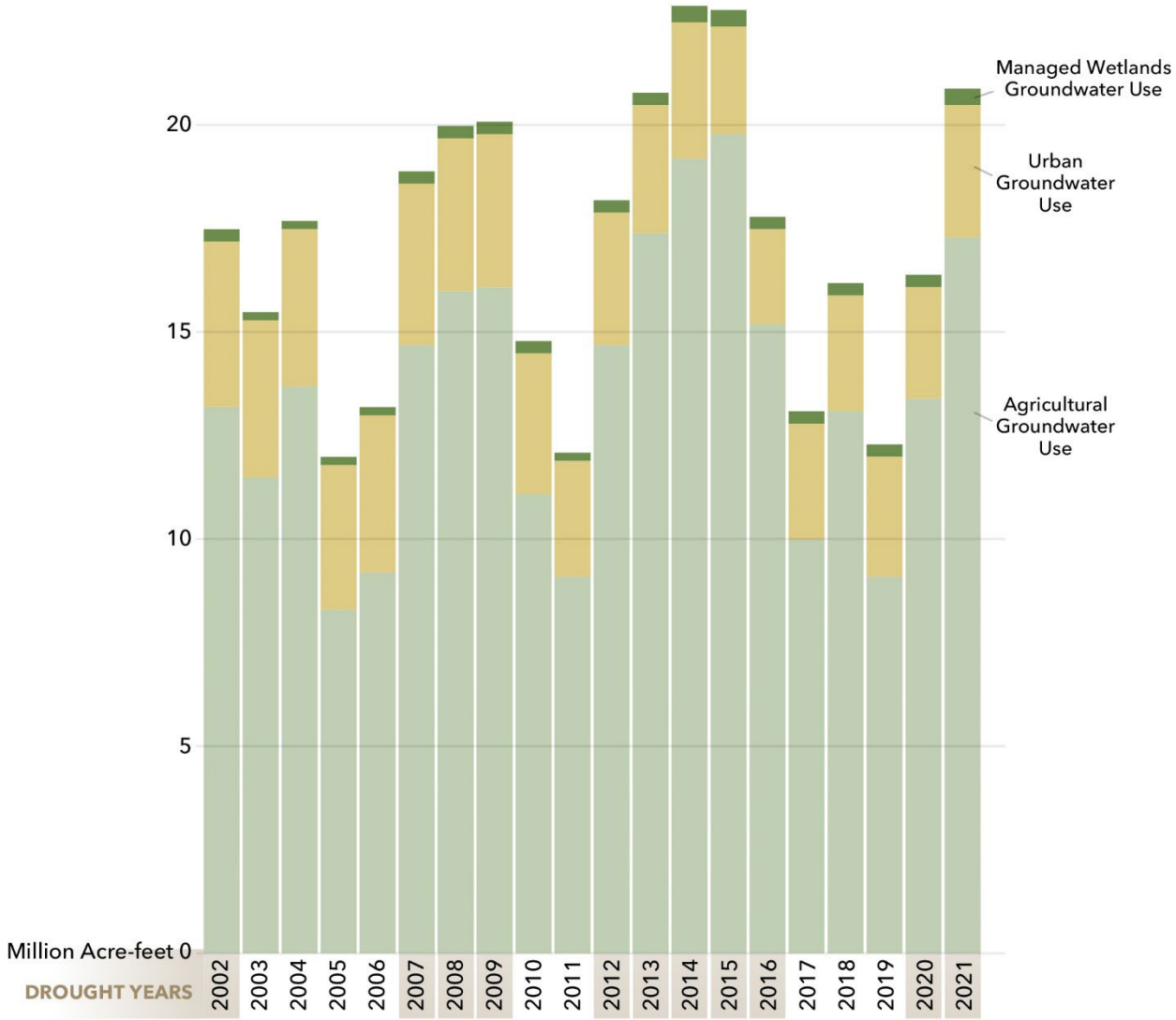
PUBLIC DRAFT

Agriculture is the primary user of groundwater in the state, accounting for approximately 80% of the average annual statewide groundwater use during the five-year period from 2017 to 2021. Urban and managed wetlands accounted for 18% and 2% of the statewide groundwater use, respectively.

Long-term trends across the three sectors reveal that agricultural groundwater use is strongly influenced by the hydrology of each water year, though other factors such as changes in land uses or crop types, improved irrigation practices, and changes in groundwater management may also play a role. Figure 4-7 and Table 4-6 shows the 2002–2021 groundwater use trends for agriculture, urban, and managed wetlands in the state. Wetter years typically show reductions in groundwater use for agriculture while drier years show increases in groundwater use. Similarly, groundwater use for managed wetlands is influenced by hydrologic conditions, with usage during dry years reaching up to twice that of wet years. While urban groundwater use also varies between wet and dry years, the fluctuations are less pronounced than in the agriculture or managed wetlands sectors. Urban groundwater use has increased slightly from a 20-year low of 2.3 maf in 2016 to approximately 3.2 maf in 2021.

PUBLIC DRAFT

Figure 4-7 Statewide Groundwater Use by Sector (Water Years 2002–2021)



PUB

Table 4-6 Statewide Groundwater Use by Sector in Million Acre-Feet (Water Years 2002–2021)

Year	Agriculture	Urban	Managed Wetlands	Total Groundwater
2002	13.2	4.0	0.3	17.5
2003	11.5	3.8	0.2	15.5
2004	13.7	3.8	0.2	17.7
2005	8.3	3.5	0.2	12.0
2006	9.2	3.8	0.2	13.1
2007	14.7	3.9	0.3	18.8
2008	16.0	3.7	0.3	20.0
2009	16.1	3.7	0.3	20.1
2010	11.1	3.4	0.3	14.7
2011	9.1	2.8	0.2	12.1
2012	14.7	3.2	0.3	18.1
2013	17.4	3.1	0.3	20.8
2014	19.2	3.3	0.4	23.0
2015	19.8	2.6	0.4	22.9
2016	15.2	2.3	0.3	17.9
2017	10.0	2.8	0.3	13.2
2018	13.1	2.8	0.3	16.2
2019	9.1	2.9	0.3	12.2
2020	13.4	2.7	0.3	16.4
2021	17.3	3.2	0.4	20.9
20-Year Average	**13.6**	**3.3**	**0.3**	**17.2**

Table 4-6 Note: Numbers may not total precisely because of rounding.

Figure 4-8 displays statewide groundwater use data as a percentage of total groundwater use by sector. The percentage of groundwater used for agriculture ranged from a low of 69% in 2005 to a high of 87% in 2015 (Table 4-7). As shown in Table 4-6, total agricultural groundwater use was lowest at 8.3 maf in 2005 and highest at 19.8 maf in 2015. The table also shows that in the past five years agricultural groundwater use has remained within the historical maximum and minimum values (Figure 4-5). However, an upward trend has emerged, as observed in 2021.

PUBLIC DRAFT

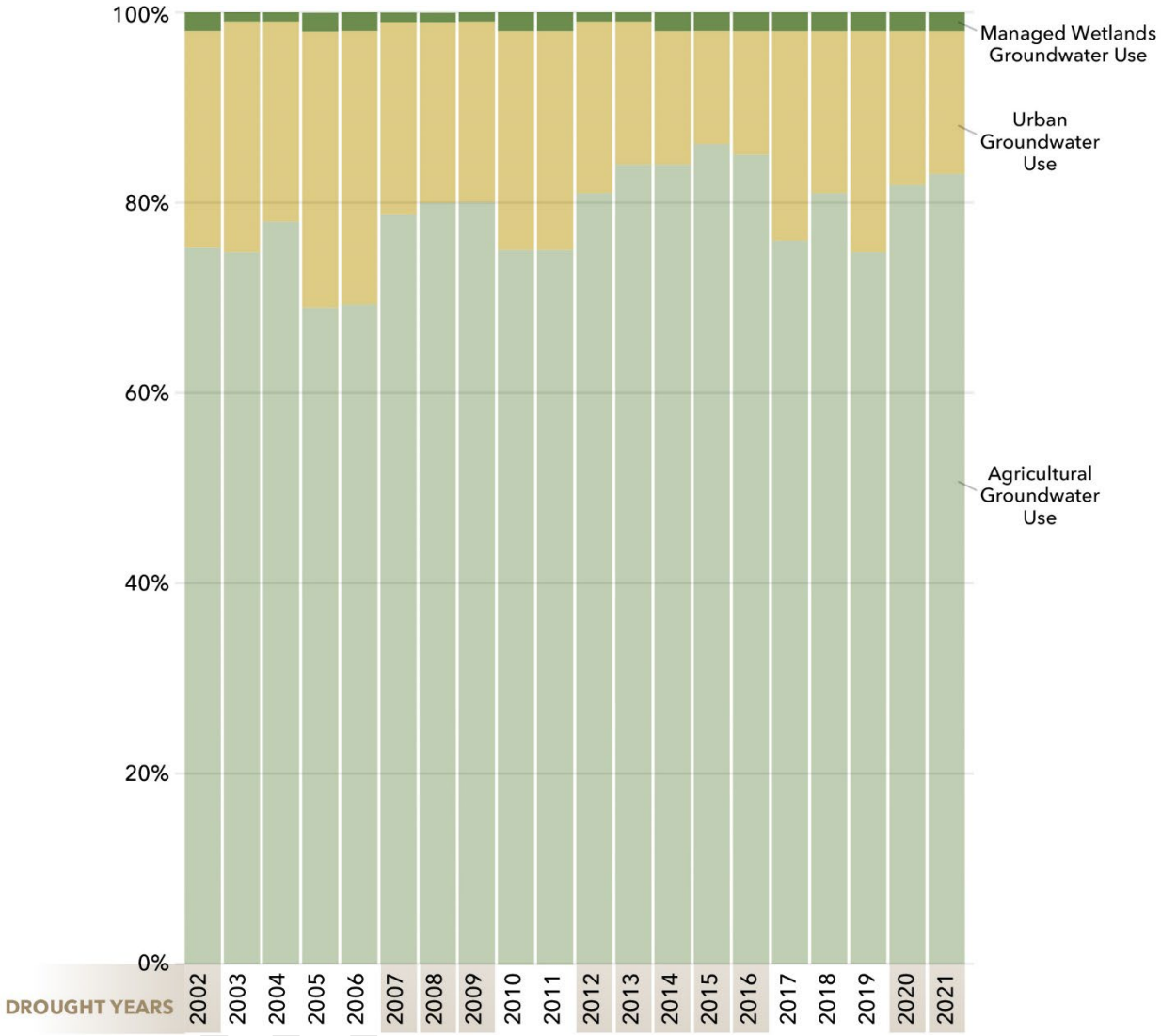
Table 4-7 Statewide Percentage of Total Groundwater Use by Sector (Water Years 2002–2021)

Year	Agriculture	Urban	Managed Wetlands
2002	76%	23%	2%
2003	74%	24%	1%
2004	78%	21%	1%
2005	69%	29%	2%
2006	70%	29%	2%
2007	78%	20%	1%
2008	80%	19%	1%
2009	80%	19%	1%
2010	75%	23%	2%
2011	75%	23%	2%
2012	81%	18%	1%
2013	84%	15%	1%
2014	84%	14%	2%
2015	87%	12%	2%
2016	85%	13%	2%
2017	76%	22%	2%
2018	81%	17%	2%
2019	74%	23%	2%
2020	81%	16%	2%
2021	83%	15%	2%
20-Year Average	**79%**	**19%**	**2%**

Table 4-7 Note: Percentages may not total precisely due to rounding.

PUBLIC DRAFT

Figure 4-8 Statewide Percentage of Total Groundwater Use by Sector (Water Years 2002-2021)



Agricultural Groundwater Use

California produces over a third of the nation's vegetables and more than three-quarters of its fruits and nuts, with a large concentration of these crops located in the Central Valley hydrologic regions. As a result, agricultural demand in these regions has historically remained high. Table
4-8 presents the average annual agricultural groundwater use by hydrologic region and the average annual agricultural groundwater use as a percentage of total agricultural water use by hydrologic region from 2017 through 2021. During this period, on an annual average basis, the three hydrologic regions that comprise the Central Valley accounted for 10,265 taf of agricultural groundwater use (82% of statewide agricultural groundwater use). The Central Valley has averaged

approximately 6.9 million acres of irrigated agricultural lands from 2017 through 2021. For reference, the statewide average is about 9.1 million acres of irrigated crops, meaning the Central Valley contains more than 75% of California's total irrigated agricultural land.

With 1,034 taf of groundwater used for agriculture, the Central Coast Hydrologic Region had the highest reliance on groundwater at 94% of the total supply. In contrast, the Tulare Lake Hydrologic Region used four times as much groundwater but had a lower reliance on groundwater at 47% during the 2017–2021 period. With the lowest groundwater use, the Colorado River Hydrologic Region is the least dependent on groundwater for agriculture at only 2% of the total supply, averaging 64 taf per year while irrigating about 620 thousand acres of agricultural land. Overall, the state's agriculture sector relied on groundwater for approximately 40% of its water supply during the 2017–2021 period.

Table 4-8 Average Annual Agricultural Use Met by Groundwater by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021)

Hydrologic Region	Agriculture Use Met by Groundwater	Total Agriculture Water Use	Agriculture Groundwater Use as a Percentage of Total Agriculture Use in the Region
North Coast	420	790	53%
San Francisco Bay	128	229	56%
Central Coast	1,034	1,099	94%
South Coast	333	515	65%
Sacramento River	2,662	7,733	34%
San Joaquin River	2,862	7,310	39%
Tulare Lake	4,742	10,090	47%
North Lahontan	113	390	29%
South Lahontan	210	256	82%
Colorado River	64	3,400	2%
Statewide	**12,567**	**31,811**	**40%**

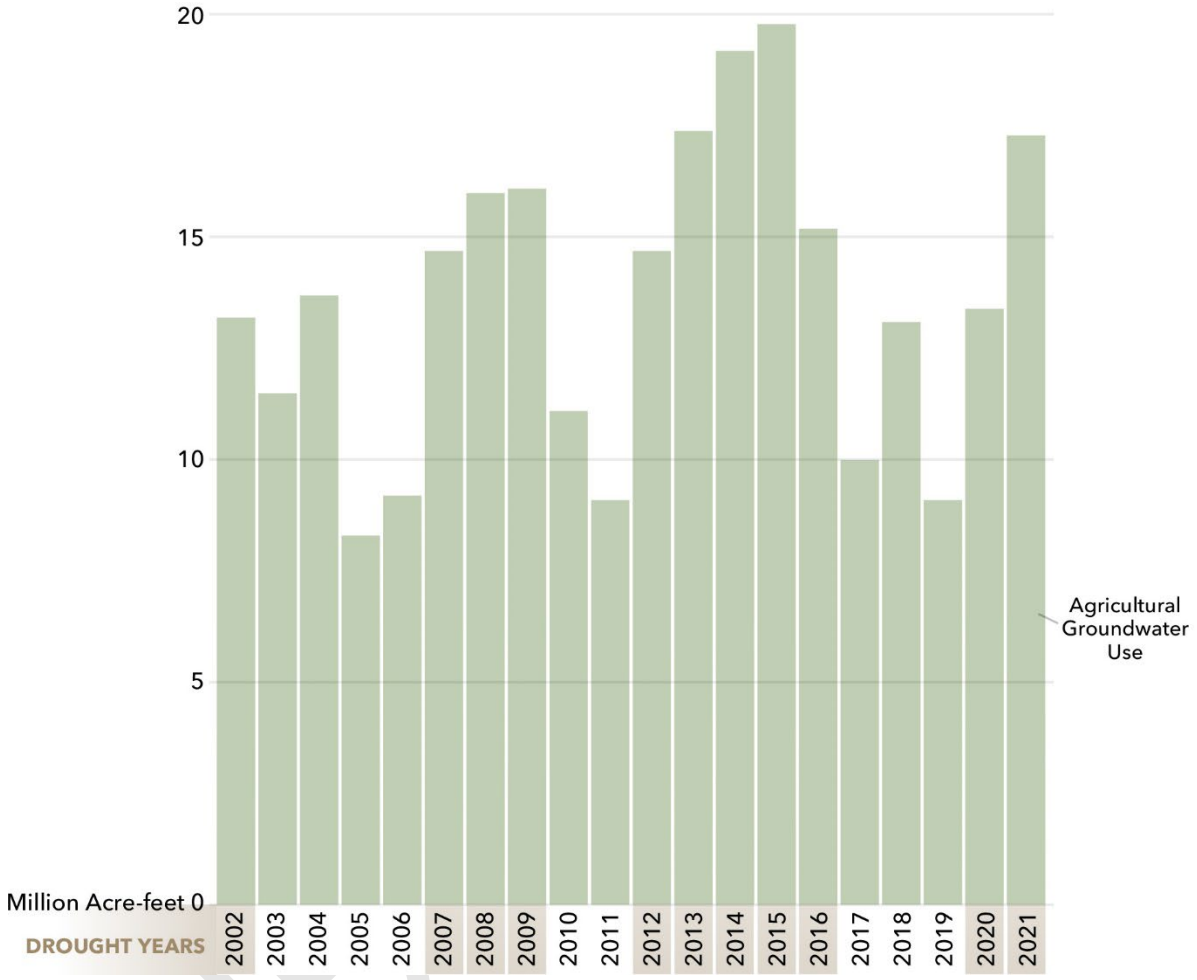
Table 4-8 Note: Numbers may not total precisely due to rounding.

Figure 4-9 displays the statewide agricultural groundwater use for the 2002–2021 period. As shown in the figure, groundwater use for agriculture has fluctuated significantly over the past 20 years, with wetter years typically using less than 10 maf of groundwater and drier years using around 15 to 20 maf. As

PUBLIC DRAFT

observed during the 2012–2016 drought, consecutive years of dry hydrologic conditions can lead to sustained increases in groundwater use.

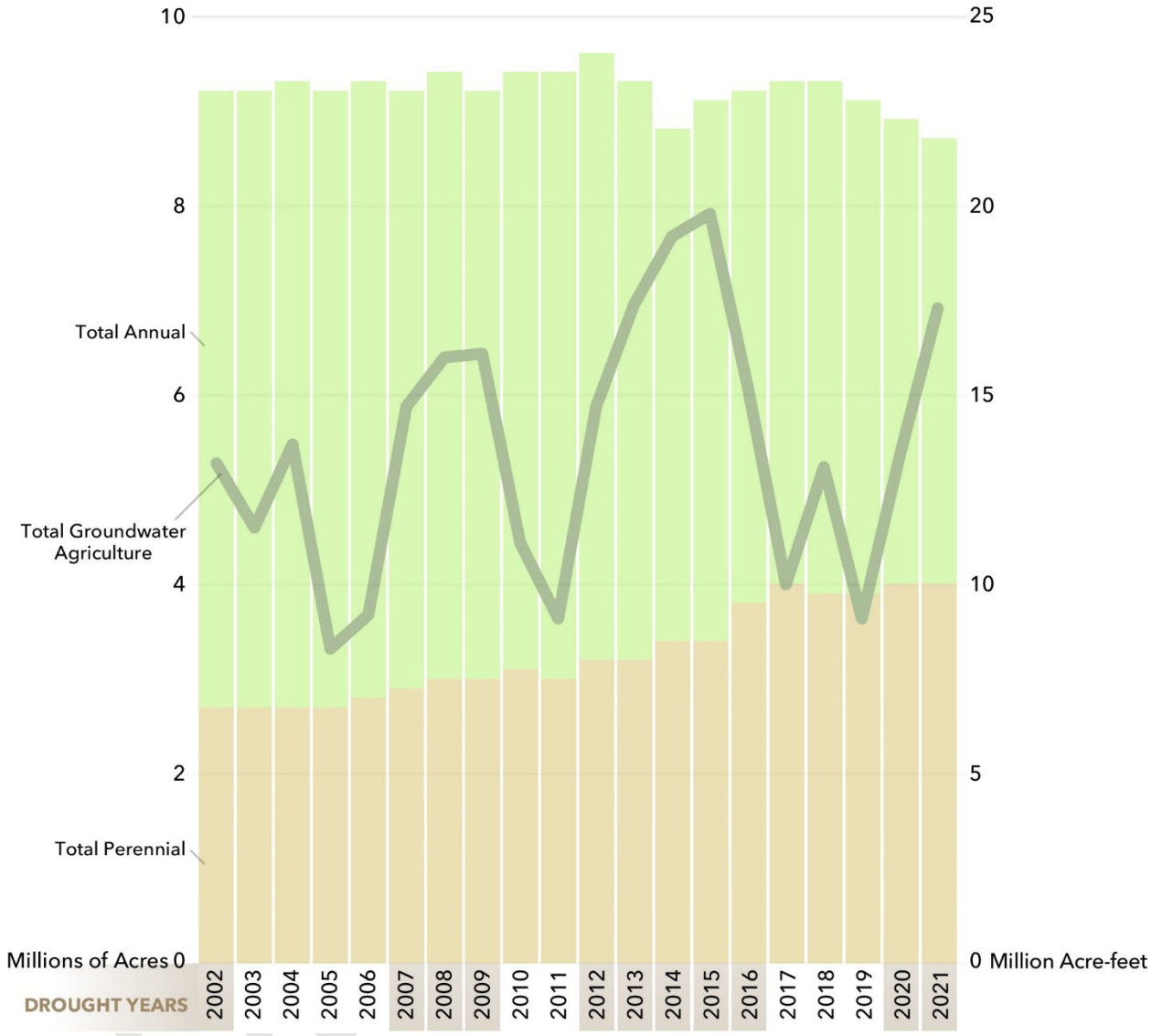
Figure 4-9 Statewide Agricultural Groundwater Use (Water Years 2002-2021)



CHANGES IN CROP TYPES

California has a variety of crop types distributed across a range of geographic regions throughout the state. These crops, and their associated water use, are assigned to one of the twenty different crop categories developed by DWR. These categories can be generally described as an annual (e.g., tomatoes, beans, corn) or a perennial (e.g., almonds, citrus, grapes) type of crop. Changes in cropping patterns observed over the 20-year period show an increase in the amount of perennial crops and a subsequent decrease in the amount of annual crops. Figure 4-10 illustrates changes in crop types alongside annual agricultural groundwater use. The variation in the amount of groundwater used generally corresponds to the hydrologic conditions. However, the overall upward trend highlights the state's agricultural sector's increasing reliance on groundwater.

Figure 4-10 Statewide Irrigated Crop Acres by Type vs. Agricultural Groundwater Use (Water Years 2002–2021)



PUBLIC

LAND FALLOWING

Many agricultural lands lie fallow each year due to various factors that landowners must consider, such as water availability, economic outlook, and insufficient land preparation. Remote-sensing data (2016, 2018–2021) have introduced a new source of information on statewide land fallowing that was previously unavailable. This dataset offers insights into how land fallowing may be used as a management practice in response to the availability of different water supplies during wet and dry years. Figure 4-11 presents the estimated annual fallow acres for each of the 10 hydrologic regions from 2016, 2018–2021 along with the 2016–2021 total statewide agricultural surface water and groundwater use. The methodology used to estimate fallow lands for these years is described in Appendix C, "Methods and Assumptions."

PUBLIC DRAFT

Figure 4-11 Fallow Acres by Hydrologic Region vs. Groundwater Use (Water Years 2016, 2018-2021)

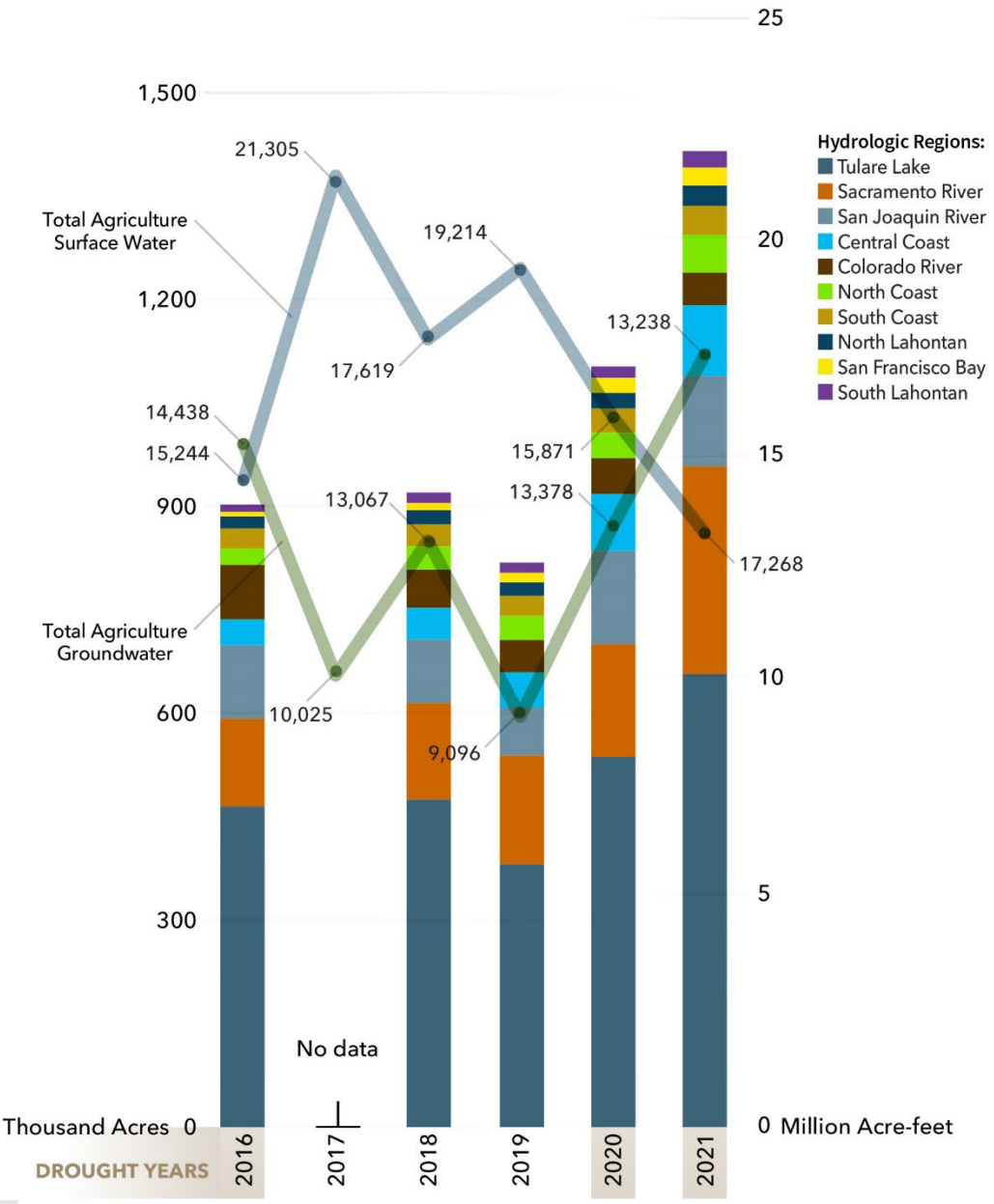


Figure 4-11 Note: Fallow acres based on DWR Statewide Crop Mapping dataset prepared by Land IQ.

Statewide estimates of fallow land, based on the DWR Statewide Crop Mapping dataset prepared by Land IQ and presented in Figure 4-11, varied between about 800 thousand acres in 2019 to over 1.4 million acres in 2021 (Mubaku 2024). As shown in the figure, fallow land acreage generally increases in drier years and decreases in wetter years. The data show an increase in agricultural groundwater

use during years of increasing fallow land and vice versa. It appears that groundwater cannot fully make up for the reduction in surface water supplies, which leads to more land being taken out of production. This could be the result of a variety of factors, such as insufficient groundwater infrastructure, the economic costs of pumping groundwater, or regulatory restrictions and groundwater management practices aimed at preventing adverse impacts from over-pumping.

According to a 2023 Public Policy Institute of California (PPIC) report, Managing Water and Farmland Transitions in the San Joaquin Valley (Hanak et al. 2023), the San Joaquin Valley — including the San Joaquin River and Tulare Lake hydrologic regions — is projected to face an average annual reduction of 3.15 million acre-feet of agricultural water supply by 2040 in order to achieve sustainability. To meet this reduction, the report estimates that between 500,000 and 900,000 acres of farmland may need to be fallowed on average, with even more land potentially fallowed during drier years.

As shown above in Figure 4-10, there is a statewide trend of crop acreage changing from annual crops to perennial crops. In general, annual crops are better suited for fallowing, whereas perennial crops are a significant investment, which makes fallowing a difficult decision. This trend in crop type changes, should it continue, could limit the flexibility and opportunity to use fallowing as a water management practice. With the potential for future water supply shortages requiring more land to be fallowed than ever before, agricultural interested parties should be prepared to face these challenges through long term planning and crop selection that allows for flexibility, and the implementation of new projects that can supplement existing water supplies or offset groundwater extractions, particularly when considering the transition from annual to perennial crops.

Urban Groundwater Use

Groundwater is an important source of water for California's urban sector, supplying an average of 38% of total urban water use over the five-year period from 2017-2021 (Table 4-9). Throughout the state, numerous communities, individual residences, and businesses rely heavily or entirely on groundwater. In many locations, high reliance on groundwater results from the absence of a reliable supply of surface water. Urban water use reported in this chapter includes single family residential, multi-family residential, commercial, industrial, and landscape irrigation.

PUBLIC DRAFT

Figure 4-12 displays the total urban water use and urban groundwater use over a 20-year period, from 2002 to 2021, along with the state's population. When comparing urban water use to California's population, there has been an overall decline in total water use despite population growth. Trends in urban groundwater use do not show a clear correlation with wetter or drier years, unlike agricultural groundwater use, which is significantly impacted by precipitation and surface water availability. This difference is likely a result of more stable surface water supplies in urban areas, along with urban water conservation measures aimed at reducing total water usage during drier years.

Figure 4-12 Statewide Annual Urban Water Use and Population

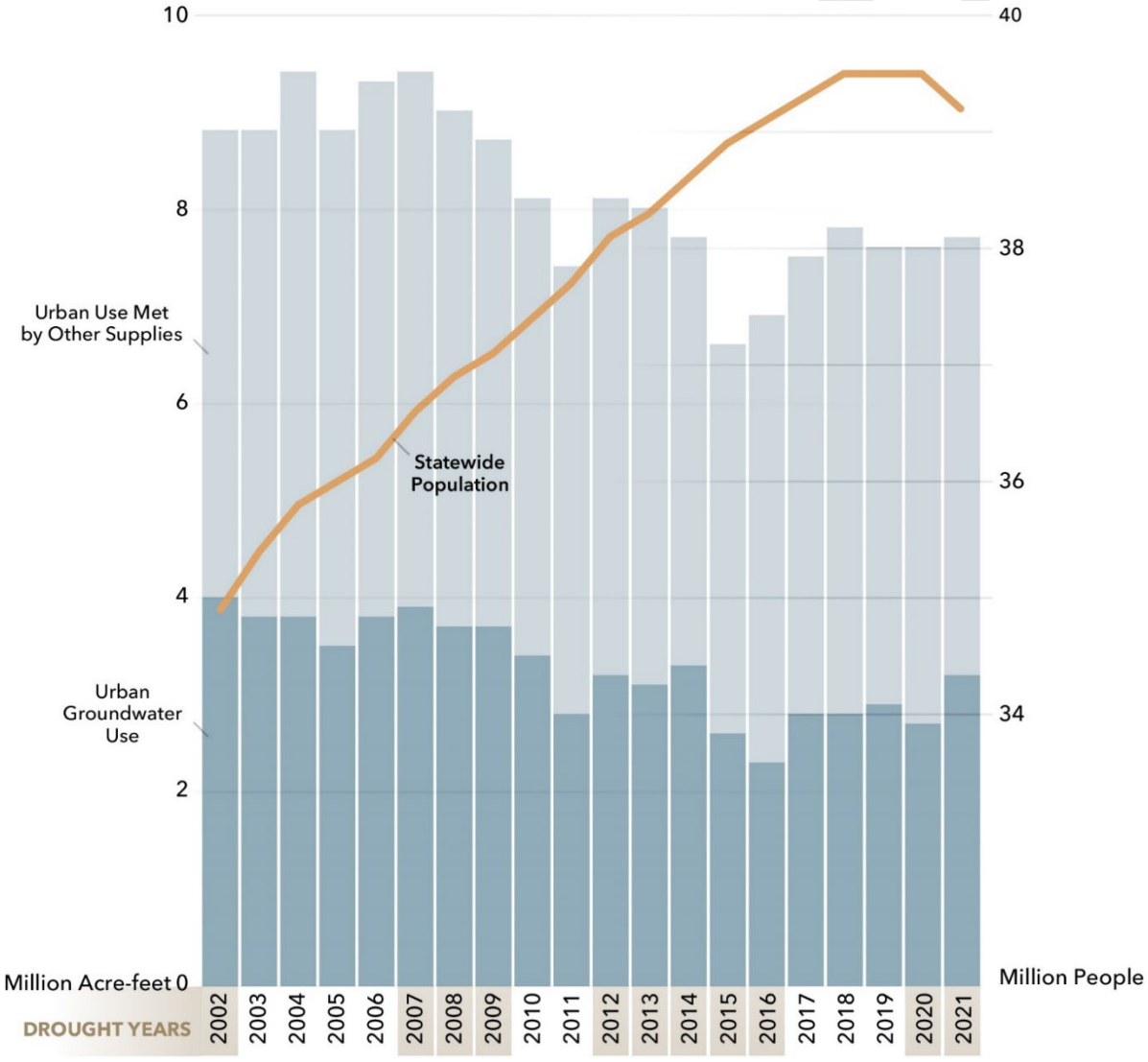


Figure 4-12 Note: Urban groundwater use includes California Water Plan estimates of groundwater use by water utilities and use by self-supplied populations.

Table 4-9 presents the average annual urban groundwater use by hydrologic region and the average annual urban groundwater use as a percentage of total urban water use by hydrologic region from 2017 through 2021. As shown in the table, the South Coast Hydrologic Region uses the highest amount of groundwater for urban use in the state, which is more than three times as much as any other hydrologic region. The North Lahontan Hydrologic Region has the highest reliance on groundwater for urban use at 86% while the San Francisco Bay Hydrologic Region is the least reliant at 14%.

Table 4-9 Average Annual Urban Use Met by Groundwater by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021)

Hydrologic Region	Urban Use Met by Groundwater	Total Urban Water Use	Urban Groundwater Use as a Percentage of Total Urban Water Use in the Region
North Coast	57	125	46%
San Francisco Bay	154	1,128	14%
Central Coast	168	240	70%
South Coast	1,157	3,494	33%
Sacramento River	307	772	40%
San Joaquin River	272	549	50%
Tulare Lake	384	538	71%
North Lahontan	25	30	86%
South Lahontan	128	235	54%
Colorado River	240	524	46%
Statewide	**2,893**	**7,635**	**38%**

Table 4-9 Note: Numbers may not total precisely due to rounding.

Managed Wetlands Pumped Groundwater Use

Some of California's hydrologic regions have managed wetlands that are reliant on pumped groundwater. Table 4-10 presents the average annual managed wetlands pumped groundwater use by hydrologic region and the average annual managed wetlands pumped groundwater use as a percentage of total managed wetlands water use by hydrologic region from 2017 through 2021. The San Joaquin River Hydrologic Region used an annual average of 254 taf of pumped groundwater for managed wetlands during this period. This pumped groundwater was 49% of the total managed wetlands water use in that region. In the state, pumped groundwater for the managed wetlands sector averaged 327 taf annually during the 2017–2021 period, representing 23% of the total annual water use for

PUBLIC DRAFT

managed wetlands. Figure 4-13 displays statewide groundwater use for managed wetlands for 2002–2021. As shown in the figure, groundwater use for managed wetlands fluctuates similarly to agricultural groundwater use, with less groundwater used in wetter years and more in drier years.

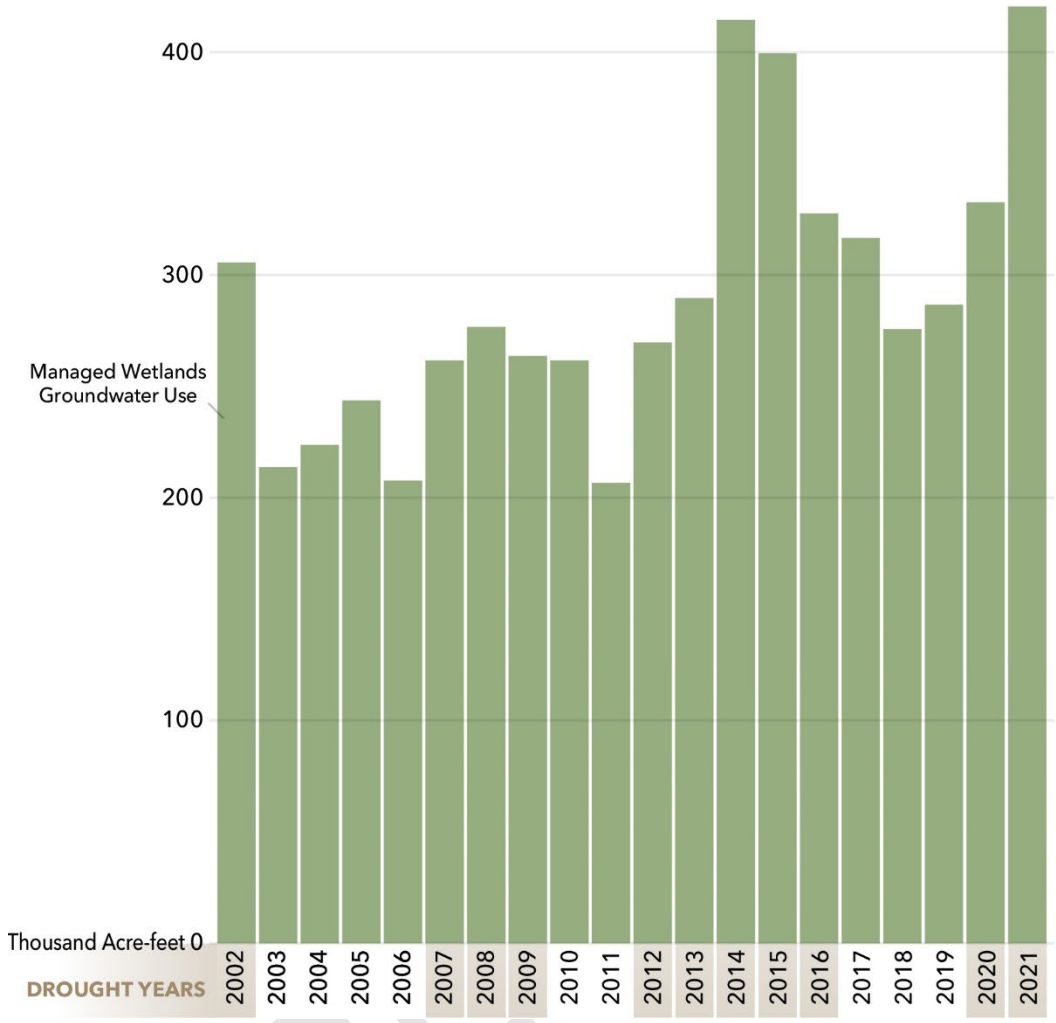
Table 4-10 Average Annual Managed Wetlands Use Met by Pumped Groundwater by Hydrologic Region in Thousand Acre-Feet (Water Years 2017–2021)

Hydrologic Region	Managed Wetlands Use Met by Pumped Groundwater	Total Managed Wetlands Water Use	Managed Wetlands Pumped Groundwater Use as a Percentage of Total Managed Wetlands Water Use in the Region
North Coast	1	161	<1%
San Francisco Bay	0	45	0%
Central Coast	0	0	0%
South Coast	<1	19	1%
Sacramento River	28	522	5%
San Joaquin River	254	518	49%
Tulare Lake	41	90	45%
North Lahontan	4	14	29%
South Lahontan	0	0	0%
Colorado River	0	45	0%
Statewide Total	**327**	**1,416**	**23%**

Table 4-10 Note: Numbers may not total precisely because of rounding.

PUBLIC DRAFT

Figure 4-13 Statewide Annual Pumped Groundwater Use for Managed Wetlands



4.2.5 Comparison Between Basin and Non-Basin Groundwater Use

This section provides a comparison of groundwater use between basins and non-basin areas. The California Water Plan does not provide water use data by basin or non-basin area. However, DWR land use data can aid in the estimation by indicating where agriculture and population centers are located. This section presents groundwater use estimates based on the proportion of agricultural and urban land within basin and non-basin areas of each hydrologic region. Additional information on the process used in this analysis can be found in Appendix C "Methods and Assumptions."

Agricultural Groundwater Use in Basin vs. Non-Basin Areas

Table 4-11 presents the basin and non-basin agricultural acres in California for 2019–2021. These years were chosen due to availability of data and to represent a

year of above-average precipitation (2019), below average precipitation (2020), and a near historical low precipitation (2021). As shown in the table, most agricultural lands overlie groundwater basins.

Table 4-11 Annual Statewide Agricultural Acreage, Basin vs. Non-Basin Areas (2019–2021)

Year	Agricultural Acres in Basin Area	Percent Agricultural Acres in Basin Area	Agricultural Acres in Non-Basin Area	Percent Agricultural Acres in Non-Basin Area
2019	8,423,165	96.9%	273,809	3.1%
2020	8,250,485	96.8%	273,545	3.2%
2021	7,938,171	96.7%	271,107	3.3%

The Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions that comprise the Central Valley contain the largest amount of agricultural land in the state. These lands are almost exclusively located within groundwater basins associated with those hydrologic regions. On average, from 2019 to 2021, about 77% of the state's agricultural lands are found in these three hydrologic regions. There is also considerable agricultural land located in the Imperial Valley, Salinas Valley, and areas north of the San Francisco Bay.

Figure 4-14 shows a map of the agricultural lands in California for basin and non-basin areas, using 2021 land use data. Figure 4-14 also includes a chart that provides the 2019–2021 three-year average percentage breakdown of agricultural acres in basin and non-basin areas. The hydrologic regions with the largest percentages of non-basin agricultural lands are the four coastal regions, with non-basin agriculture ranging from about 10% to 30% of the total agricultural area of the corresponding region. While the more inland hydrologic regions have non-basin agricultural areas comprising up to 3% of total agricultural acres within the regions, they collectively represent 36% of the statewide agricultural acres in the non-basin area. The WY 2019–2021 agricultural acreage percentages in basin and non-basin areas are also presented in Table 4-12.

PUBLIC DRAFT

Figure 4-14 2021 Basin and Non-Basin Agricultural Land

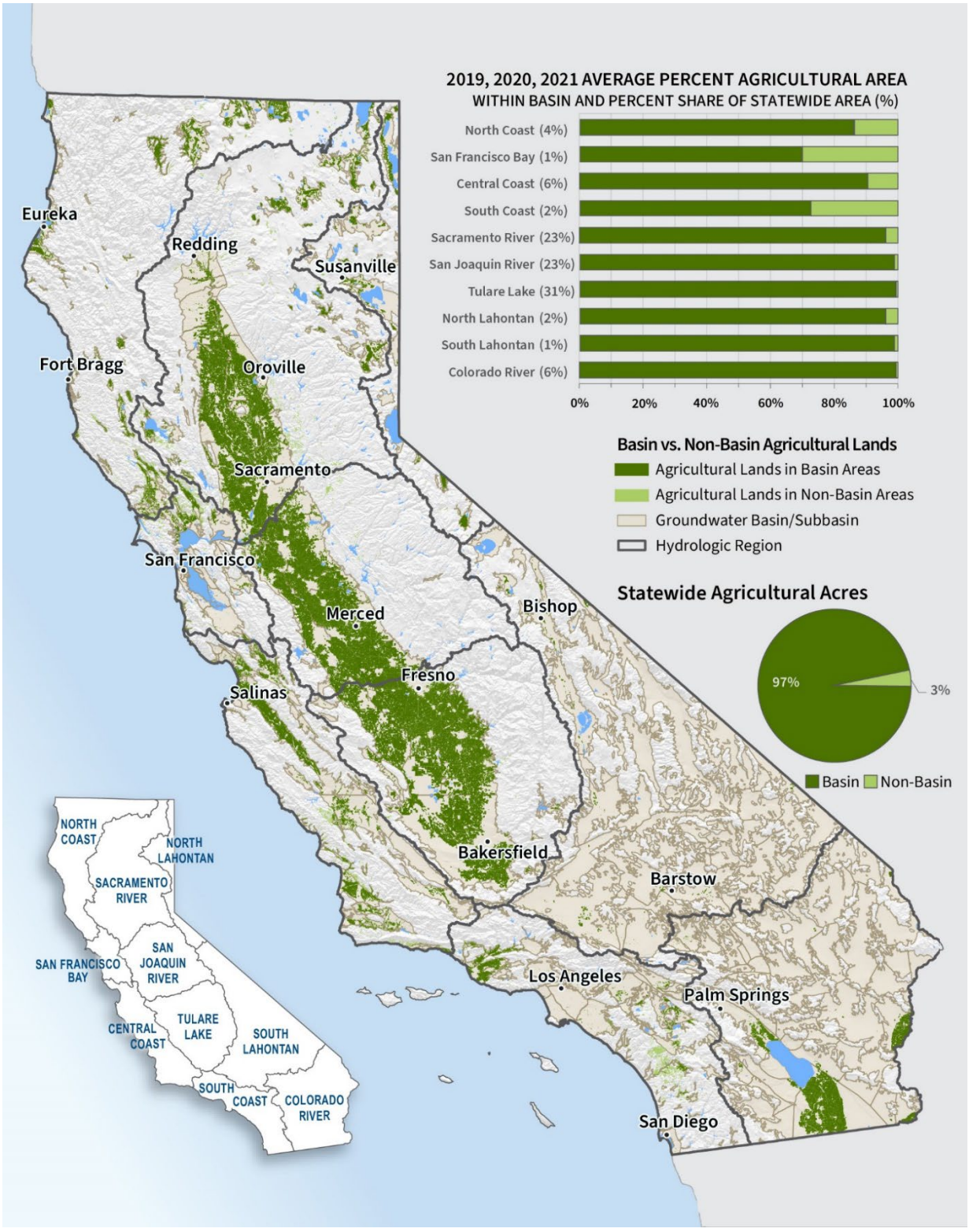


Figure 4-14 Note: Map displays 2021 land use data. Charts display three-year (2019–2021) average.

Table 4-12 Percent Agricultural Area in Basin and Non-Basin Areas by Hydrologic Region (2019–2021)

Hydrologic Region	Percent Acres in Basin Area (2019)	Percent Acres in Non-Basin Area (2019)	Percent Acres in Basin Area (2020)	Percent Acres in Non-Basin Area (2020)	Percent Acres in Basin Area (2021)	Percent Acres in Non-Basin Area (2021)
North Coast	86.4%	13.6%	86.4%	13.6%	85.8%	14.2%
San Francisco Bay	71.3%	28.7%	69.3%	30.7%	69.2%	30.8%
Central Coast	90.5%	9.5%	91.1%	8.9%	90.9%	9.1%
South Coast	73.2%	26.8%	72.9%	27.1%	72.8%	27.2%
Sacramento River	96.9%	3.1%	96.7%	3.3%	96.5%	3.5%
San Joaquin River	99.2%	0.8%	99.3%	0.7%	99.3%	0.7%
Tulare Lake	99.5%	0.5%	99.6%	0.4%	99.5%	0.5%
North Lahontan	96.6%	3.4%	96.3%	3.7%	95.0%	5.0%
South Lahontan	99.6%	0.4%	99.6%	0.4%	98.9%	1.1%
Colorado River	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
Statewide Total	**96.9%**	**3.1%**	**96.8%**	**3.2%**	**96.7%**	**3.3%**

Figures 4-15 and 4-16 display the annual agricultural acreage by hydrologic region in basin and non-basin areas, respectively (note the different scales between the two figures). When comparing annual changes in agricultural acreage between the hydrologic regions and basin and non-basin areas for 2019, 2020, and 2021, most areas of the state show relatively small fluctuations in agricultural acreage regardless of hydrologic conditions. However, the basin areas in the Tulare Lake Hydrologic Region (Figure 4-15) appear to be more affected by changing hydrologic conditions, with a reduction in agricultural land of about 300,000 acres between 2019 and 2021.

PUBLIC DRAFT

Figure 4-15 Agricultural Acres in Basin Area by Hydrologic Region (2019-2021)

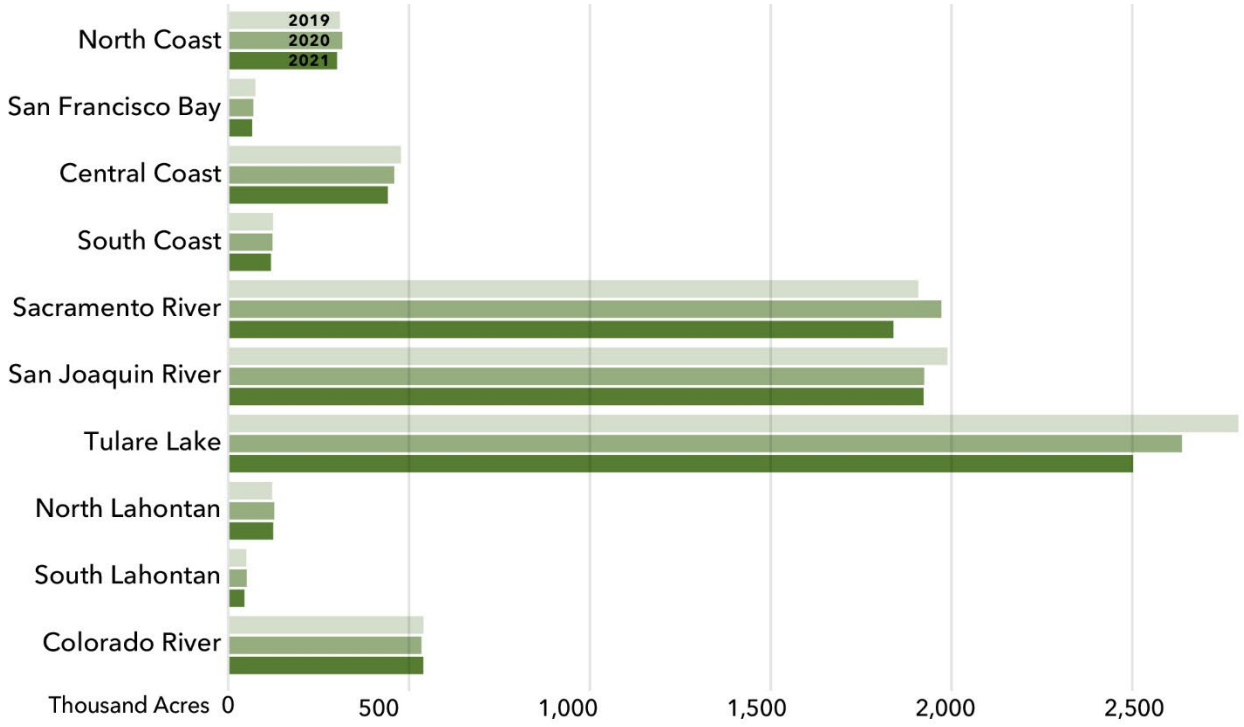


Figure 4-16 Agriculture Acres in Non-Basin Area by Hydrologic Region (2019-2021)

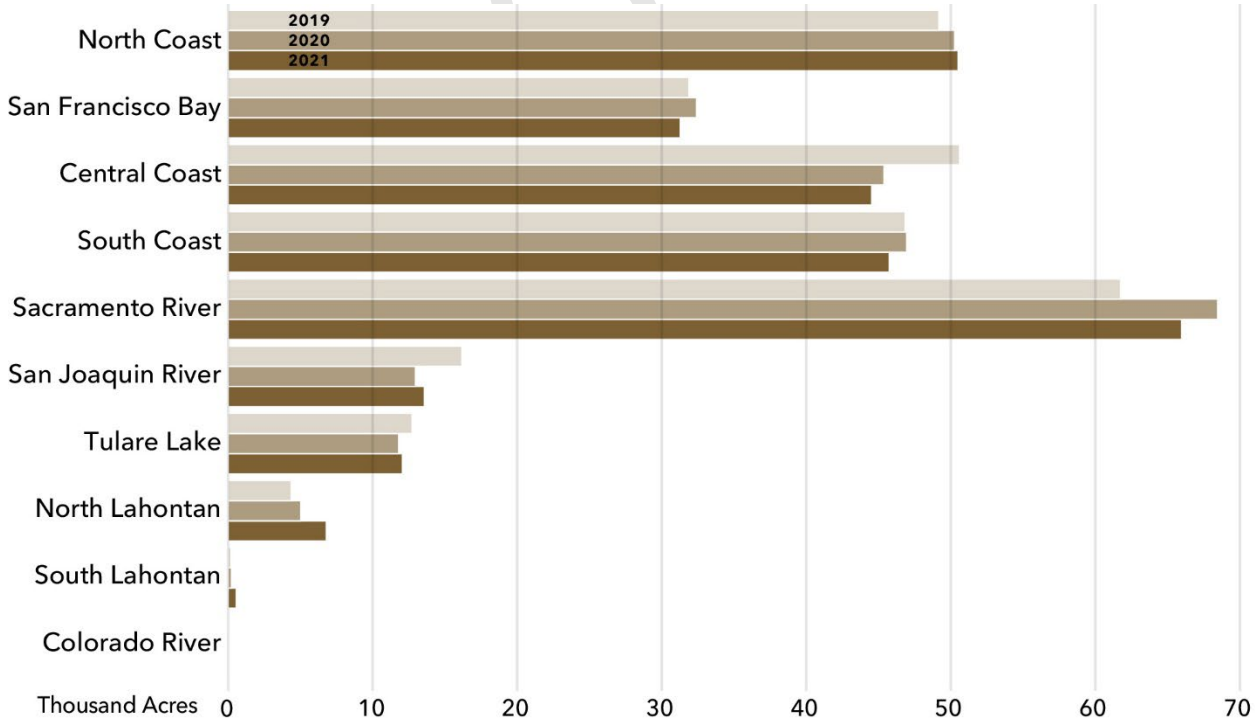


Table 4-13 presents the 2019–2021 basin versus non-basin agricultural groundwater use estimates for each hydrologic region and statewide. Agricultural groundwater use estimates for basin versus non-basin areas are calculated based on the percentages of agricultural land within the basin and non-basin areas.

Table 4-13 Agricultural Groundwater Use, Basin vs. Non-Basin Areas by Hydrologic Region in Thousand Acre-Feet (Water Years 2019–2021)

Hydrologic Region	Use in Basin Area (2019)	Use in Non-Basin Area (2019)	Use in Basin Area (2020)	Use in Non-Basin Area (2020)	Use in Basin Area (2021)	Use in Non-Basin Area (2021)
North Coast	345	54	338	53	318	53
San Francisco Bay	99	40	97	43	75	34
Central Coast	914	96	866	85	936	94
South Coast	162	59	221	82	287	108
Sacramento River	2,073	67	2,716	94	3,129	112
San Joaquin River	2,399	19	2,869	19	3,602	25
Tulare Lake	2,451	11	5,463	24	8,028	39
North Lahontan	97	3	127	5	104	6
South Lahontan	159	1	218	1	242	3
Colorado River	44	0	57	0	74	0
Statewide Total	8,744	352	12,971	407	16,796	472

Figures 4-17 and 4-18 display the annual agricultural groundwater use by hydrologic region in basin and non-basin areas, respectively (note the different scales between the two figures). When comparing annual changes in agricultural groundwater use between the different hydrologic regions and basin and non-basin areas for 2019–2021, most areas of the state show similar trends of increasing agricultural groundwater use as hydrologic conditions become drier — in both basin and non-basin areas. However, some areas of the state, such as the North Coast and San Francisco Bay hydrologic regions, show stable or a slight decrease in groundwater use during drier conditions (Figures 4-17 and 4-18), even with relatively stable agricultural acreage over the same period (Figures 4-15 and 4-16).

PUBLIC DRAFT

Figure 4-17 Agriculture Groundwater Use in Basin Areas by Hydrologic Region (Water Years 2019-2021)

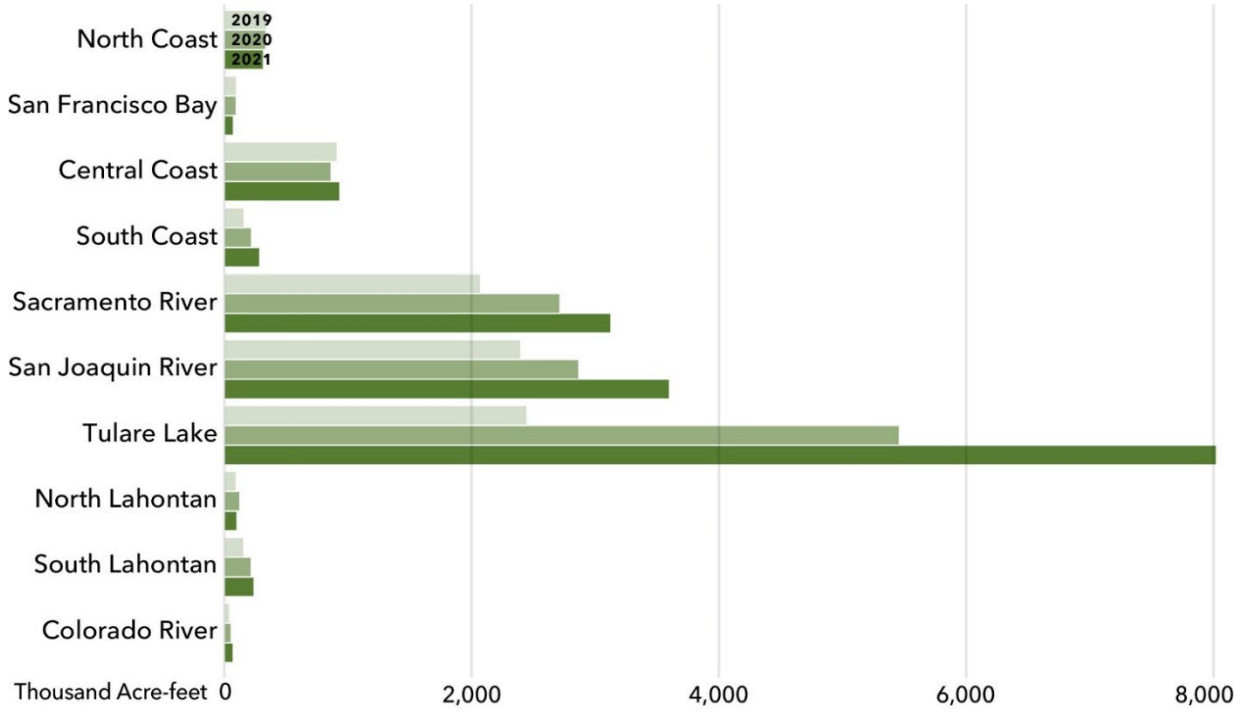
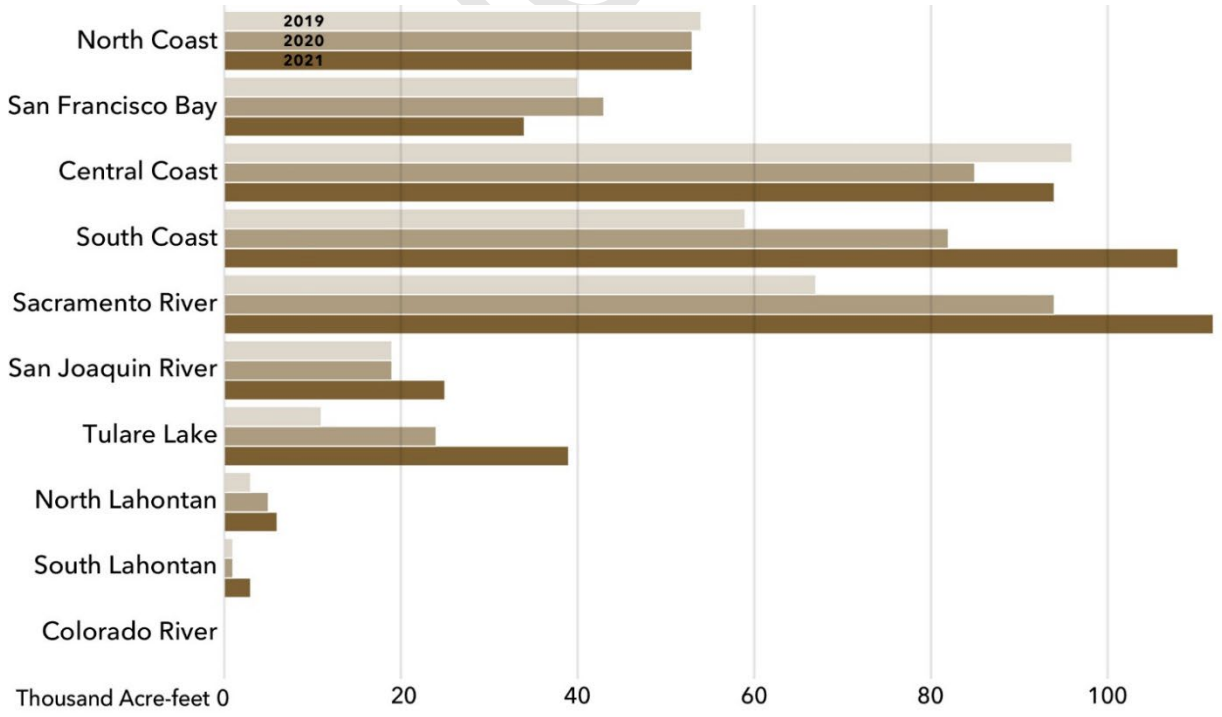


Figure 4-18 Agriculture Groundwater Use in Non-Basin Areas by Hydrologic Region (Water Years 2019-2021)



Urban Groundwater Use in Basin vs. Non-Basin Areas

Table 4-14 presents the urban acres in basin and non-basin areas. It shows that there have been minimal changes in urban land use in both basin and non-basin areas from 2019 to 2021. Unlike agriculture, where approximately 3% of the total agricultural area is located within non-basin areas, a much greater share of urban land is located within non-basin areas at approximately 25%. These areas face unique challenges regarding groundwater, which are discussed in Chapter 3, "California's Natural and Built Groundwater Infrastructure."

Table 4-14 Annual Statewide Urban Area, Basin vs. Non-Basin Areas (2019–2021)

Water Year	Urban Acres in Basin Area	Percent Urban Acres Basin Area	Urban Acres in Non-Basin Area	Percent Urban Acres in Non-Basin Area
2019	3,628,488	74.2%	1,263,013	25.8%
2020	3,663,016	74.2%	1,270,928	25.8%
2021	3,674,232	74.3%	1,271,305	25.7%

Many of California's largest urban areas have been developed within basin areas. Major cities in the South Coast, San Francisco Bay, and Sacramento River hydrologic regions are among the state's most populous. Figure 4-20 presents a map of California's urban areas, based on 2021 land use data, overlaid with groundwater basins and hydrologic regions. The figure also includes a chart showing the three-year average (2019–2021) percentage of urban land use within basin and non-basin areas. As shown in the figure, the South Coast Hydrologic Region has the most urban acres in the state, accounting for approximately 44% of the total statewide urban land. Table 4-15 provides annual urban land use data for both basin and non-basin areas from 2019 to 2021. The breakdown by hydrologic region indicates minimal changes in the percentage of urban land within basin versus non-basin areas over this period.

PUBLIC DRAFT

Figure 4-19 2021 Statewide Urban Area, Basin vs. Non-Basin Areas

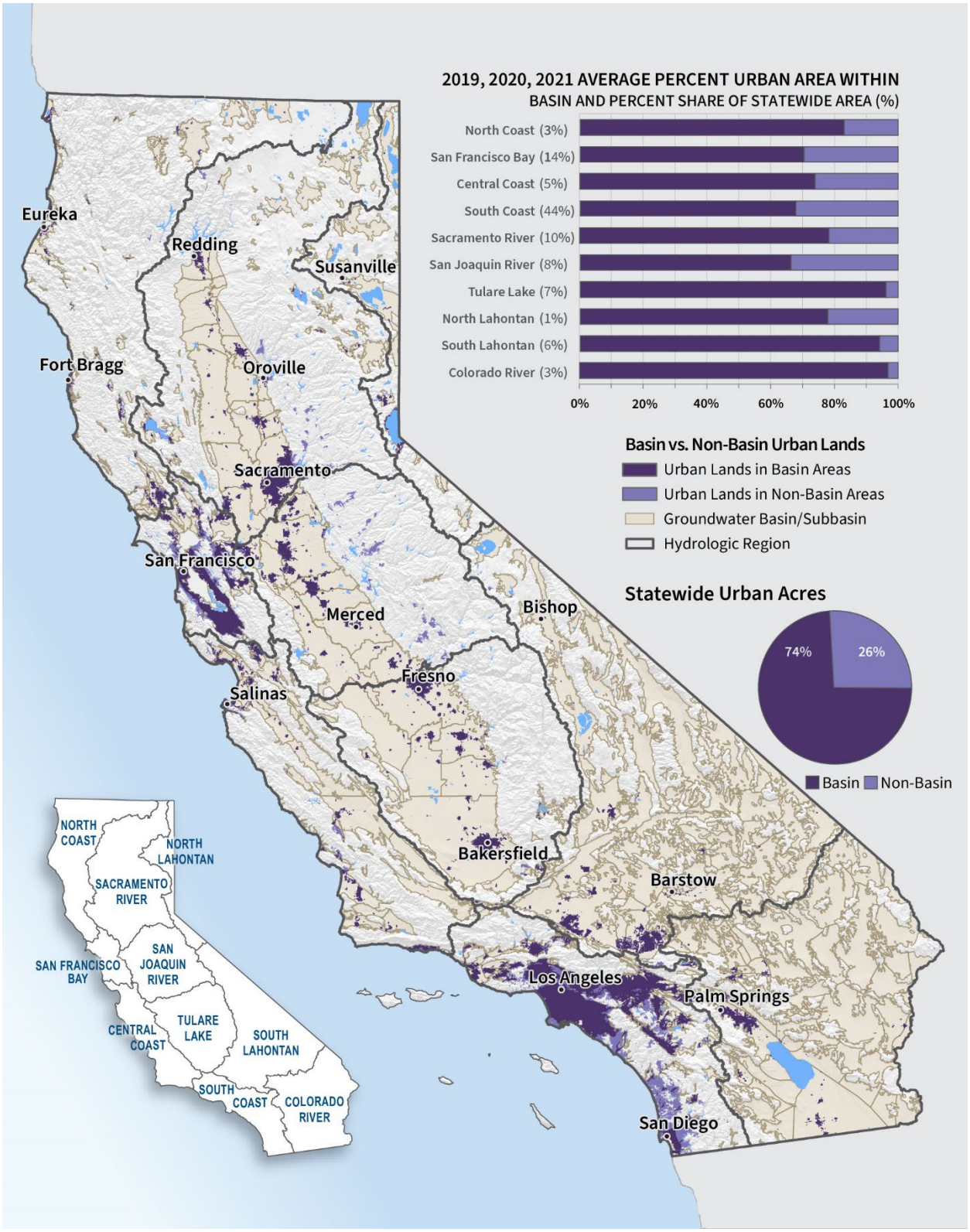


Table 4-15 Percent Urban Area in Basin and Non-Basin Areas, Hydrologic Region (2019, 2020, 2021)

Hydrologic Region	Percent Acres in Basin Area (2019)	Percent Acres in Non-Basin Area (2019)	Percent Acres in Basin Area (2020)	Percent Acres in Non-Basin Area (2020)	Percent Acres in Basin Area (2021)	Percent Acres in Non-Basin Area (2021)
North Coast	83.0%	17.0%	83.5%	16.5%	83.5%	16.5%
San Francisco Bay	70.5%	29.5%	70.5%	29.5%	70.4%	29.6%
Central Coast	73.7%	26.3%	74.3%	25.7%	74.3%	25.7%
South Coast	67.9%	32.1%	67.9%	32.1%	67.9%	32.1%
Sacramento River	78.5%	21.5%	78.2%	21.8%	78.2%	21.8%
San Joaquin River	66.0%	34.0%	66.3%	33.7%	67.0%	33.0%
Tulare Lake	95.8%	4.2%	95.9%	4.1%	96.3%	3.7%
North Lahontan	78.4%	21.6%	78.6%	21.4%	77.9%	22.1%
South Lahontan	94.6%	5.4%	94.6%	5.4%	94.4%	5.6%
Colorado River	96.8%	3.2%	96.9%	3.1%	97.1%	2.9%
Statewide Total	74.2%	25.8%	74.2%	25.8%	74.3%	25.7%

Figures 4-20 and 4-21 display the annual urban acres by hydrologic region in basin and non-basin areas, respectively (note the different scales between the two figures). As shown in the figures, urban acres from 2019 to 2021 in both basin and non-basin areas is generally stable.

PUBLIC DRAFT

Figure 4-20 Urban Acres in Basin Areas by Hydrologic Region (2019-2021)

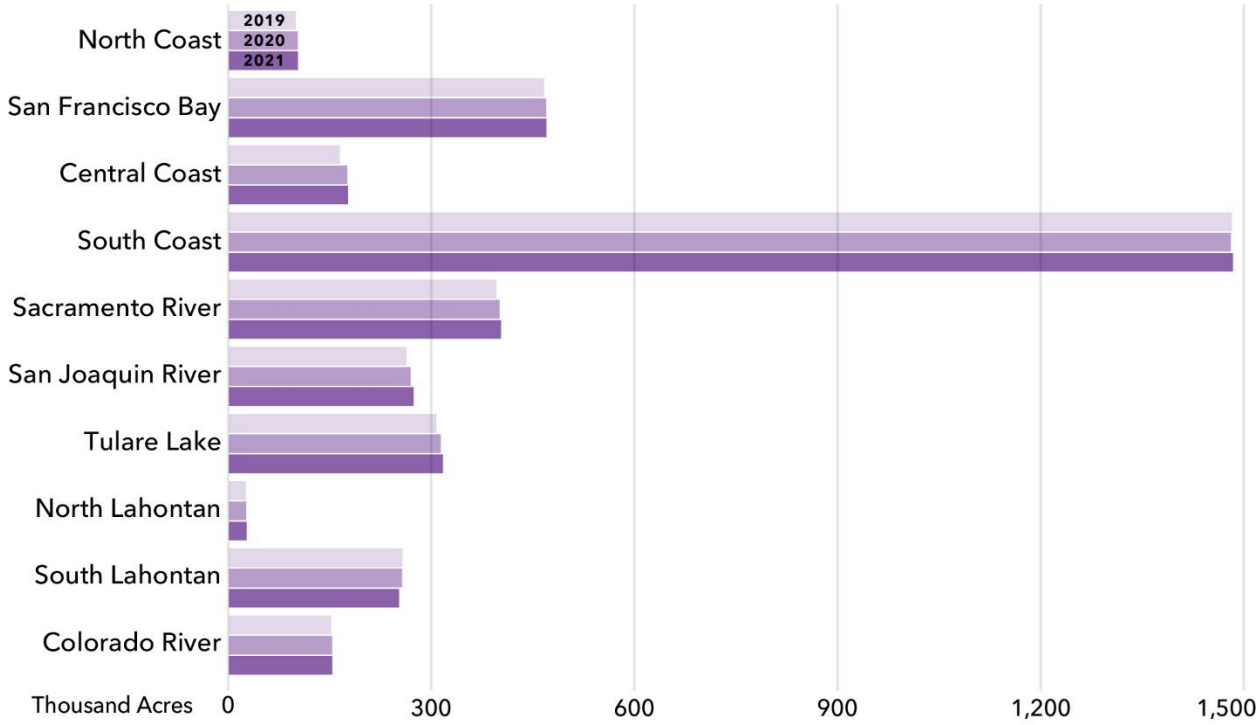
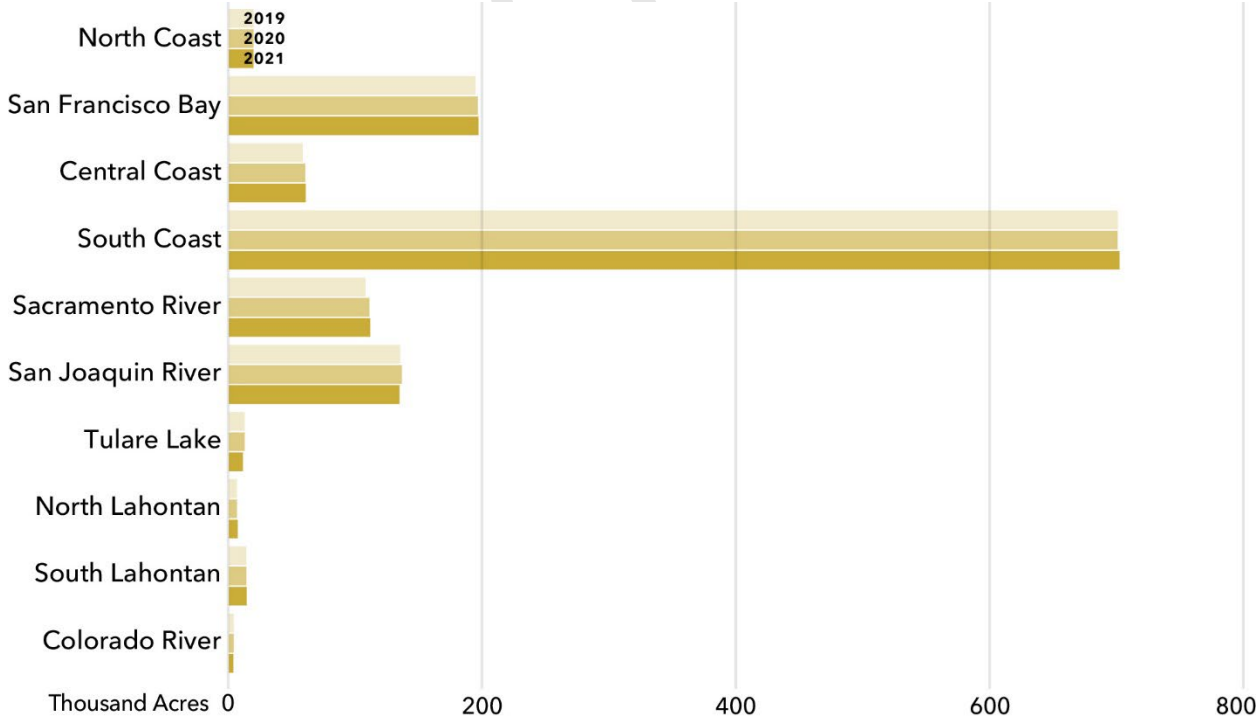


Figure 4-21 Urban Acres in Non-Basin Areas by Hydrologic Region (2019-2021)



Similar to agricultural groundwater use estimates, urban groundwater use estimates for basin and non-basin areas are calculated based on the percentage of urban land within each area.

Table 4-16 presents the 2019–2021 basin versus non-basin urban groundwater use estimates for each hydrologic region and statewide.

Table 4-16 Urban Groundwater Use, Basin vs. Non-Basin Areas, Hydrologic Region in Thousand Acre-Feet (Water Years 2019–2021)

Hydrologic Region	Use in Basin Area (2019)	Use in Non-Basin Area (2019)	Use in Basin Area (2020)	Use in Non-Basin Area (2020)	Use in Basin Area (2021)	Use in Non-Basin Area (2021)
North Coast	42	9	55	11	50	10
San Francisco Bay	101	42	103	43	125	52
Central Coast	122	44	131	45	131	45
South Coast	810	383	719	340	821	388
Sacramento River	223	61	254	71	267	74
San Joaquin River	167	86	193	98	199	98
Tulare Lake	334	15	379	16	430	17
North Lahontan	21	6	19	5	20	6
South Lahontan	122	7	121	7	144	9
Colorado River	250	8	96	3	344	10
Statewide Total	**2,192**	**660**	**2,069**	**639**	**2,531**	**709**

Figures 4-22 and 4-23 display the annual urban groundwater use by hydrologic region in basin and non-basin areas, respectively (note the different scales between the two figures). As shown in the figures, the South Coast and Colorado River hydrologic regions exhibited similar fluctuations in urban groundwater use, which did not align with trends observed in other areas of the state. Since these hydrologic regions rely heavily on imported water from outside California (e.g., the Colorado River), the state's hydrologic conditions in a given year may have less impact on their water supplies compared to other regions. In contrast, urban groundwater use in many other hydrologic regions followed a more typical response, increased groundwater use during drier years, though to a lesser extent than the increases observed in agricultural groundwater use.

PUBLIC DRAFT

Figure 4-22 Urban Groundwater Use in Basins by Hydrologic Region (Water Years 2019-2021)

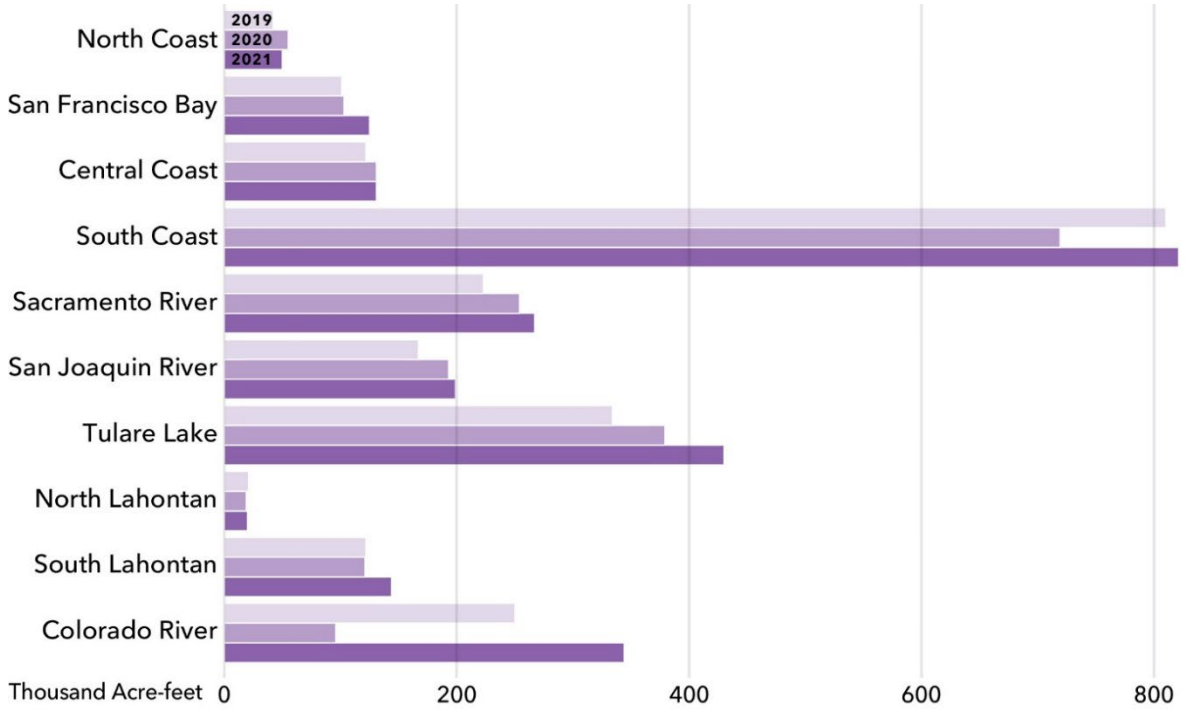
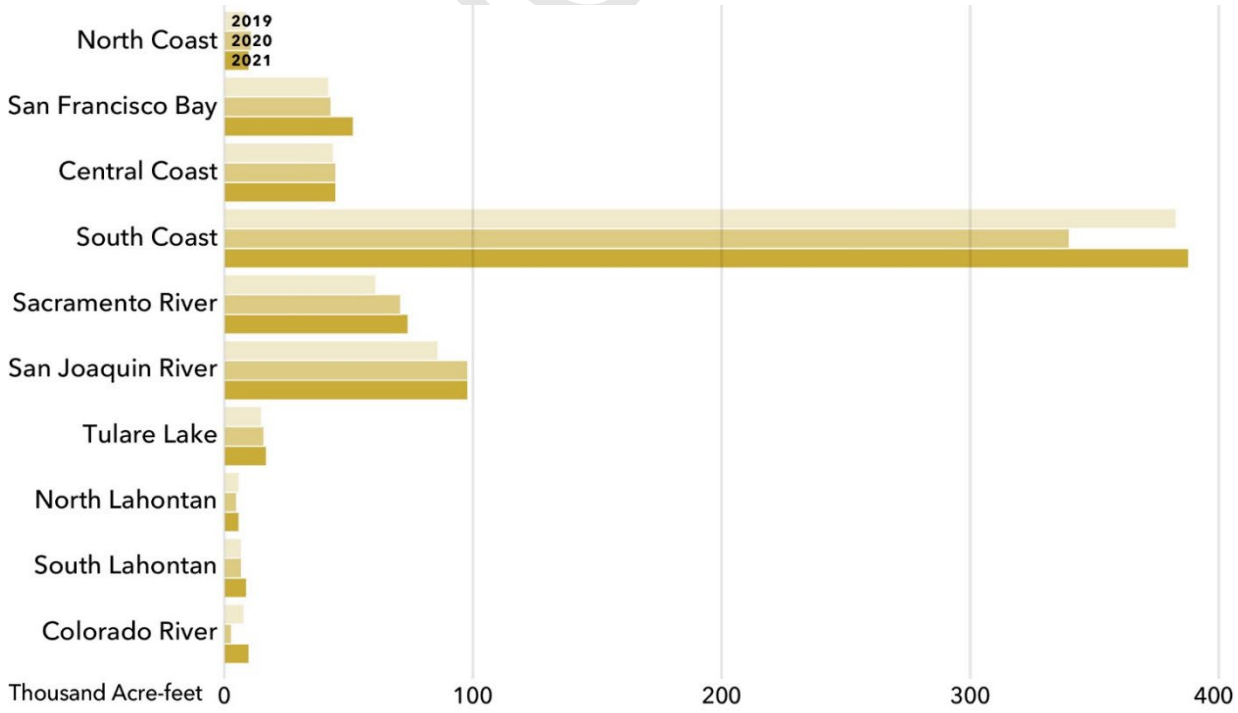


Figure 4-23 Urban Groundwater Use in Non-Basin Areas by Hydrologic Region (Water Years 2019-2021)



4.2.6 Water Use in SGMA Reporting Basins

Following the adoption of a GSP or an approved Alternative, managing agencies in medium- and high-priority basins are required to submit an annual report and associated data to DWR through the SGMA Portal's Annual Report Module. These reports include information on groundwater elevations, groundwater extraction, surface water supply used for or available for groundwater recharge and/or in-lieu use, total water use, and change in groundwater storage.

The data presented in this section are sourced from the Total Water Use dataset posted on the California Natural Resource Agency's (CNRA) Open Data website. This dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024, including several low- and very low-priority basins that have voluntarily developed and submitted GSPs. While managing agencies for many Alternatives submitted annual reports prior to 2021, these earlier reports are not included in the Total Water Use dataset because the previous reporting format for Alternatives did not align with SGMA Portal's Annual Report Module format.

In WY 2023, 100 basins submitted a total of 133 annual reports. This is a significant increase from WY 2019, when only 18 critically overdrafted basins and five non-critically overdrafted basins submitted reports, reflecting the broader SGMA reporting requirements beginning in WY 2021. Table 4-17 presents the data on the number of basins that have submitted annual reports, total water use, groundwater extraction, and change in groundwater storage for WY 2019–2023 reported by the submitting basins.

While 100 of the 102 basins with GSPs and Alternatives reported their water use and other required data in WY 2023, there were 415 basins across the state that did not. These include low- and very low-priority basins which are not required to and did not develop a GSP or an Alternative under SGMA, and approximately 30 basins managed by a court-appointed watermaster. Watermasters from adjudicated areas are also required to submit similar annual reports; however, they are not included in this summary as the reports typically cover portions of basins or multiple basins, and several include non-basin areas. Additionally, the adjudicated areas have various standard reporting periods. The following analysis does not include data from these 415 basins.

PUBLIC DRAFT

Table 4-17 GSP and Alternative Annual Report Summary in Thousand Acre-Feet (Water Years 2019–2023)

Water Year	Number of Basins Submitting Annual Reports	Total Water Use	Groundwater Extractions	Change in Groundwater Storage
2019	23	18,554	6,936	1,598
2020	26	16,370	9,163	-2,642
2021	94	29,051	18,562	-7,920
2022	98	27,261	17,606	-6,502
2023	100	30,900	10,105	8,847

Table 4-17 Notes: Numbers may not total precisely because of rounding. Dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024. Only critically overdrafted basins were required to report in WYs 2019 and 2020; however, some non- critically overdrafted basins voluntarily submitted annual reports during these and subsequent years and they have been included in the totals. Annual reports submitted under Alternatives prior to WY 2021 are not included.

Data provided in annual reports highlight the notable impact of hydrologic and climatic conditions on groundwater storage throughout the submitting basins. In WY 2023, a wet year, total water use remained generally consistent with two previous dry years (considering the difference in the number of reporting basins). However, groundwater extraction decreased significantly, and groundwater storage increased substantially. This shift reflects a preference for surface water use over groundwater use when adequate supplies are available.

Managers of GSPs and Alternatives from medium- and high-priority basins are required to report total water use by sector and source in annual reports. The sectors, sources, and trends observed between WYs 2019 and 2023 are discussed below. Several low- or very low-priority basins have voluntarily submitted annual reports and are included in the section below.

SGMA Reporting Basin Water Use by Source

Annual reports provide water use data both as a total and broken down by source type when available. Source types are categorized as groundwater, surface water, recycled water, reused water, and other, which can include precipitation, imported water, and diversions for surface water and/or groundwater storage and remediation treatment technologies. Figure 4-24 and Table 4-18 present total water use by source type for WY 2019 through 2023. More basins reported total water use in WYs 2021, 2022, and 2023 compared to 2019 and 2020, primarily

PUBLIC DRAFT

because additional basins began submitting annual reports to DWR starting in 2021 to comply with SGMA requirements.

Total water use for SGMA-reporting basins declined between WY 2019 and 2020. WY 2019 was hydrologically above normal or wet throughout the state where additional surface water was available for use. However, the drier conditions in the San Joaquin Valley during WY 2020 led to a decrease in total water use. WYs 2021 and 2022 were both considered drought years over much of the state, making groundwater the primary water source. Although hydrologic conditions improved significantly in WY 2023, with historically high precipitation events, total water use only saw a small increase compared to the drier WYs 2021 and 2022. However, the primary water source shifted from groundwater to surface water. As shown in Figure 4-25, surface water accounted for approximately 30% of total water supplies used in WYs 2021 and 2022. In WY 2023, the increased availability of surface water allowed SGMA-reporting basins to rely more on these supplies instead of groundwater, resulting in a 30% increase in surface water use and a corresponding decrease in groundwater use.

Table 4-18 Water Use by Source Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 2019–2023)

Water Year	Basins Reporting	Groundwater	Surface Water	Recycled Water	Reused Water	Other	Total
2019	23	6,936	10,845	86	21	1,018	18,906
2020	26	9,163	6,519	122	13	534	16,351
2021	94	18,562	9,592	256	53	607	29,070
2022	99	17,606	8,497	280	46	748	27,177
2023	100	10,105	19,505	233	101	1,362	31,306

Table 4-18 Notes: Numbers may not total precisely because of rounding. Dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024. Only critically overdrafted basins were required to report for WYs 2019 and 2020; however, some non- critically overdrafted basins voluntarily submitted annual reports during these and subsequent years and they have been included in the totals. Annual reports submitted under Alternatives prior to WY 2021 are not included.

PUBLIC DRAFT

Figure 4-24 Water Use by Source Reported in GSP and Alternative Annual Reports (Water Years 2019–2023)

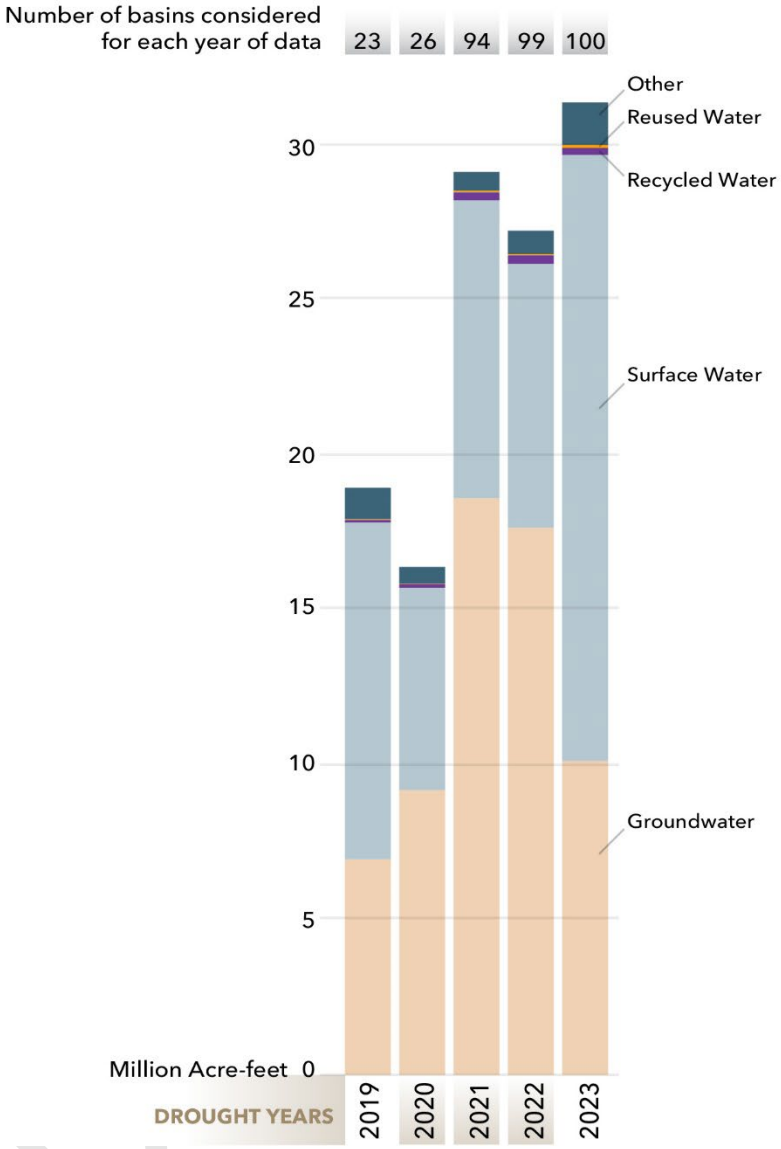


Figure 4-24 Note: The number at the top of each bar indicates the number of basins that submitted an annual report for that year.

Figure 4-25 Percent Water Use by Source Reported in GSP and Alternative Annual Reports (Water Years 2019-2023)

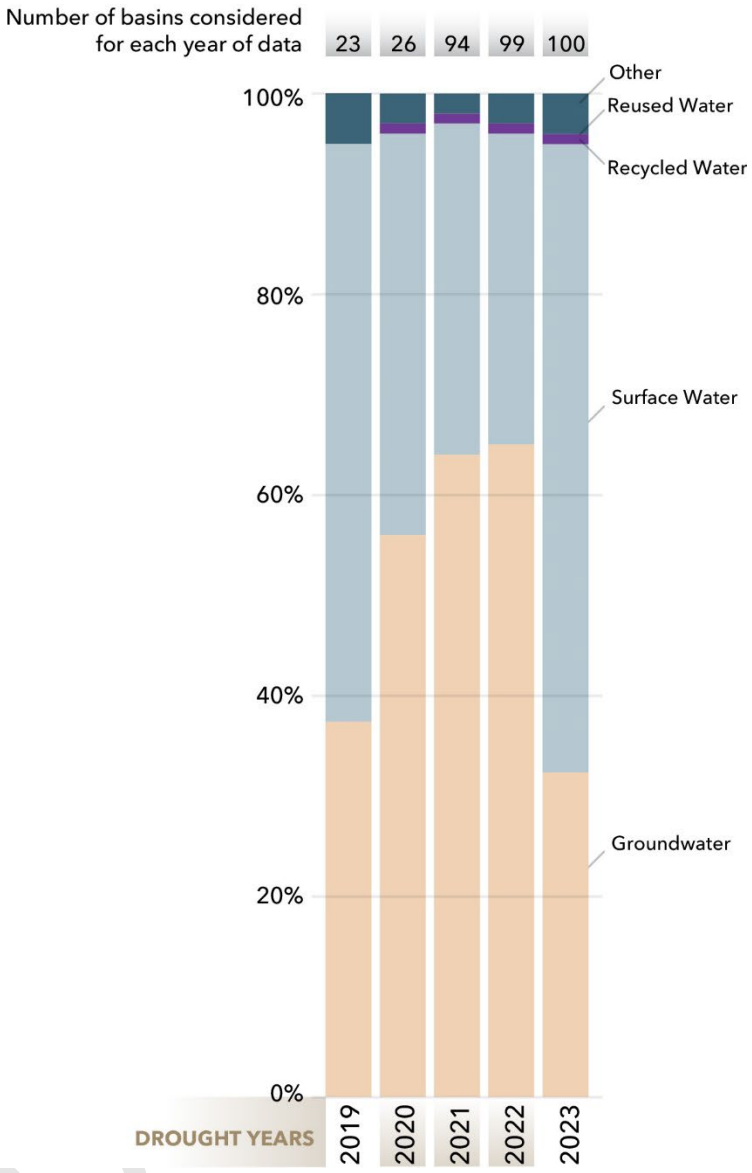


Figure 4-25 Note: The number at the top of each bar indicates the number of basins that submitted an annual report for that year.

Within SGMA reporting basins, water use by source varied significantly across hydrologic regions during WYs 2021 through 2023 (Figure 4-26). Groundwater continues to be the predominant source of water in these basins, serving as the primary water source in eight of the 10 hydrologic regions. Surface water is another prominent source of water throughout the SGMA reporting basins and is the main source of water supply for the remaining two hydrologic regions. While they are not the major source of water in SGMA reporting basins, recycled and

reused water sources have continued to provide valuable water supply for water managers to meet local demands.

The Colorado River Hydrologic Region relies significantly on water supplies from the Colorado River. Water managers with water rights to the Colorado River granted under the Seven Party Agreement in 1931 (United States Bureau of Reclamation 2008) report this water supply as "Other," as shown in Figure 4-26. In the San Francisco Bay Hydrologic Region, surface water accounted for about 60% of the total water use during WYs 2021 through 2023. Many basins in this region fall within the service areas of major local projects that import surface water, such as the Hetch Hetchy Regional Water System, the Mokelumne Aqueduct system, and the State Water Project. The reliance on surface water in the San Francisco Bay Hydrologic Region is likely driven by several factors, including established surface water rights, interagency agreements, ordinances, and challenges associated with relying solely on groundwater in this area, such as limited supply and the risk of seawater intrusion.

The Central Valley (which encompasses the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions) has historically relied on both groundwater and surface water to meet local demands (see Water Use by Sector for additional details). As shown in Table 4-19, most of the water use occurs in the Central Valley. SGMA-reporting basins in the Central Valley accounted for approximately 87% of total water use among all SGMA-reporting basins in California. To meet demand, these basins have also integrated additional water sources, such as recycled water, reused water, water transfers, and treated water from remediation systems.

PUBLIC DRAFT

Figure 4-26 Hydrologic Region Percent Water Use by Source Reported in GSP and Alternative Annual Reports (Water Years 2021–2023)

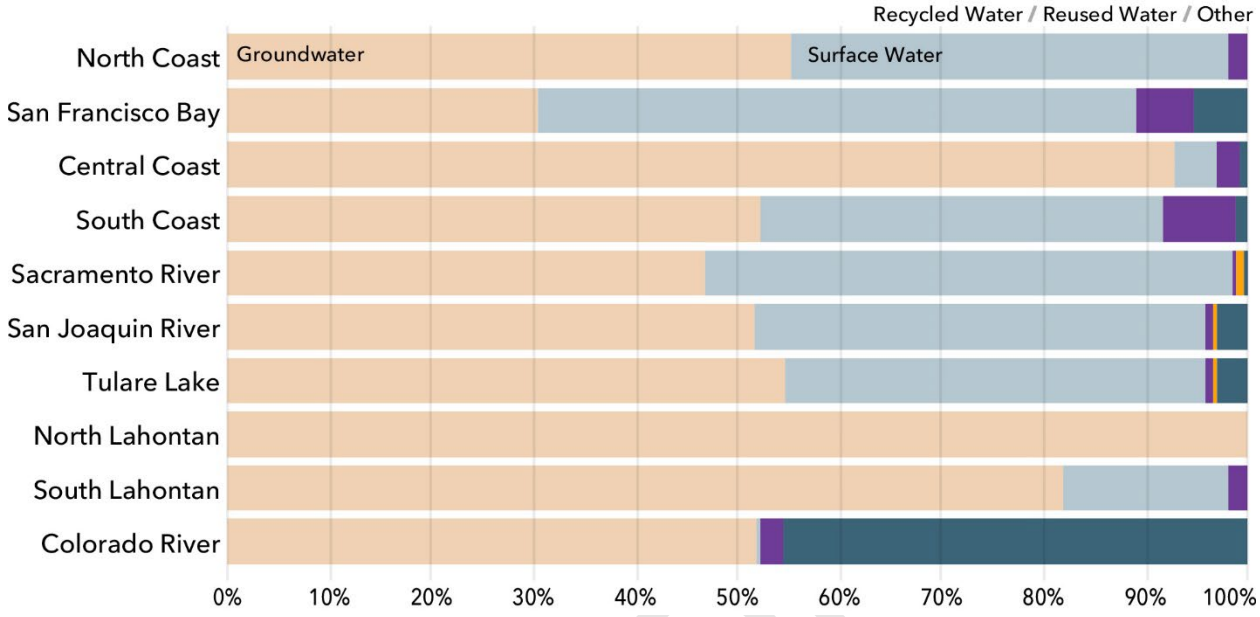


Figure 4-26 Notes: The number of basins submitting annual reports in each hydrologic region sometimes varied by year. Data for the North Lahontan Hydrologic Region is based on a single reporting basin, which results in the region being shown as 100% reliant on groundwater.

PUBLIC D

Table 4-19 Hydrologic Region Average Annual Water Use by Source Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 2021–2023)

Hydrologic Region	Groundwater	Surface Water	Recycled Water	Reused Water	Other
North Coast	229	177	8	—	—
San Francisco Bay	158	306	28	—	28
Central Coast	878	39	19	—	9
South Coast	578	437	77	—	13
Sacramento River	3,393	3,732	5	52	34
San Joaquin River	3,803	3,250	33	13	221
Tulare Lake	6,019	4,580	71	1	330
North Lahontan	5	—	—	—	—
South Lahontan	53	10	1	—	—
Colorado River	309	1	14	—	271
Total in Reporting Basins	**15,424**	**12,531**	**256**	**67**	**906**

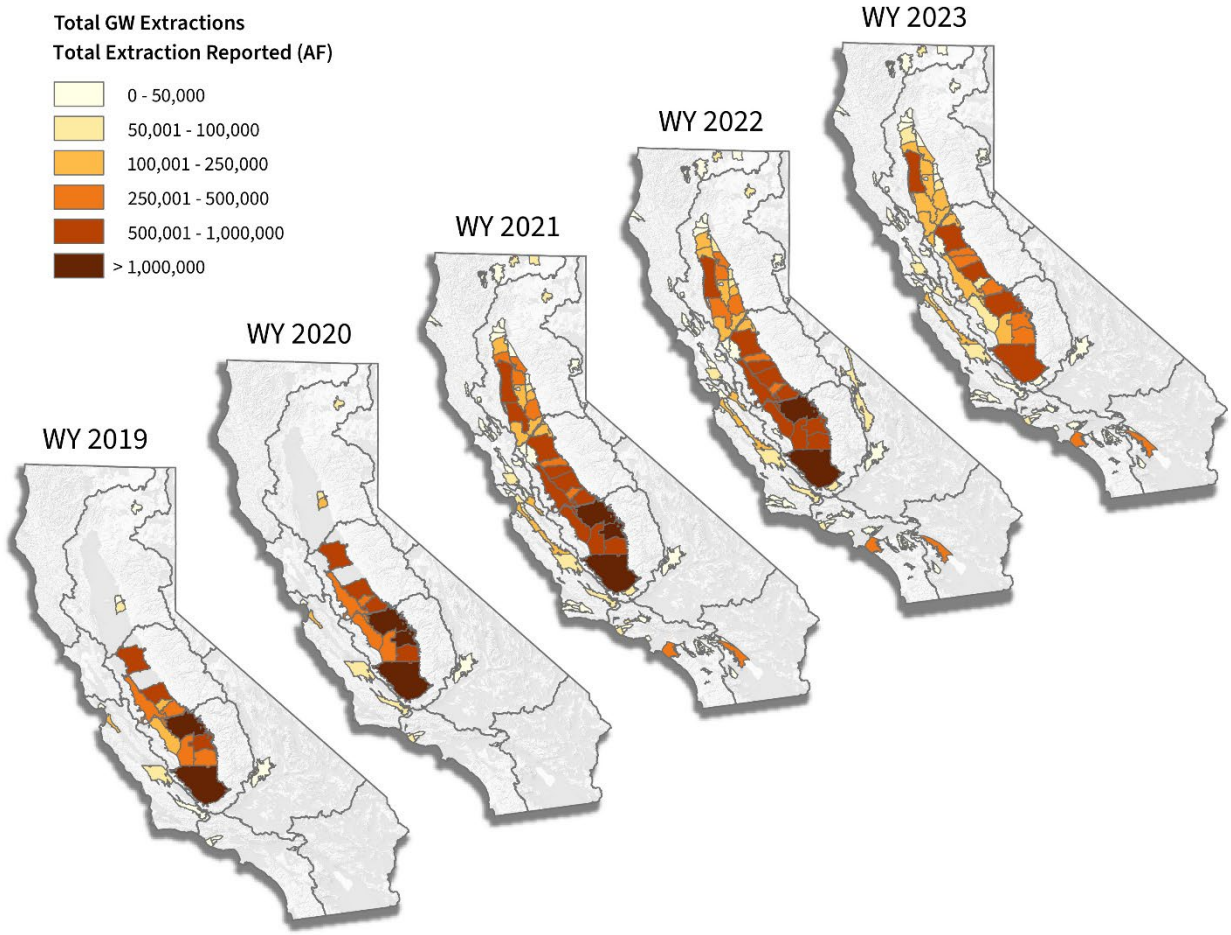
Table 4-19 Notes: Numbers may not total precisely due to rounding. Dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024. Source water use volumes are in thousand acre-feet and an average over Water Years 2021-2023.

Groundwater use data is primarily based on groundwater extractions that are recorded through automated metering, self-reporting, or model estimations. Groundwater extraction is prevalent across SGMA-reporting basins and increases in extractions, outside of what is typical for their regions, can be associated with periods of extended drought, less surface water availability, land use changes, and changes in demand for the various water use sectors. Figure 4-27 shows the groundwater extractions by basin for each water year from 2019 through 2023. Groundwater extractions generally increased across the reporting basins as drought conditions worsened from WYs 2020 to 2022. WY 2023, after the end of the drought, shows reductions in groundwater extractions.

Reporting of groundwater extraction is crucial for implementing SGMA, as it provides DWR, groundwater managers, and the public with insight into factors that may affect a basin's groundwater conditions. These factors are evaluated by water managers as they plan to achieve sustainability while meeting local demands.

PUBLIC DRAFT

Figure 4-27 Groundwater Extraction Reported in GSP and Alternative Annual Reports (Water Years 2019-2023)



SGMA Reporting Basin Water Use by Sector

This section summarizes the total groundwater and surface water used to meet urban, agricultural, and industrial demands, as well as the needs of managed wetlands and native vegetation. Other water uses within SGMA-reporting basins include rural domestic/residential use, small public water supply systems, remediation activities, and federal lands.

As shown in Table 4-20 and Figures 4-28 and 4-29, water use by sector does not significantly change across water years. Both WY 2019 and 2020 show similar breakdown between agricultural and urban water use. Similarly, there is little difference in water demand between the critically dry year of 2022 and the wet year of 2023. The number of reporting basins jumps significantly from 2020 to 2021 when basins required to submit annual reports changed from only critically overdrafted basins (CODs) to all medium- and high-priority basins (some were

added later depending on when a basin was prioritized as medium- or high-priority).

Rather than affecting overall water demand, water year types primarily influence surface water availability and the balance between surface water and groundwater use, as described in the "Recent Trends in Groundwater Use" section. The total groundwater use by source (Table 4-18) in the SGMA-reporting basins, as reported in annual reports, does not equal the total reported by water use sectors (Table 4-20) due to unreported sector use values, minor variations in annual data entries, and possible differences in calculation methods, such as whether conveyance losses or MAR totals were included or not. Continued coordination with GSAs is important for consistent reporting of total groundwater use by source and by water use sectors.

Table 4-20 Sector Water Use Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 201-2023)

Water Year	Agricultural	Industrial	Urban	Managed Wetlands	Native Vegetation	Other	Total
2019	14,118	31	903	401	139	98	17,835
2020	13,544	28	967	308	109	403	15,884
2021	24,092	137	3,306	544	108	676	29,069
2022	21,655	120	3,142	459	307	843	26,841
2023	21,896	121	2,986	654	213	291	30,562

Table 4-20 Notes: Numbers may not total precisely due to rounding. Dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024. Only critically overdrafted basins were required to report for WYs 2019 and 2020; however, some non-critically overdrafted basins voluntarily submitted annual reports during these and subsequent years and they have been included in the totals. Annual reports submitted under Alternatives prior to WY 2021 are not included. The number of reporting basins is shown in Figure 4-28.

PUBLIC DRAFT

Figure 4-28 Water Use by Sector Reported in GSP and Alternative Annual Reports (Water Years 2019–2023)

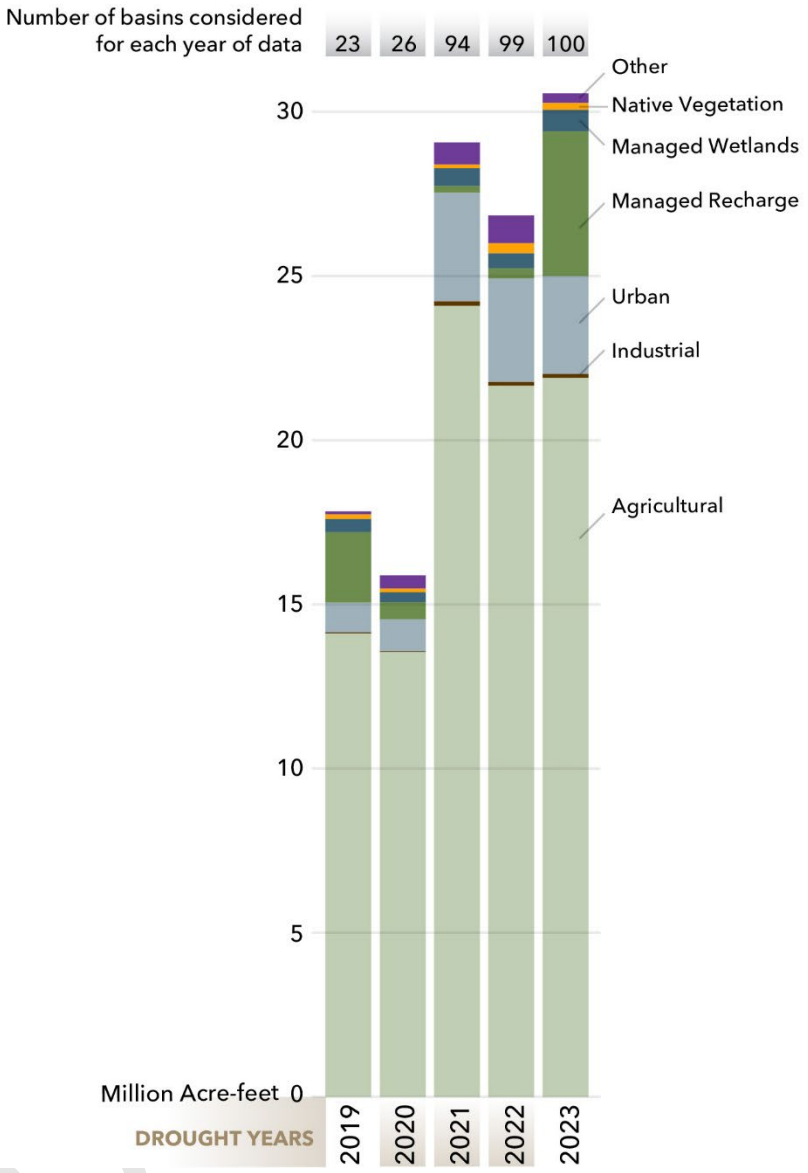


Figure 4-28 Note: The number at the top of each bar indicates the number of basins that submitted an annual report for that year.

Figure 4-29 Percent Water Use by Sector Reported in GSP and Alternative Annual Reports (Water Years 2019-2023)

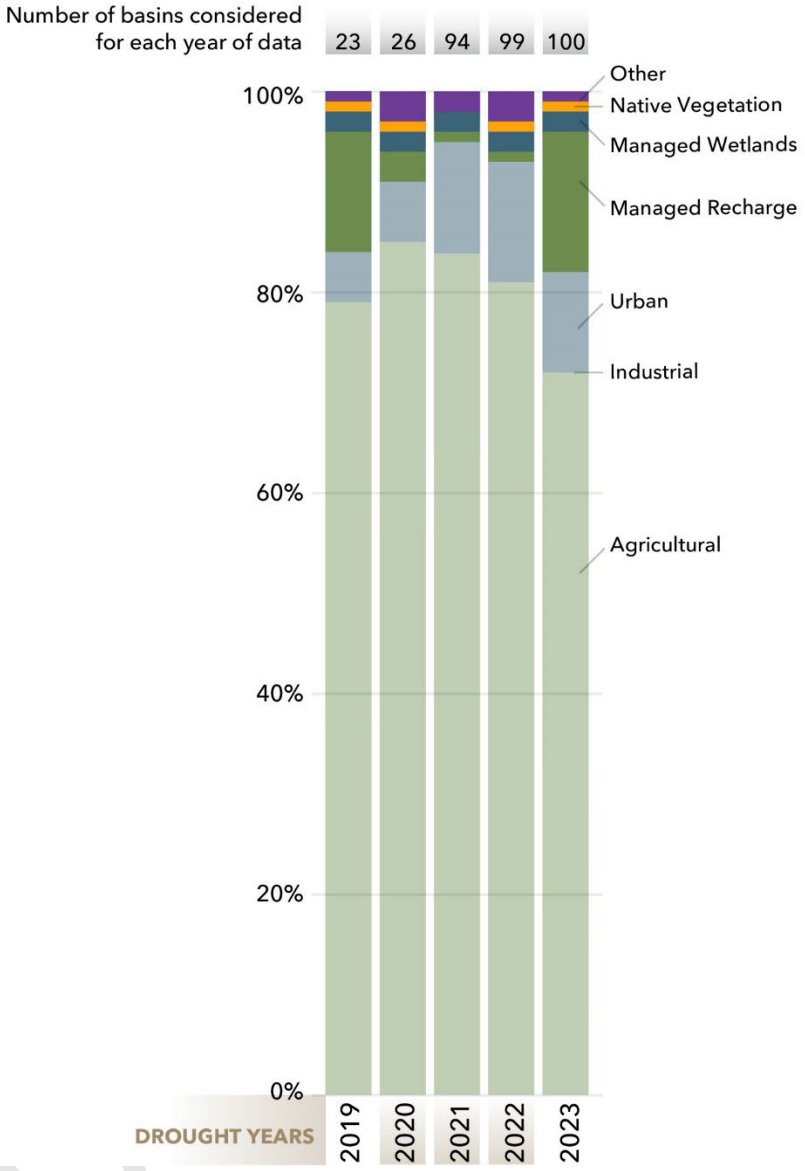


Figure 4-29 Note: The number at the top of each bar indicates the number of basins that submitted an annual report for that year.

As previously discussed, water demand varies across hydrologic regions for each water use sector. Table 4-21 presents the water use by sector for each hydrologic region. The breakdowns by hydrologic region are limited to 2021–2023 to ensure a more consistent comparison. Including 2019 and 2020 would result in inconsistencies when comparing against later years, as data from those years are limited to critically overdrafted basins, whereas 2021 onward includes all other medium- and high-priority basins reporting under SGMA.

Groundwater basins in the Central Valley accounted for approximately 92% of total agricultural water demand across all reporting basins, with a significant percentage of this demand (on average) met by groundwater for WYs 2021 to 2023. In contrast, some regions, such as the San Francisco Bay, have limited agricultural production capacity. As a result, water use in these basins is primarily allocated to the urban sector. Water use sectors in the "Other" category include those related to groundwater and surface water dependent ecosystems, such as managed wetlands and native vegetation. Water use in these sectors is heavily concentrated in the Central Valley hydrologic regions, specifically in areas adjacent to the San Joaquin River, the Sacramento River, their tributaries, and the Sacramento-San Joaquin River Delta.

Table 4-21 Hydrologic Region Average Annual Water Use by Sector Reported in GSP and Alternative Annual Reports in Thousand Acre-Feet (Water Years 2021–2023)

Hydrologic Region	Agricultural	Industrial	Urban	Managed Wetlands	Native Vegetation	Other
North Coast	333	0	37	2	2	—
San Francisco Bay	35	29	419	92	0	7
Central Coast	792	3	120	19	—	—
South Coast	206	1	795	47	11	8
Sacramento River	6,258	59	482	11	215	139
San Joaquin River	6,359	7	425	55	300	52
Tulare Lake	8,253	23	560	1,415	16	1
North Lahontan	—	—	2	—	—	—
South Lahontan	32	2	11	—	8	3
Colorado River	278	2	294	—	—	—
Total in Reporting Basins	**22,548**	**126**	**3,145**	**1,641**	**552**	**209**

Table 4-21 Notes: Numbers may not total precisely due to rounding. Dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024. Sector water use volumes are in thousand acre-feet and an average across Water Years 2021–2023.

PUBLIC DRAFT

Change in Groundwater Storage in SGMA Reporting Basins

As required by SGMA, GSAs must develop sustainability criteria for groundwater storage to ensure sustainable conditions across their basins. Annual reporting provides agencies an opportunity to inform water users about how groundwater conditions are influenced by hydrologic conditions, climate fluctuations, the implementation of sustainable practices, and the varying demands of different water sectors. Reporting basins are required to report changes in groundwater storage to DWR via their annual reports.

The methods used to calculate changes in groundwater storage vary by basin, depending on the characteristics of their respective aquifers. These calculations are largely based on the availability of data and the resources that managing agencies allocate for this analysis. The approaches used, either individually or in combination, in annual reports to calculate change in storage are listed in Table 4-22.

Table 4-22 Change in Groundwater Storage Calculation Methods from Annual Reports

Calculation Method	Description
Groundwater Elevation Differences & Supplemental Analyses	Groundwater elevations are measured periodically, and the difference from the previous year is used to determine the annual change in storage volume. Basins have incorporated this difference into model simulations or other analytical methods to improve the change in storage estimates. Additional analyses, such as linear regression or the incorporation of specific yields and storage coefficients, can also be used alongside groundwater elevation changes to refine storage calculations.
Water Budget, Water Balance	Change in storage is calculated by accounting for all water inflows and outflows in the basin, including evapotranspiration (ET), interbasin flow, groundwater extraction, surface water imports, precipitation, and recharge.
Model Simulations	Several basins estimate changes in groundwater storage using numerical models tailored to their specific basin or region. These models are typically based on surface and subsurface flow dynamics and incorporate groundwater elevations, lithologic characteristics, land use, water use, and climate data. To ensure accuracy, models are regularly calibrated with the most recent data.

As presented in Table 4-17, changes in groundwater storage are driven by hydrologic conditions, total water use, and groundwater extraction, with the most significant declines in storage occurring during dry/critically dry periods. Table 4-

PUBLIC DRAFT

23 shows the surface area of reporting basins by hydrologic region and the total change in groundwater storage per acre from WYs 2021 through 2023. Half the hydrologic regions, including the San Francisco Bay, Central Coast, South Coast, North Lahontan, and Colorado River, have experienced increased storage despite periods of significant drought (Figure 4-30). In contrast, the remaining hydrologic regions have experienced declines in groundwater storage, with the most substantial reductions observed in the North Coast, Sacramento River, San Joaquin River, and Tulare Lake.

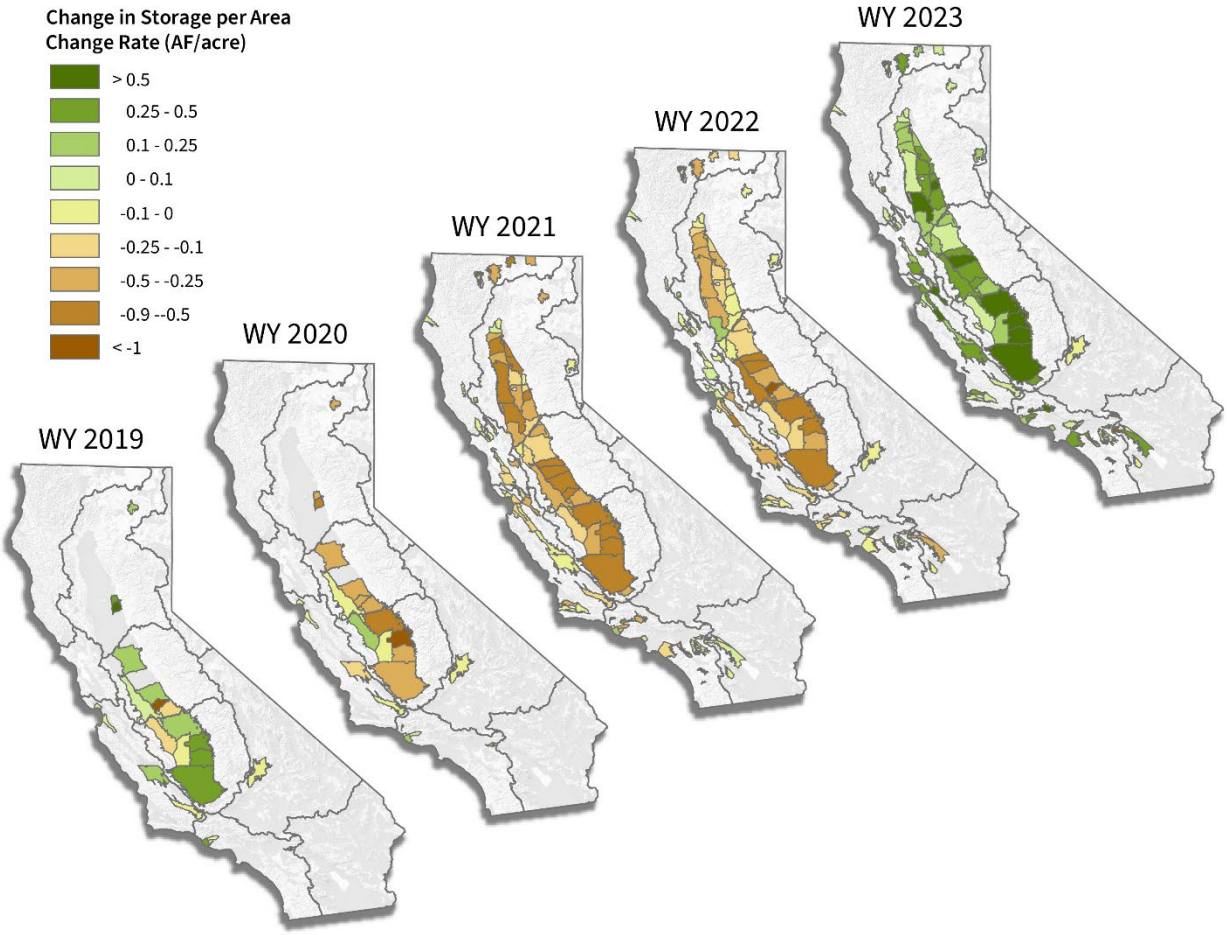
Table 4-23 Total Change in Storage by Hydrologic Region Reported in GSP and Alternative Annual Reports (Water Years 2021–2023)

Hydrologic Region	Change in Groundwater Storage (taf)	Surface Area (acres)	Change in Groundwater Storage per Area (af/acre)
North Coast	-265	663,596	-0.40
San Francisco Bay	60	532,208	0.11
Central Coast	56	1,824,158	0.03
South Coast	180	860,566	0.21
Sacramento River	-1,629	4,247,850	-0.38
San Joaquin River	-2,137	3,642,051	-0.59
Tulare Lake	-1,815	4,973,800	-0.36
North Lahontan	2	14,800	0.14
South Lahontan	-36	601,925	-0.06
Colorado River	10	447,022	0.02
Total in Reporting Basins	-5,574	17,807,976	-0.31

Table 4-23 Notes: Numbers may not total precisely due to rounding. Dataset includes annual report data submitted under GSPs and Alternatives through August 19, 2024. Surface area calculated based on the extent of reporting basins in each hydrologic region.

PUBLIC DRAFT

Figure 4-30 Annual Change in Storage Rates by Basin Reported in GSP and Alternative Annual Reports (Water Years 2019-2023)



Although hydrologic conditions improved in WY 2023, many basins continued to experience the lingering effects of previous drought conditions on their respective groundwater systems, as shown in groundwater level change maps in Chapter 6, "Groundwater Conditions." This highlights the ongoing reliance on groundwater when other sources, such as surface water, are not available. Total water use, specifically groundwater extraction, has had the largest impact on changes in groundwater storage.

Evaluating Water Use in Low- and Very Low-Priority Basins and Non-Basin Areas

Groundwater management efforts in California are primarily focused on medium- and high-priority basins, as mandated by SGMA. These basins are prioritized based on factors such as population, groundwater dependency, and overdraft risk. While SGMA has resulted in significant advancements in the reporting and availability of

groundwater information in these basins, information remains limited for low- and very low-priority basins. Because low- and very low-priority basins that chose not to submit GSPs or Alternatives are exempt from the mandatory monitoring and management requirements of SGMA, there is little systematic data on groundwater extraction, types of use (e.g., domestic vs. agricultural), or water sources (e.g., groundwater vs. surface water) in these areas. Without mandates for monitoring and reporting, understanding the extent of groundwater extraction, recharge, and overall water use in these areas remains limited. This lack of information poses challenges for statewide water planning and integrated water management.

Limited monitoring and reporting in these basins often stem from the perception that they face fewer sustainability challenges compared to medium- and high-priority basins. While this may be true in many cases, the lack of comprehensive data creates gaps in understanding how water use in these basins interacts with broader regional hydrologic systems, particularly during droughts. This data gap makes it difficult to assess the cumulative impacts of groundwater use on interconnected surface water systems and the long-term sustainability of these basins. Additionally, the absence of detailed records complicates efforts to adapt water management strategies to changing conditions, such as population growth or climate variability.

Additional information from very low- and low-priority basins is expected to become available in the future. As noted in Chapter 2, "Progress Toward Sustainable Groundwater Management," while the formation of a GSA and the preparation of a GSP or Alternative are only required for medium- and high-priority basins, nine very low- and low-priority basins have voluntarily chosen to adopt SGMA's groundwater management framework. Of the state's 515 basins and subbasins, GSPs or Alternatives have been prepared and adopted in 102 basins. As groundwater management continues to take form in the very low- and low-priority basins, more data and information will become available.

Data on water use in non-basin areas, particularly groundwater use, is often limited due to a lack of network of monitoring wells to track groundwater levels, water quality, and groundwater extraction. These areas are often rural or remote, with smaller populations and lower water demand, making investments in water monitoring infrastructure less feasible or incentivized. Additionally, the widespread reliance on private wells, which are generally exempt from metering and reporting, further limits the availability of data.

PUBLIC DRAFT

Regulatory gaps also contribute to the scarcity of data. Non-basin areas are not subject to SGMA, and without this regulatory framework, there is no formal mandate for users to report groundwater extraction data nor to establish sustainable management criteria intended to avoid undesirable results. The absence of local groundwater management entities, such as the GSAs that oversee basins under SGMA, further exacerbates the issue, leaving these areas without dedicated entities to monitor, measure, and manage groundwater use. In some cases, local groundwater ordinances adopted by cities or counties provide a form of oversight, though these vary widely in scope and enforcement.

Finally, the variability of water use in non-basin areas further complicates data collection efforts. Water use in the non-basin areas can be highly seasonal, particularly in agricultural and recreational contexts, and often depends on fluctuating surface water availability or rainfall. This intermittent, rain-dependent usage pattern makes it harder to track trends over time.

Addressing these challenges will require targeted investments in monitoring infrastructure, enhanced regulatory frameworks, and collaborative watershed management efforts to improve understanding of water use in these under-monitored regions.

Until additional monitoring and reporting of water use data in non-SGMA participating low- and very low-priority basins and non-basin areas become available, whether through voluntarily reporting, state assistance, or regulatory changes, the most useful sources for estimating water use in these areas are the statewide land use mapping and water use estimates from the California Water Plan. However, it should be noted that the California Water Plan's water supply and use data are not specifically developed for groundwater basins or non-basin areas. To develop basin versus non-basin estimates, the percentage of agricultural and urban land use is applied to water supply and use data at the hydrologic region scale. The current methodology for estimating water use in non-basin areas is based on general land use categories (i.e., agricultural or urban) and does not consider specific land use types (e.g., individual crop type). To develop basin versus non-basin estimates, percentage of agricultural and urban land use is applied to water supply and use data at the hydrologic region scale.

Further improvements to existing data collection efforts will create opportunities for more accurate estimates of water use in basin and non-basin areas. Enhancing information on water supply sources for all agricultural land use, improving the accuracy and activity status of domestic wells, and fostering greater local

PUBLIC DRAFT

engagement with those who live or work in these areas are significant ways DWR can better understand the challenges and successes in regions not covered by SGMA reporting requirements.

4.3 Groundwater Recharge

The California Water Code WAT § 10721 defines groundwater recharge, or recharge, as "the augmentation of groundwater, by natural or artificial means." As indicated in the Water Code, and further described in this section, recharge to the state's aquifers can result from natural processes, such as infiltration of precipitation or subsurface flow, or from human activity, either intentionally or unintentionally.

The occurrence of natural recharge areas, descriptions of recharge methods, and the infrastructure by which managed aquifer recharge is applied are discussed in detail in Chapter 3, "California's Natural and Built Groundwater Infrastructure." The following subsections discuss the best available information regarding the known volume of recharge that occurs in those settings across the state. The accurate quantification of recharge to an aquifer is essential for understanding inflows to the groundwater system, tracking changes in groundwater storage, and developing a representative water budget. Currently, there is no statewide repository or systematic reporting and tracking of groundwater recharge. However, as the necessity and opportunities for recharge become more apparent in the face of climate-driven weather extremes, the state is working to improve understanding and tracking of recharge, address data gaps, and provide local support and tools for expanding this important groundwater component.

4.3.1 Baseline Recharge

Baseline recharge refers to water that reaches an aquifer through either (1) natural processes, known as natural recharge; or by (2) incidental recharge, which occurs when water is unintentionally recharged into the aquifer due to human activities. Natural recharge occurs through precipitation infiltration across the landscape, floodplain inundation, seepage from surface water bodies, and/or subsurface flow from upgradient recharge areas. Incidental recharge refers to water that reaches the aquifer from human activities such as unlined canals, other conveyance systems, stormwater capture, infiltration from irrigation practices, surface draining wells or dry wells, septic systems, etc. In these cases, recharge may be unintentional and not a primary objective of the activity. However, if recharge from these activities is intentionally enhanced (e.g., deep tilling of ag

PUBLIC DRAFT

lands or fallowed fields) or water is directed to these areas specifically for increased recharge, it can be classified as managed aquifer recharge rather than incidental recharge. Incidental recharge, though unintentional, can be a significant source of recharge to groundwater.

Baseline recharge is difficult to quantify because of variability in precipitation and evapotranspiration (ET), minimal information on land surface and shallow subsurface permeability, and the lack of direct measurements. Hydrologic models currently provide the best available information regarding baseline recharge contributions to groundwater systems; however, these models are generally region-specific and focus primarily on groundwater basins. A statewide model or compilation of data for baseline recharge has not been developed to date. Recent updates to the Fine Grid Version of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSimFG), Sacramento Valley Groundwater-Surface Water Model (SVSim), and the updated Central Valley Hydrologic Model (CVHM2) (see Chapter 3, "California's Natural and Built Groundwater Infrastructure," for details about these models) have improved the accuracy of recharge components in water-balance calculations for the Central Valley and represent the best available data for this type of recharge.

In a recent study, *Groundwater Sustainability and Land Subsidence in California's Central Valley* (Faunt et al. 2024), CVHM2 was used to estimate recharge into the Central Valley aquifers. An annual average of approximately 10.2 maf/yr of total recharge in the Central Valley was estimated by the simulation model for the period between 1962 to 2019. This recharge comes from various sources including: (1) net land-surface recharge (precipitation recharge plus agricultural recharge minus the root uptake of groundwater), (2) small watershed recharge via underflow and runoff, (3) canal seepage, (4) urban water-use recharge, (5) managed aquifer recharge, and (6) net seepage from streams. Modeled annual average recharge for these sources are shown in Table 4-24.

The results indicate that net land-surface recharge accounts for the majority of recharge to the Central Valley, at about 87% of total recharge. Surrounding watersheds contribute about 7% of total recharge, with 3% from underflow (mountain block recharge) and 4% from small watershed runoff in ephemeral or intermittent streams. Recharge from canal seepage, MAR, and urban areas accounts for 5.5%, while net seepage from streams contributes less than 1%. These results show that baseline recharge (sources 1 through 4 and 6 above) is simulated to comprise the majority of groundwater recharge to the Central Valley, approximately 95% of total recharge and estimated at over 9.6 maf.

PUBLIC DRAFT

Table 4-24 Average Annual Recharge Volumes into the Central Valley Modeled by CVHM2 (Faunt et al. 2024)

Recharge Source to Central Valley	Average Percent of Total Recharge	Approximate Average Annual Recharge Volume (af/yr)
Net land-surface recharge (precipitation and agricultural recharge minus root uptake)[2]	87	8,917,700
Underflow from surrounding watersheds (mountain block recharge) [2]	3	340,500
Small watershed runoffs[2]	4	364,800
Net seepage from streams[2]	<1	8,107
Canal seepage, managed aquifer recharge (MAR), and urban recharge	5.5	559,400
Total Recharge (all sources)[1]	**100**	**10,214,800**

Table 4-24 Notes:

1. *The total recharge value in acre-feet is not equal to the sum of recharge volumes in acre-feet of all sources due to rounding and conversion factors. Estimates simulated for the period between 1962 to 2019.*
2. *Sources for baseline recharge.*

In addition to the CVHM2 analysis, the C2VSimFG model provides another regional-scale simulation of groundwater recharge in the Central Valley. While both models estimate total and component recharge, their methodologies and data representations differ in meaningful ways. A summary of C2VSimFG results and a comparison to CVHM2 is presented below.

C2VSimFG is capable of simulating groundwater recharge from a variety of sources. These simulated flows provide valuable insights into groundwater recharge, although they reflect net changes in groundwater storage rather than direct recharge volumes by source. Net flows used to investigate recharge in C2VSimFG include: (1) net flow from the land surface resulting from deep percolation of applied water and precipitation to groundwater and uptake from the root zone (net land surface recharge), (2) net flow from small watersheds along the edge of the model domain and/or reservoirs (boundary inflow), (3) net flow from streams due to streamflow seepage and groundwater discharge into streams and through subsurface tile drains (net streamflow seepage), and (4) recharge due to managed aquifer recharge and seepage from diversions and bypass conveyance (miscellaneous net recharge flow). While these net flows provide an insight into baseline recharge, they do not quantify recharge in its most

PUBLIC DRAFT

rudimentary form: groundwater inflow by source. Rather, these net flows represent the main contributors to increases in groundwater storage by accounting for source-specific groundwater inflows and their opposing outflows.

In its latest release, version 1.5, C2VSimFG estimates an average annual 8.09 maf/yr of total recharge in the Central Valley for water years 1974-2021. Approximately 5.64 maf/yr or 70% is attributed to baseline recharge while 2.45 maf/yr or 30% is attributed to managed aquifer recharge. The largest contributor to baseline recharge is from net land surface recharge, while the smallest is from boundary inflows. Net flows related to baseline and managed aquifer recharge are shown in Table 4-25.

Table 4-25 Average Annual Recharge Volumes into the Central Valley Modeled by C2VSimFG for Water Years 1974-2021

Recharge Source to Central Valley[1]	Average Percent of Total Recharge[5]	Approximate Average Annual Recharge Volume (af/yr)[5]
Net boundary flow	2%	191,630
Net land-surface flow[2]	60%	4,883,785
Net seepage from streamflow[3]	7%	561,633
Miscellaneous net recharge flow[4]	30%	2,452,653
Total[1]	**100%**	**8,089,701**

Table 4-25 Notes:

1. *Net flows represent the main contributors to increases in groundwater storage. These values account for source specific groundwater inflows and opposing outflows.*
2. *Net land surface flow volume is calculated as the total of deep percolation due to seepage of applied water and precipitation minus root water uptake.*
3. *Runoff from the small watersheds along the edge of the model domain is routed to and included in streamflow.*
4. *Miscellaneous net recharge flow is calculated as the total of managed aquifer recharge and seepage from bypass conveyance and diversions.*
5. *Aggregation of percentages and/or volumes of net flows to calculate baseline recharge or aggregation of baseline recharge and managed aquifer recharge to calculate total will not reproduce exactly as reported in Table 4-24 due to rounding errors.*

A comparison of recharge estimates between C2VSimFG and CVHM2 is shown in Table 4-26, highlighting differences in both total and component recharge values. The estimated volume of total recharge for the California Central Valley varies between C2VSimFG version 1.5 and CVHM2. C2VSimFG version 1.5 estimates 2.13 maf/yr less total recharge into the California Central Valley than CVHM2. This

PUBLIC DRAFT

difference accounts for approximately 26% and 21% of the average annual recharge simulated by C2VSimFG version 1.5 and CVHM2, respectively. Additionally, the magnitudes and proportions of the various recharge sources vary between model results. While net land-surface recharge remains the greatest source of recharge between both models, boundary inflows are the smallest contributor for C2VSimFG version 1.5 while net stream seepage is the smallest contributor for CVHM2.

Table 4-26 Differences in recharge estimates between C2VSimFG and CVHM2 for Water Years 1974-2021

Recharge source to the California Central Valley[1]	Differences between models (af/yr)	Percentage of C2VSimFG version 1.5 estimate	Percentage of CVHM2 estimate
Net boundary flow / underflow from surrounding watersheds	148,870	78%	44%
Net land-surface flow[2]	4,033,915	83%	45%
Net seepage from streamflow[3, 4]	-553,526	-99%	-6828%
Small watershed runoffs[4]	NA	NA	NA
Miscellaneous net recharge flow[5]	-1,893,253	-77%	-338%
Total Recharge	**2,125,099**	**26%**	**21%**

Table 4-26 Notes:

1. *Net flows represent the main contributors to increases in groundwater storage. These values account for source specific groundwater inflows and opposing outflows.*
2. *Net land surface flow volume is calculated as the total of deep percolation due to seepage of applied water and precipitation minus root water uptake.*
3. *Small watershed runoff was not readily available for comparison since C2VSimFG version 1.5 routs it to streamflow.*
4. *Miscellaneous net recharge flow is calculated as the total of managed aquifer recharge and seepage from bypass conveyance and diversions. While CVHM2 includes recharge from urban landuse, the estimate calculated by C2VSimFG version 1.5 does not.*

The differences in the simulated estimates of recharge between the two models stems from the distinct ways each model simulates the physical processes and aggregation the flows. For example, the volume estimated for net streamflow seepage is calculated differently between models. C2VSimFG routs small watershed runoff to its streamflows, thus accounting for this within its estimate of streamflow seepage. In contrast, USGS study reports runoff from small watersheds estimated with CVHM2 as an individual flow. Additionally, the USGS study includes recharge from urban landuse within its miscellaneous net recharge

PUBLIC DRAFT

flow while C2VSimFG includes it within its net-land surface flow. As a result, comparing recharge volumes between the USGS study and C2VSimFG is complex and requires appropriate contextulization. This emphasizes that accurate interpretation and effective inclusion of model results into groundwater management benefits greatly from a thorough understanding of both, the composition of the model's simulation and the assumptions and limitations of its results.

In addition to regional-scale modeling approaches, emerging studies are applying novel data sources and remote sensing technologies to further characterize baseline recharge—especially for components that remain difficult to measure directly, such as mountain block recharge. *Mountain front recharge*, which refers to groundwater that flows laterally from an adjacent mountain block and replenishes an aquifer, is particularly difficult to measure and quantify. Faunt et. al. (2024) estimated that there was approximately 340 taf of mountain front recharge, roughly 3% of the total annual average recharge to the Central Valley. In another recent study, *Isogeochemical Characterization of Mountain System Recharge Processes in the Sierra Nevada, California* (Armengol et al. 2024), Armengol et al. used a multi-tool isogeochemical approach to characterize mountain flow paths and mountain system recharge in the northern Tulare Basin, California. End-member mixing analysis results indicate that mountain block recharge originating from the Sierra Nevada, generally as recharge occurring during peak of snowmelt, is a significant recharge component to the valley aquifer, representing 31% to 53% of the valley groundwater composition in this area. This suggests greater hydraulic conductivity than previously thought between the Sierra Nevada and Central Valley (Armengol et al. 2024).

Another study, *Subsurface Water Flux in California's Central Valley and Its Source Watershed from Space Geodesy* (Argus et al. 2022), used Global Positioning System displacement, Gravity Recovery and Climate Experiment (GRACE) gravity data, reservoir water volumes, and snowpack to estimate subsurface water flux (mountain block recharge). This study estimated a total of 40.5 maf/yr of water recharges the Central Valley aquifers each year, with 20 maf/yr from rivers, 13.8 maf/yr from precipitation, and 4 maf/yr from subsurface-water flux (mountain block recharge).

Exciting new research, estimation methods, and models are providing more knowledge and insights on baseline recharge in California than ever before. However, the variability in estimates of mountain front recharge into the Central Valley groundwater system — 3%, 31% to 53%, and 10%, respectively — as

PUBLIC DRAFT

presented in the studies above, highlights the need for continued research and refinement. A deeper understanding of the hydrogeologic processes and physical conditions that contribute to baseline recharge would help to better refine recharge estimates in the future. Since baseline recharge cannot be directly measured, expansion of data collection and monitoring — within both basin and non-basin areas — will be crucial for improving our understanding of recharge mechanisms, particularly for subsurface flow from adjacent non-basin areas into the alluvial aquifer systems.

DWR has been and will continue coordinating and collaborating with multiple entities, such as the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory's GRACE Program, and the United States Geological Survey (USGS), to stay abreast of the best available information for baseline recharge estimates, while also supporting new research in this field. Additionally, DWR is enhancing its existing C2VSimFG model, which will enable more comprehensive estimates for baseline recharge and its impacts on groundwater storage changes across the Central Valley. An improved understanding of broad-scale hydrogeologic changes over time will provide valuable context and insights into regional changes in groundwater storage and key components of the hydrologic cycle, such as baseline recharge.

4.3.2 Managed Aquifer Recharge

Managed Aquifer Recharge (MAR) is water intentionally infiltrated from the land surface or directly injected into an aquifer for replenishment, later use, and/or long-term water resources management. MAR utilizes both the built and natural infrastructure to capture, convey, and store surface water in the aquifers. As discussed in Chapter 3, "California's Natural and Built Groundwater Infrastructure," California's aquifers offer vastly more water storage capacity than all surface water reservoirs combined. MAR has been identified as a key strategy for water supply management and resiliency in California and as a tool to help achieve groundwater sustainability. By capturing excess surface water during wet years and storing it underground for use in dry years, MAR can support long-term water resiliency by partially mitigating the negative impacts of climate-driven extreme weather patterns. In the context of SGMA, MAR can also help to achieve and maintain groundwater sustainability by offsetting groundwater extraction—potentially helping agencies reduce or eliminate impacts associated with various sustainability indicators.

PUBLIC DRAFT

The Newsom Administration's California's Water Supply Strategy set a goal of increasing average annual groundwater recharge by 500,000 acre-feet. Additionally, the California Water Plan Update 2023 identified improving resiliency and reinvestment in California's natural and built State, federal, and regional "backbone" water infrastructure, including expanding opportunities for MAR, as key objectives in California's roadmap to water resilience.

The 2020 study *Managed Aquifer Recharge as a Drought Mitigation Strategy in Heavily-Stressed Aquifers* (Wendt DE et.al. 2021), assessed the impacts of MAR in heavily stressed aquifers in the Tulare Basin. Results of this study indicate that MAR provided both short-term and long-term benefits to groundwater levels and helped to mitigate the impacts of droughts.

MAR can have a significant impact on local agency water budgets. A notable example is the MAR system established by the Orange County Water District (OCWD). The OCWD has a diverse water supply portfolio of 30 percolation basins, levees, and dams to channel Santa Ana River flow for increased percolation, managed wetlands, stormwater capture, and a Groundwater Replenishment System that produces 130 million gallons of high-quality recycled drinking water daily for customer use and aquifer recharges. Combined, these methods resulted in over 90 billion gallons (approximately 276,000 acre-feet) of recharge for fiscal year 2023–2024, which significantly increased the average water supply of the basin (Orange County Water District 2024).

While MAR can be readily measured and quantified, there is no established system for systematic and regular statewide reporting, leading to significant data gaps. Currently, estimating the volume of MAR relies on a combination of data sources, models, and assumptions, making it difficult to develop a comprehensive understanding of recharge across the state. One challenge in measuring and tracking MAR volumes is that the amount of water applied at the ground surface does not necessarily equal the volume that reaches the water table. Water applied to the land surface for MAR may be lost to runoff and ET, or infiltrate and then re-emerge in gaining surface water bodies before reaching the aquifer system. To address this issue, the term "effective recharge" is used in this document to refer to the volume of applied water for MAR that reaches the aquifer system. Generally, this will be equal to MAR volume minus ET and vadose zone lateral flows. An exception to this is direct injection recharge, such as Aquifer Storage and Recovery (ASR). In this method, the effective recharge and MAR volume are equal since the water is being directly added to the aquifer via an injection well and doesn't infiltrate through the vadose zone.

PUBLIC DRAFT

While it is important to know the total volume of surface water diverted for MAR, effective recharge is the more relevant metric for calculating water budgets and determining changes in groundwater storage. For more guidance regarding accounting for recharge in water budgeting, see DWR's *Draft Handbook for Water Budget Development, With or Without Models* (California Department of Water Resources 2020). MAR also depends on the availability of surface water and the ability to divert it. The availability of surface water fluctuates seasonally and from year-to-year and is significantly impacted by climate change and extreme events. It is challenging to understand the potential impacts of climate change and its associated extreme weather patterns, such as atmospheric rivers, on the timing and availability of surface water. However, it is important for local and regional agencies, policymakers, and permitting authorities to consider these impacts when developing effective water management strategies and identifying recharge opportunities.

Estimates on Surface Water Available for Recharge

It is important to note that water available for recharge may be described by different entities in different ways. Some use "water available" to mean all water in a system at a given time, which would be inclusive of appropriated and unappropriated water — in this report, this is called "physical water available." Others, such as the Water Board, consider only unappropriated water as water available — in this report, this is called "legal water available." Due to complexities related to hydrology, water storage and conveyance operations, environmental flow needs, and variable demands and water use, estimating physical and legal water available is challenging. All water availability analysis methods have their limitations and challenges. The following factors contribute to the complexity in understanding water availability:

- Seasonality. Many water rights are only for water use or storage in a portion of the year (e.g., irrigation season).
- Variable demand. Water users may not be using the full-face value of their water right, especially during wet years.
- Start of season reservoir storage. While storage permits are based on the capacity of a reservoir, reservoirs are typically not empty at the start of the wet season. Water in storage is variable year-to-year depending on operating requirements and wetness of preceding year(s).
- Data quality. Actual water use data may be incomplete or inaccurate.
- System operations. Water may be needed to meet other regulatory requirements, such as flow and water quality needs.
- Complex water rights. Multiple water rights may service the same area.

PUBLIC DRAFT

- Water reuse. Water may be used multiple times as it flows through a watershed. For example, water may be stored in a reservoir used for hydropower generation, then released and used downstream to meet environmental flow requirements, then diverted further downstream for irrigation.
- State filings. Water may be held in reserve for future projects and licensing.

In 2018, DWR released the *Water Available for Replenishment* (WAFR) report, the Department's best estimate at the time, based on available information, of physical water available and regional diversion capacities for replenishment of groundwater in the state. The WAFR report estimated 1.5 million acre-feet of surface water may be available statewide for recharging groundwater basins in an average year (California Department of Water Resources 2018).

The WAFR report underscores the high variability in the amount of surface water potentially available for recharge across different hydrologic regions of the state as shown in Figure 4-31. Five of the 10 hydrologic regions account for 90% of the estimated water available for recharge, with the Sacramento River Hydrologic Region alone comprising nearly 45% of the state's total estimated water available for recharge. These findings indicate that hydrologic regions with less surface water available for recharge may need to develop a more diversified portfolio of water supply alternatives.

Figure 4-31 DWR Estimate of Average Annual Surface Water Available for Recharge, by Hydrologic Region

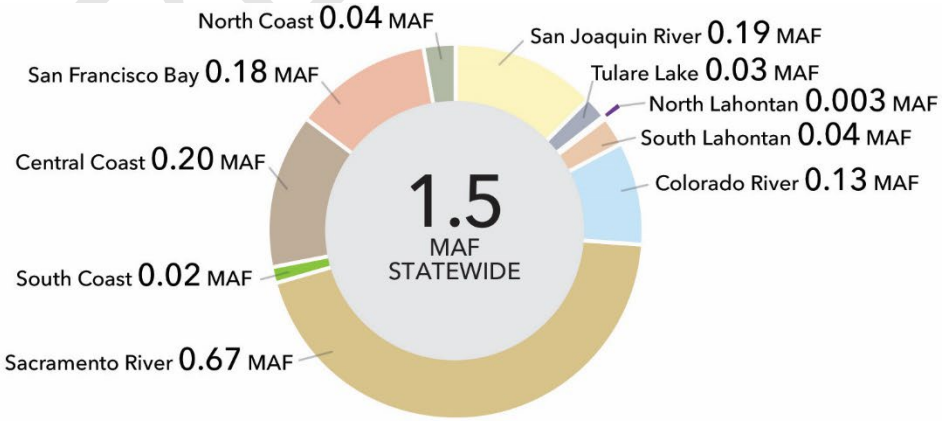


Figure 4-31 Note: maf = million acre-feet.

Since the release of the WAFR report, additional localized efforts to quantify water available for recharge have supplemented its estimates. Proposed Projects and

Management Actions (PMAs) in many GSPs have provided estimates of water available for recharge. Additionally, DWR is currently conducting watershed-scale Flood-MAR reconnaissance studies to assess climate change vulnerability and evaluate Flood-MAR strategies for multi-sector benefits and climate resilience.

The first of these studies was conducted in partnership with DWR and Merced Irrigation District (MID). Climate change projections of the study indicate that increased runoff from winter storm events will result in peak flows exceeding downstream flood thresholds in MID. The study demonstrated that climate change is likely to alter river hydrology, changing both the timing and volume of runoff, and highlighted the role of Flood-MAR in adapting water management strategies in California (California Department of Water Resources 2024a). Additional watershed studies are being conducted by DWR and local partners for all five tributary watersheds of the San Joaquin River, including the Calaveras, Stanislaus, Tuolumne, Merced, and Upper San Joaquin watersheds (which also include Chowchilla and Fresno rivers).

PPIC conducted an analysis of the additional uncaptured water available for recharge in the San Joaquin Valley in 2017 and 2023. PPIC estimated the amount of additional water potentially available for recharge, after accounting for required instream flows and Delta conditions, totaled 5.3 maf in 2017 and 3.5 maf in 2023. However, PPIC notes that capacity limitations of diversion and conveyance facilities likely made high peak flows difficult to capture (Peterson et al. 2024). PPIC subsequently analyzed the estimated additional uncaptured water that was available for recharge in WY 2023 from the Sacramento and San Joaquin rivers. For the Sacramento River, after accounting for required exports, in-Delta use, and Delta outflows, PPIC estimated that an additional 11 maf of water was potentially available for recharge in WY 2023, with 1.8 maf of that total being flood flows (generally able to divert without a water right). The remaining 9.2 maf would generally require a permit from the State Water Resources Control Board (State Water Board) for diversion. For the San Joaquin River, after accounting for minimum instream flows, required outflows for the Delta, exports and in-Delta use, PPIC estimated a total of 3.4 maf was potentially available for recharge in WY 2023, with 1.1 maf being flood flows, 0.6 maf of available water from unused exports, and 1.7 maf of water in the ”trade off space,” which involves required tradeoffs between exporters and upstream diverters, where increases in upstream diversions would require export reductions. The diversions, apart from flood flows, would also generally require a permit from the State Water Board (Peterson et al. 2024).

PUBLIC DRAFT

None of the water availability analyses described above are sufficient to make a finding that unappropriated water is legally available for applying for a new water right, those analyses need to follow State Water Board guidance. What the analyses do indicate is that there are potential opportunities throughout the state to capture water for recharge, particularly during wet years or periods of flooding, such as 2017, 2019, and 2023.

Quantifying the water potentially available for recharge is essential for long term planning, as the necessary infrastructure must be in place to safely capture and convey excess flows during extreme weather events, which could require large diversion and conveyance capacities and facilities that may not be used every year. Additional groundwater recharge planning will be conducted as part of the California Water Plan Update 2028, in accordance with SB 659 of 2023, to "provide actionable recommendations to develop additional groundwater recharge opportunities that increase the recharge of the state's groundwater basins without reducing the amount of water available for environmental purposes or any other purpose allowed under state law." As these weather extremes persist and potentially intensify because of climate change, Californians must remain adaptable and responsive to these changing conditions.

Reported MAR Volumes

DWR is compiling existing and future MAR information into a central repository. This effort will provide a more comprehensive picture of MAR across the state and its impacts on groundwater systems and water management. Although many data gaps remain, SGMA implementation has provided an important first look at MAR activities in many priority groundwater basins throughout the state.

As part of SGMA implementation, GSAs and other local agencies are required to report MAR within their groundwater basins on an annual basis (Department of Water Resources 2024b). SGMA annual reports have been submitted in phases:

- Annual reports for Alternatives and adjudicated basins were first submitted in 2017 for WY 2016.
- Annual reports for 18 critically overdrafted basins and five non-critically overdrafted basins were first submitted in 2020 for WY 2019.
- Annual reports for the remaining SGMA-reporting basins were first submitted in 2022 for WY 2021.

PUBLIC DRAFT

Annual reporting currently provides the most comprehensive information available for MAR in California. Annual MAR volumes, reported in annual reports submitted under GSPs and Alternatives, for WYs 2019 to 2023 are summarized in Table 4-27 and depicted in Figure 4-32. Data from annual reports submitted for adjudicated areas are not included in the tables and figures presented in this section, because these reports typically cover portions of basins or multiple basins, or include non-basin areas, and have various standard reporting periods. The WY 2023 annual report data is the most comprehensive dataset to date, with 93 high- and medium-priority basins reporting — representing approximately 90% of total statewide groundwater extraction — along with seven very low-priority basins. When also considering adjudicated areas within the state, which submit annual reports through a separate process, this brings the total number of reporting basins to 130. These basins collectively account for 98% of groundwater extraction across all 515 basins in California. Receiving this information on an annual basis is a significant step towards DWR's efforts to better understand and track recharge activities in California.

As shown in Table 4-27, WY 2023 had the highest amount of MAR reported, totaling 4,884,847 acre-feet (af), followed by WY 2019 with 2,793,850 af. A comparison of MAR data from these two wet years reveals the following:

- Although 17 basins reported recharge in WY 2019 compared to 25 basins in WY 2023, those same 17 basins accounted for 90% of the total MAR volume in WY 2023.
- These 17 basins recharged an additional 1,597,403 af in WY 2023 compared to WY 2019, representing approximately 1.6 times the volume recharged in WY 2019.
- All but three basins reported increased recharge volumes in WY 2023 compared to WY 2019, with individual basin recharge volumes in WY 2023 ranging from 0.7 times to over 8.1 times that of WY 2019.
- Overall, an additional 2,090,997 af of water were recharged in WY 2023 compared to WY 2019, an increase of about 1.8 times.

PUBLIC DRAFT

Table 4-27 Managed Aquifer Recharge Volumes Reported in GSP and Alternative Annual Reports (Water Years 2019–2023)

Water Year	Statewide Precipitation (inches, % of long-term average)	Number of Basins Submitting Annual Reports	Number of Basins Reporting Managed Aquifer Recharge	Managed Aquifer Recharge Volume (af)
WY 2019	28.4 in, 126%	32	17	2,793,850
WY 2020	15.6 in, 70%	35	16	1,036,204
WY 2021	11.1 in, 50%	94	15	583,040
WY 2022	16.4 in, 73%	99	18	617,965
WY 2023	30.9 in, 138%	100	25	4,884,847

Table 4-27 Notes: Table based on available data from California Natural Resources Agency (CNRA) Open Data as of 09/27/2024 and DWR review of Alternatives to GSP annual report documents. Precipitation based on National Oceanic and Atmospheric Administration (NOAA) Climate at a Glance, compared against 1901-2000 long term average. Drought years include Water Years 2020–2022.

Although more agencies reported recharge in WY 2023 compared to WY 2019, the significant increase in groundwater recharge in WY 2023 is also reflective of the historic levels of precipitation received during that water year. According to California Water Watch, the statewide snowpack on April 1, 2023, was 245% of normal, compared to 161% on April 1, 2019, and statewide precipitation on April 1, 2023, was 150% of average, compared to 127% of average on April 1, 2019. Furthermore, while WY 2023 had only an 18% increase in precipitation compared to WY 2019, a larger portion of that precipitation fell as snow, resulting in a 52% increase in snowpack compared to WY 2019. The increased snowmelt runoff in WY 2023, combined with a cooler than average spring, fed the state's reservoirs, rivers, and canals for a longer period of time, creating more opportunities for diversions for recharge.

Compared to WY 2022, which was a drought year, eight additional basins reported recharge for WY 2023 that had not reported recharge in WY 2022. An additional 4,266,882 af of water were recharged in WY 2023, which is about eight times the volume recharged in WY 2022. Individual basin recharge volumes in WY 2023 ranged from 1.05 times to over 188 times that of WY 2022. The weather whiplash experienced between the critically dry WY 2022 and the record-setting wet WY 2023 demonstrates the importance of being prepared for extreme weather. This preparedness allows basins to take advantage of extreme wet conditions to alleviate impacts from extreme dry conditions. Additionally, climate change

PUBLIC DRAFT

projections indicate that precipitation in the future may fall less as snow and more as rain, which may have implications for the timing and duration of water available for recharge.

Figure 4-32 presents the GSPs and Alternatives annual report recharge volumes for each reporting basin for WYs 2019 through 2023, normalized by basin area. The Central Valley accounts for a majority of the state's recharge, with the largest recharge amounts occurring in the San Joaquin Valley. In WY 2023, the San Joaquin Valley accounted for over 4.1 maf of recharge, which is about 84% of the state's total recharge. For more detailed information about the GSP managed aquifer recharge volumes for WY 2023, see the *California's Groundwater Conditions Semi-Annual Update: May 2024* (California Department of Water Resources 2024c).

PUBLIC DRAFT

Figure 4-32 Managed Aquifer Recharge per Acre by Basin Reported in GSP and Alternative Annual Reports (Water Years 2019-2023)

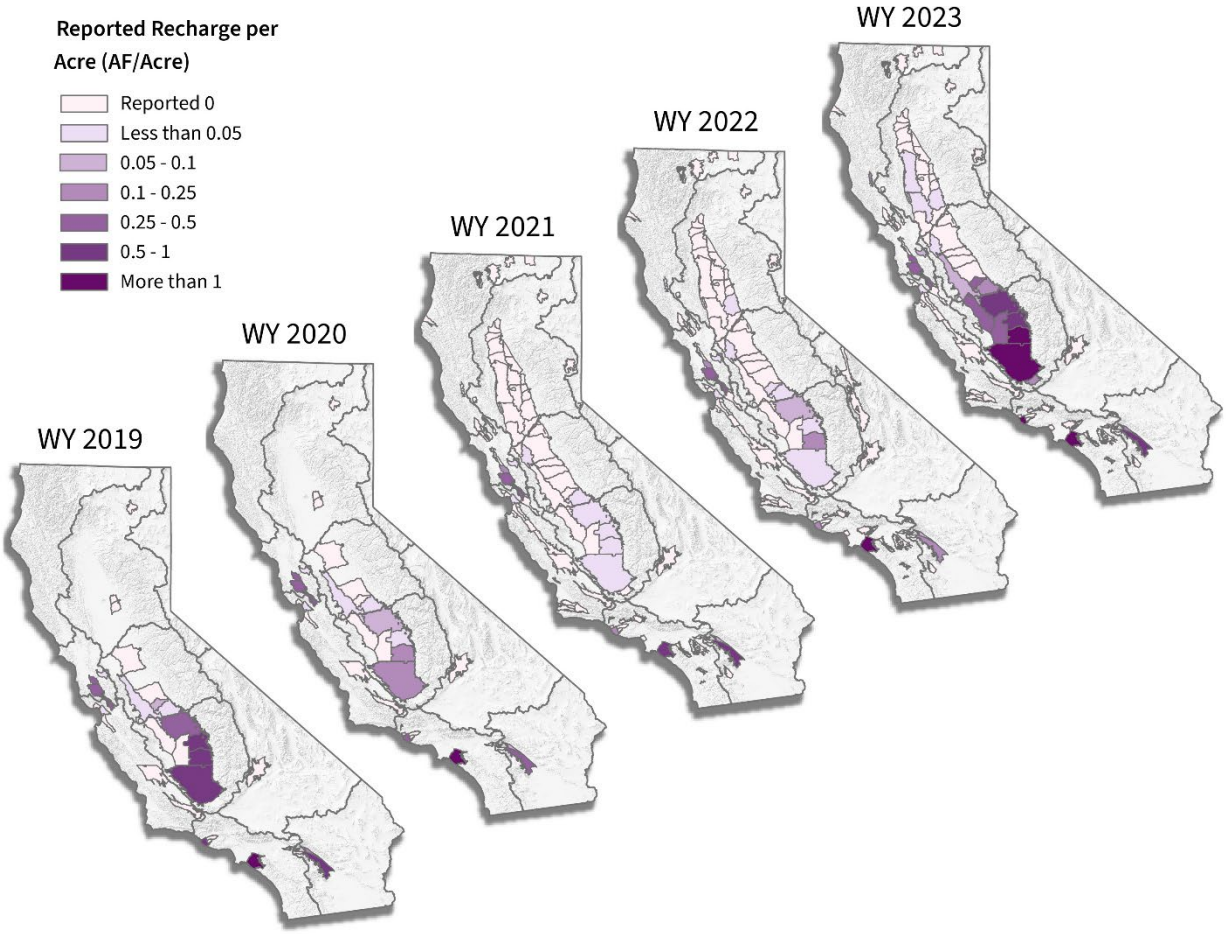


Figure 4-32 Note: Figure based on available groundwater recharge data from California Natural Resources Agency (CNRA) Open Data as of 09/27/2024 and DWR review of Alternative to GSP annual report documents.

Figure 4-33 and Table 4-28 show total reported GSP and Alternative MAR volumes for WYs 2019 through 2023 across the state's 10 hydrologic regions. Tulare Lake Hydrologic Region reported the highest total groundwater recharge for WY 2019–2023, with approximately 6.8 maf, and about 69% of total recharge for the period. The hydrologic regions with the next highest reported total MAR volumes are respectively South Coast Hydrologic Region at about 1.5 maf (15.3%), Colorado River Hydrologic Region at almost 812 taf (8.2%), San Francsico Bay Hydrologic Region at about 439 taf (4.4%), and San Joaquin River Hydrologic Region at about 197 taf (2.0%).

Although the Tulare Lake and South Coast hydrologic regions reported the highest volumes of recharge each year, other hydrologic regions experienced the greatest expansion in recharge activity. The San Joaquin River Hydrologic Region showed the largest increase in recharge activity, with a 484% increase from about 28 taf in WY 2019 to over 162 taf in WY 2023. Similarly, recharge in the San Francisco Bay Hydrologic Region increased by about 40 taf during the same period, representing a 61% increase. The San Joaquin Valley, which includes the San Joaquin River and Tulare Lake hydrologic regions, reported 7 maf of recharge between WYs 2019 and 2023, accounting for 71% of the total statewide recharge during that period. In WY 2023 alone, the San Joaquin Valley recharged over 4.1 maf, representing 84% of the total reported recharge for that year.

Figure 4-33 Managed Aquifer Recharge Volumes by Hydrologic Region Reported in GSP and Alternative Annual Reports (Water Years 2019-2023)

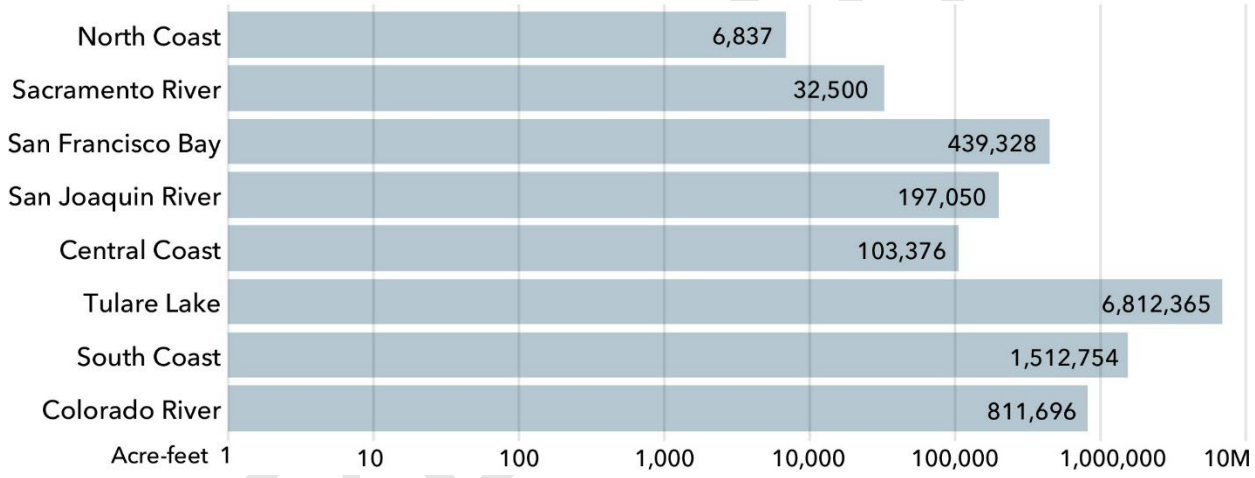


Figure 4-33 Notes: Figure based on available groundwater recharge data from California Natural Resources Agency (CNRA) Open Data as of 09/27/2024 and DWR review of Alternatives to GSP annual report documents, shown in Table 4-28. Hydrologic regions that reported zero MAR are not shown.

PUBLIC DRAFT

Table 4-28 Managed Aquifer Recharge Volumes by Hydrologic Region Reported in GSP and Alternative Annual Reports in Acre-Feet (Water Years 2019–2023)

Hydrologic Region (HR)	WY 2019	WY 2020	WY 2021	WY 2022	WY 2023	HR Total	Percent of 5-Year Total
North Coast	0	0	0	1,467	5,370	6,837	0.1%
San Francisco Bay	83,128	81,808	65,091	86,239	123,062	439,328	4.4%
Central Coast	23,107	22,632	17,272	19,701	20,664	103,376	1.0%
South Coast	313,572	328,259	227,562	237,920	405,441	1,512,754	15.3%
Sacramento River	0	0	0	200	32,300	32,500	0.3%
San Joaquin River	27,797	3,257	719	2,805	162,472	197,050	2.0%
Tulare Lake	2,075,075	492,803	109,638	194,147	3,940,702	6,812,365	68.7%
North Lahontan	0	0	0	0	0	0	0.0%
South Lahontan	0	0	0	0	0	0	0.0%
Colorado River	271,171	107,445	162,758	75,486	194,836	811,696	8.2%
Total	**2,793,850**	**1,036,204**	**583,040**	**617,965**	**4,884,847**	**9,915,906**	100.00%

Table 4-28 Notes: Table based on available groundwater recharge data from California Natural Resources Agency (CNRA) Open Data as of 09/27/2024 and DWR review of Alternatives to GSP annual report documents. Data only represents those basins that submit annual reports.

The large volumes of water recharged in WY 2023 also reflect the collaborative efforts of federal, State, and local agencies and landowners to expedite high flow diversions, facilitate and implement recharge projects, and maximize the use of existing natural and built groundwater infrastructure. These efforts capitalized on the opportunity to capture the high flows for recharge, far surpassing the California's Water Supply Strategy goal of expanding annual recharge by 500,000 af by more than 13 times.

Recharge activities vary considerably across California, influenced by a range of physical, hydrologic, and institutional factors. As discussed in Chapter 3, "California's Natural and Built Groundwater Infrastructure," the hydraulic

PUBLIC DRAFT

connection between the ground surface and aquifer is a key determinant to recharge, along with the availability of excess surface water — often from storm events, snowmelt, or flood flows — and the infrastructure needed to divert and deliver that water to recharge areas. Effective implementation depends on the existence of conveyance systems — such as canals, pipelines, and distribution networks — to transport water from its source to these recharge sites. When implemented effectively, MAR can reduce downstream flood risks, mitigate land subsidence, improve water quality, support groundwater-dependent ecosystems, and help sustain agricultural productivity. However, these benefits are only realized where hydrologic opportunity, physical conditions, and infrastructure align — highlighting the highly site-specific nature of MAR across California.

State-Enhanced Recharge Efforts

The intense flooding in WY 2023 and the heightened flood risk in several areas of the state resulted in the activation of emergency response by federal, State, and local agencies to protect communities. Governor's Executive Orders N-7-23, N-4-23, and N-6-23 expedited diversions from waterways for flood risk reduction and groundwater recharge by clarifying that diversions of high flows for flood management can be used to recharge aquifers. DWR and local agencies worked together to leverage existing conveyance, diversion capacity, and resources to divert as much excess water as possible from the local river systems and away from vulnerable communities at risk of flooding or experiencing active flooding.

A reported 401,317 af of floodwater was diverted under the Executive Orders for flood risk reduction and groundwater recharge onto 92,070 acres of land. Figure 4-34 shows the points of diversion and parcels reported to the State Water Board where floodwater was diverted and recharged. It is likely that much of the recharge that occurred under the Executive Orders is captured in the annual report data submitted under GSPs and Alternatives; however, there were many diversion points and parcels that are in the low- or very low-priority basins of Owen’s Valley, Rose Valley, Fremont Valley, and Antelope Valley. Except for Owens Valley. which does submit annual reports, the remaining three basins are not required to submit annual reports. Additionally, some diversion points were located in the high priority basin of Indian Wells Valley; however, no MAR was reported for this basin in the WY 2023 annual report data. The reported recharge from diversions in these areas —approximately 244,030 af — is in addition to what was documented in the WY 2023 annual reports. This means that the actual total recharge in WY 2023 is 5,127,877 af, which is greater than the total shown in Table 4-28 based on just data from annual reports.

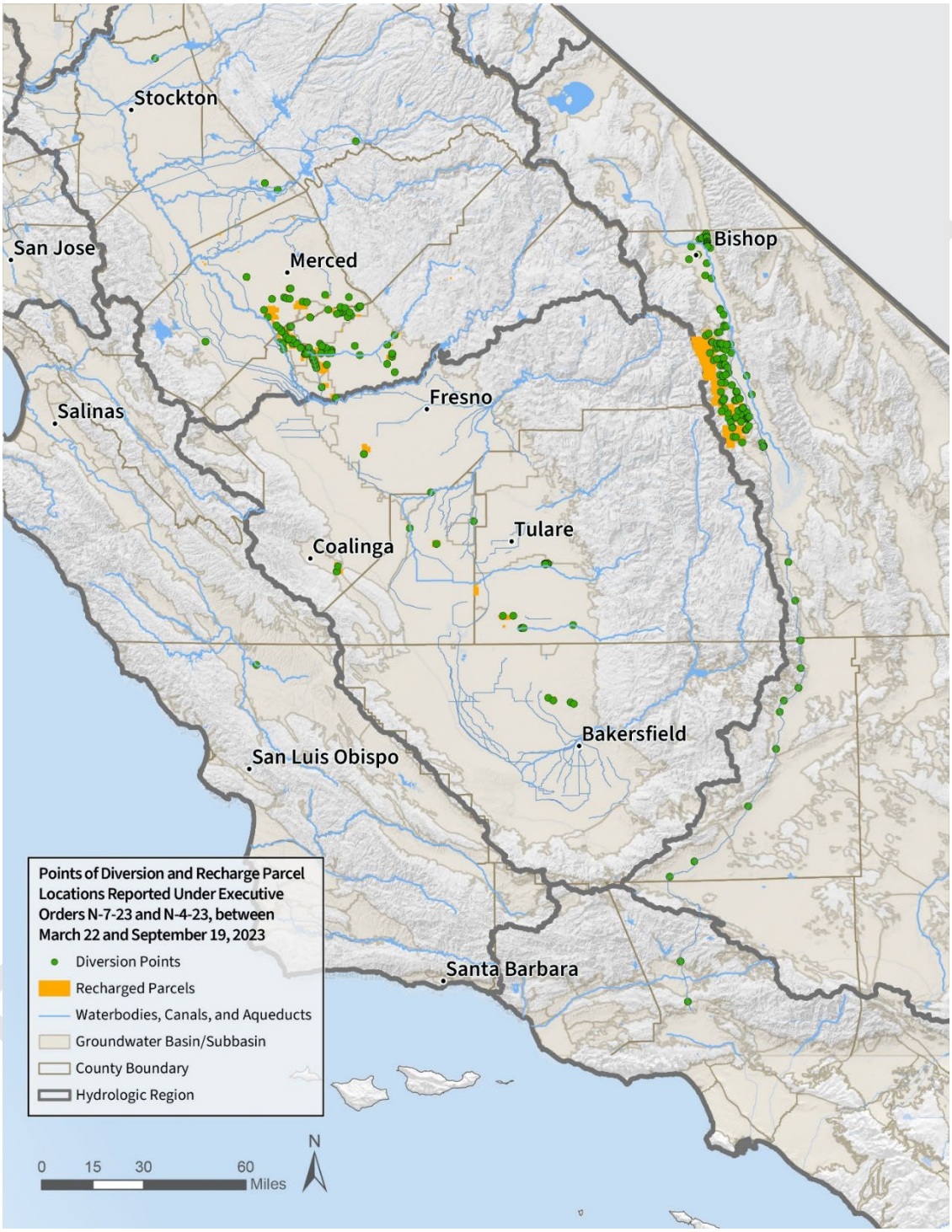
PUBLIC DRAFT

The abundance of surface water in WY 2023 led to more agencies initiating recharge activities and demonstrated the importance of local readiness to adapt and seize opportunities to capture high flows for recharge when available. Local agencies that had developed recharge programs and coordinated with local landowners were able to take advantage of wet conditions in 2023 to increase recharge efforts. For example, Madera County was well positioned to divert local high flows for recharge in 2023 because of advance planning and identification of landowners willing to flood their fields for recharge. Over 84 points of diversion in Madera County recharged just over 73,000 af of floodwater through executive orders in 2023 — Madera County had the largest response in the Central Valley to the executive orders due to their early planning and landowner outreach.

The Executive Orders also called for collaboration between State agencies to expedite permitting and coordination with local agencies. In WY 2023, the State Water Board issued 10 temporary permits authorizing diversion of a total of 669,353 af of surface water for recharge. Additionally, the State Water Board granted a Temporary Use Change Permit to the U.S. Bureau of Reclamation (Reclamation), allowing up to 602,182 af in additional diversions for recharge in the San Joaquin Valley. Between WYs 2019 and 2023, a total of 29 temporary permits were issued with a combined diversion capacity of 1,100,384 af. However, during this period, only 31,383 af of water were actually diverted.

PUBLIC DRAFT

Figure 4-34 Points of Diversion and Groundwater Recharge Parcel Locations Reported under Executive Orders N-7-23 and N-4-23, between March 22 and September 19, 2023



In response to the extensive outreach and feedback received from local agencies during the flood emergency, DWR launched the 2023 Temporary Flood Diversion Equipment and Recharge Enhancement Emergency Effort (further described in Chapter 2, "Progress Toward Sustainable Groundwater Management"). The effort provided 30 temporary pumps to six local agencies in the San Joaquin Valley to divert more flood water from local waterways for groundwater recharge. Over 11,000 af of diversions for groundwater recharge were reported under this effort, which is likely captured in the annual report data submitted under GSPs and Alternatives. DWR also assisted local agencies in land clearing by removing 291 acres of orchards and vineyards, which prepared the land to receive future floodwater for groundwater recharge, reducing the local district's flood risk and increasing recharge capacity. A follow-on initiative, the Flood Diversion and Recharge Enhancement program, is currently in progress supporting an additional 14 contracts for flood diversion and groundwater recharge activities such as temporary pump purchase and rental, temporary recharge basin repair and construction, temporary conveyance installation, and land clearing. The participating local agencies in the 2023 Emergency Effort and 2024 Flood Diversion and Recharge Enhancement Initiative are summarized in Figure 4-35 and Tables 4-29 and 4-30.

PUBLIC DRAFT

Figure 4-35 Participating Local Agencies in the 2023 Temporary Flood Diversion Equipment and Recharge Enhancement and follow-on Flood Diversion and Recharge Enhancement Initiative

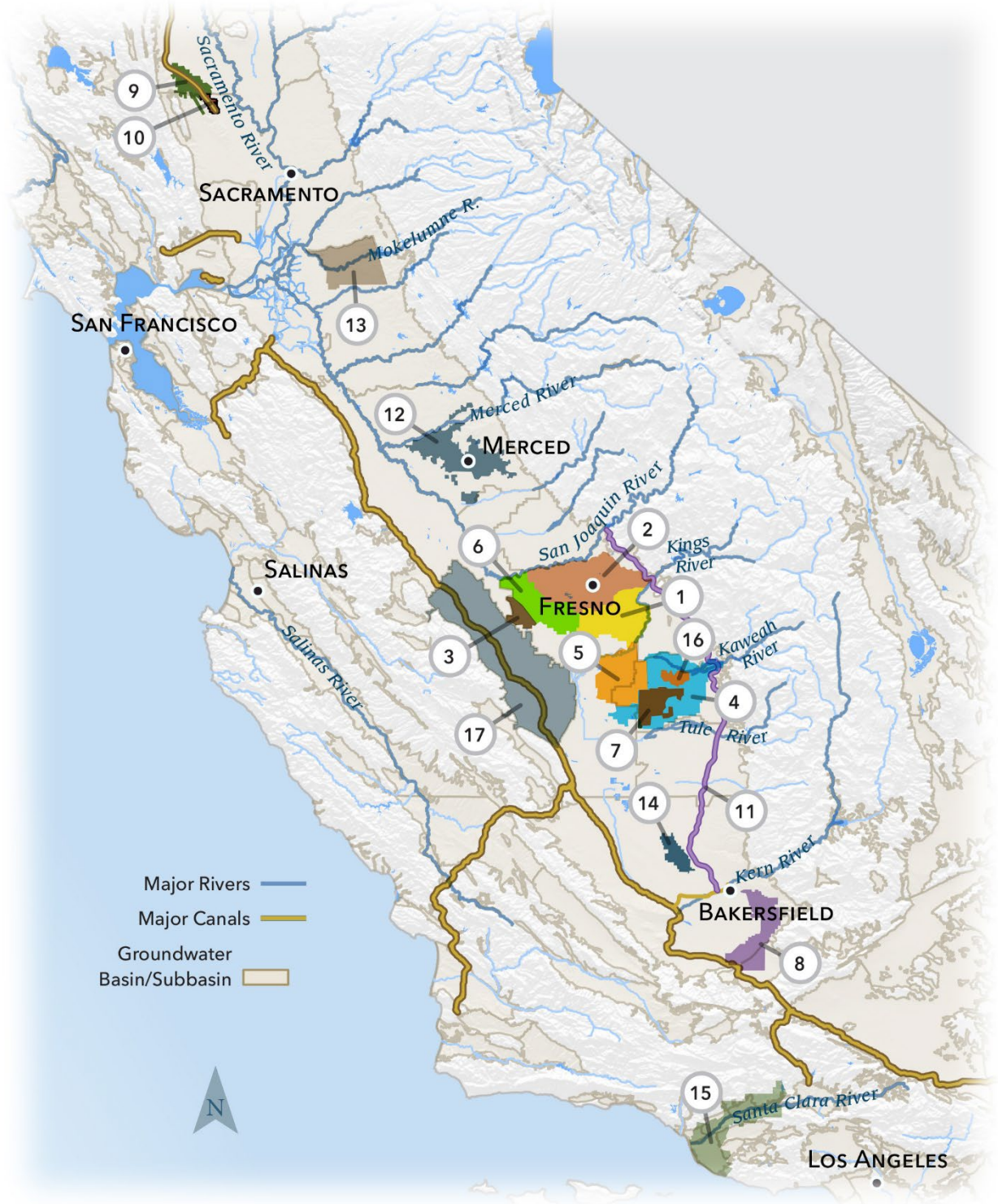


Table 4-29 2023 Temporary Flood Diversion Equipment and Recharge Enhancement Effort

Local Agency of District Name	Temp Flood Diversion	Land Clearing	Total Units Completed	Figure 4-35 Reference
Consolidated Irrigation District	—	Yes	197 acres	1
Fresno Irrigation District	Yes	—	1 pump, 1 siphon	2
James Irrigation District	Yes	—	1 pump	3
Kaweah Delta Water Conservation District	Yes	Yes	3 pumps, 91 acres	4
Kings County Water District	Yes	—	5 pumps	5
McMullin Area Groundwater Sustainability Agency	Yes	Yes	16 pumps, 80 acres	6
Tulare Irrigation District	Yes	—	4 pumps	7

Table 4-30 Flood Diversion and Recharge Enhancement Initiative Projects, 2024 to 2026

Local Agency or District Name	Temp Flood Diversion	Land Clearing	Temp Flood Basins	Temp Conveyance Enhancements	Figure 4-35 Reference
Arvin-Edison Water Storage District	Yes	—	Yes	Yes	8
Colusa County Water District	Yes	—	Yes	—	9
Consolidated Irrigation District	Yes	Yes	Yes	—	1
Dunnigan Water District	Yes	—	—	—	10
Fresno Irrigation District	—	Yes	Yes	—	2
Friant Water Authority	Yes	—	—	Yes	11
Kaweah Delta Water Conservation District	Yes	—	—	—	4

PUBLIC DRAFT

Local Agency or District Name	Temp Flood Diversion	Land Clearing	Temp Flood Basins	Temp Conveyance Enhancements	Figure 4-35 Reference
Merced Irrigation District	Yes	—	—	—	12
North San Joaquin Water Conservation District	Yes	—	—	—	13
Shafter-Wasco Irrigation District	Yes		Yes	—	14
Tulare Irrigation District	Yes	—	—	—	7
United Water Conservation District	Yes	—	—	—	15
City of Visalia	—	Yes	—	—	16
Westlands Water District	—	Yes	—	—	17

In July 2023, Senate Bill 122 codified many provisions of the flood diversion Executive Orders into the California Water Code (CWC) Section 1242.1. This statute allows parties to divert flood waters for groundwater recharge without a water right under certain conditions. Similar to the Executive Orders, CWC Section 1242.1 places requirements on the location and timing of diversions and mandates reporting of all diversions to the State Water Board and the appropriate GSA. A summary of the diversions resulting from these State-enhanced groundwater recharge diversion efforts during WY 2023 is shown in Table 4-31.

PUBLIC DRAFT

Table 4-31 Water Year 2023 State-Enhanced Diversions for Flood Risk Reduction and Recharge

State-Enhanced Diversion Pathway	Reported Diversions (acre-feet)	Permitted Capacity (acre-feet)	Data Source
Diversions under Executive Orders	401,317	Not applicable	Governor's Executive Orders N-7-23 & N-4-23 For Flood Diversion
Water Code § 1242.1	0	Not applicable	Flood Recharge Diversions (Water Code §1242.1)
State Water Board Temporary Permits — Underground Storage	20,031	669,353	Pending Temporary Permits for Underground Storage
State Water Board Temporary Use Change Petition — United States Bureau of Reclamation	20,677	602,182	Temporary Urgency Change Petitions
DWR's 2023 Temporary Flood Diversion Equipment and Recharge Enhancement Effort	11,161	Not applicable	Participating Local Agency Reporting. See DWR's Groundwater Recharge for additional information.
Total	**453,186**	**1,271,535**	**—**

In January 2025, Governor Newsom issued Executive Order N-16-25 to facilitate the capture and storage of water from atmospheric river storms in Northern California. This order streamlined the process for diverting flood flows for groundwater recharge by waiving certain requirements under Water Code Section 1242.1, thereby enabling local agencies to act more swiftly in response to flood conditions. As a result, in February and March 2025, the Dunnigan Water District and Rancho Murieta Community Services District became the first local agencies to implement flood diversions under the streamlined provisions, effectively enhancing groundwater recharge efforts during the flood events.

Ongoing State support, enhancement, and streamlining of local recharge efforts, like those described above, are critical for achieving California's long-term water resiliency goals and adapting to climate-driven weather extremes.

Groundwater Banking Volumes

Groundwater banking in California is a key strategy for managing water supply (see Chapter 3, "California's Natural and Built Groundwater Infrastructure," for

PUBLIC DRAFT

additional details). It involves intentionally recharging aquifers by diverting and storing surface water underground during wet periods for withdrawal and use in dry periods. This practice helps mitigate the effects of climate variability, supports sustainable groundwater management, and provides a critical buffer against water shortages. Many groundwater banking programs operate in California through partnerships between water agencies, farmers, and local governments, leveraging existing infrastructure such as percolation basins and injection wells.

Modeled data for ten major water banks in the Central Valley for WYs 1961 to 2019 show a cumulative groundwater recharge volume of approximately 11.3 million acre-feet (Bond et al. 2023). It is likely that groundwater banking activities are now being reported under SGMA implementation and are reflected in the annual MAR volumes.

Other MAR Estimates

Managed aquifer recharge volumes have also been estimated using local agency surveys. In the wet years of 2017 and 2023, which followed multi-year droughts, the PPIC surveyed urban and agricultural water management agencies in the San Joaquin Valley about their groundwater recharge activities, challenges, and perspectives (Hanak et al. 2018 and Peterson et al. 2024). In 2017, 66 out of 81 agencies responded, with 46 agencies reporting groundwater recharge projects and 20 reporting none. Reported on-site active groundwater recharge for 2017 totaled 3.4 maf (not including in-lieu recharge; see next section for discussion of in-lieu recharge), with an additional 0.5 maf banked off site through partnerships within the Central Valley. PPIC then conducted a regression analysis to estimate groundwater recharge volumes for the agencies that did not report groundwater recharge or respond to the survey. The regression analysis produced a rough estimate of total valley-wide on-site groundwater recharge at 6.5 maf, with an additional 0.9 maf of off-site banked recharge (Hanak et al. 2018).

In 2023, of the 128 local agencies that responded to the survey, 59 provided groundwater recharge estimates, with 11 reporting no groundwater recharge activity. The total reported on-site active groundwater recharge in 2023 was 4 maf (not including in-lieu recharge). Similar to 2017, a regression analysis was performed to estimate groundwater recharge volumes for agencies that either did not report recharge projects or did not respond to the survey. The analysis produced a rough estimate of 7.6 maf for total valley-wide on-site groundwater recharge in 2023, representing a 17% increase from 2017 (Peterson et al. 2024).

PUBLIC DRAFT

In-Lieu Recharge

As discussed in Chapter 3, "California's Natural and Built Groundwater Infrastructure," in-lieu recharge occurs when surface water is provided to groundwater users, thereby leaving groundwater in the aquifer that would have otherwise been extracted. In-lieu recharge is not explicitly identified in GSP annual report data; however, in the previously discussed 2017 and 2024 PPIC surveys of San Joaquin Valley water managers, in-lieu recharge was identified by local agencies as a significant method of groundwater recharge in their basins, second only to dedicated groundwater recharge basins. In-lieu recharge was reported to account for nearly a quarter of the total groundwater recharge volumes, at an estimated 0.8 maf in 2017 and 1.3 maf in 2023; however, tracking of this method of recharge was inconsistent (Peterson et al. 2024).

Urban Recharge

Urban groundwater recharge sources, such as stormwater capture and recycled water, are also not explicitly reported in GSP annual reports, but were included in PPIC surveys. Neither stormwater capture nor recycled water were identified as groundwater recharge sources in 2017, but both were reported as sources in 2023. Stormwater basins were reported to contribute 0.1 maf to total recharge in 2023. Recycled water was reported by 8% of respondents in 2023, compared to none in 2017. Although the relative volumes of these sources were small compared to other water sources, first-time reporting indicates a growing interest in exploring additional opportunities for groundwater recharge in different settings (Peterson et al. 2024).

In addition to the PPIC surveys, groundwater recharge is also reported through Urban Water Management Plans (UWMPs). Groundwater recharge as a use sector for the purposes of UWMP reporting refers to the managed and intentional replenishment of natural groundwater supplies using man-made systems like infiltration basins or injection wells. Water used for groundwater banking or storage may also be reported in this way. If that water is pumped back out in the same year, it is then counted as a groundwater supply, either as a wholesale or retail demand. While this reporting framework helps track intentional recharge activities, the volumes reported under this sector in UWMPs are typically very small. As a result, UWMPs are not a major source of information on groundwater recharge when compared to other reporting tools, such as those required under the SGMA.

PUBLIC DRAFT

In-lieu and urban groundwater recharge are also being utilized in other areas of the state, but tracking remains inconsistent, lacks centralization, and presents significant data gaps.

4.4 Water Accounting in California's Groundwater Management

The California Water Code Section 10721 defines water budget as an accounting of the total groundwater and surface water entering and leaving a basin including the changes in the amount of water stored. Water budgets are one of the most fundamental tools for effective groundwater management. As a quantitative accounting of a designated area's inflows, outflows, and change in storage over a specific period, water budgets provide critical insights that empower groundwater managers to make informed and effective decisions. By systematically quantifying water supplies and users, water budgets help identify trends, assess variability, and guide management strategies.

Within the framework of SGMA, water resources accounting serves a pivotal role in planning and achieving sustainable groundwater management. GSAs are required to include comprehensive water budget as part of their GSPs. A water budget enables GSAs to assess historical and current conditions, identify data gaps, analyze seasonal and long-term impacts of management actions on water supplies and demands, and evaluate the interdependence of various hydrologic components. The water budget also assists in estimating sustainable yield, defining sustainable management criteria, and development and implementation of management actions and projects. By integrating these insights into GSP planning and implementation, water budgets support proactive and adaptable groundwater management that enhances long-term water resilience.

Water budget development can be challenging because of the quantity and quality of data required. While measured data is preferred, historical data is often scarce or unavailable. This scarcity is due to past funding constraints, difficulties in monitoring, or lack of incentives for data collection. Additionally, known errors can significantly undermine a dataset's reliability, and inadequate documentation may limit the ability to adequately account for measurement error. As a result, groundwater managers are often required to estimate rather than rely solely on field measurements.

Some water budget components can be estimated analytically by defining and discretizing an area of interest using physical boundaries, selecting representative

PUBLIC DRAFT

hydrogeologic parameters, and applying a governing flow equation with appropriate boundary conditions. For example, many of the water budget components are interrelated with each other and domains of the hydrologic cycle (e.g., root zone, surface water). This added complexity, combined with the uneven spatial variability among water budget components, introduces uncertainty related to scale and the timing of interactions.

When and where historical data is unavailable and analytical methods are deemed to be insufficient for handling high degrees of spatial and temporal variability, groundwater managers often estimate missing data using numerical models. These models typically account for groundwater flows, surface water flows, and their interactions and are often called integrated hydrologic models or groundwater models.

Integrated hydrologic models (also referred to as a numerical model) are highly effective for groundwater management and planning. Beyond analyzing historical water supply and demand trends and their impact on groundwater resources and the environment, these models can also be used to develop and evaluate management strategies in response to potential future change(s). For example, potential shifts in water demand in an area can be incorporated into a model to simulate the effects of population growth and land use changes, while changes in water supply can be modeled to assess the impacts of regulatory requirements and climate change. This makes the numerical model a powerful tool for evaluating impacts of groundwater projects. Additionally, a numerical model can be used to assess potential management strategies and actions before implementation, such as:

- Conjunctive water use practices.
- Direct and indirect recharge.
- Fallowing.
- Supply augmentation.
- Water recycling.
- Water use efficiency improvements.

As a result, a numerical model offers a scientifically defensible approach to optimize groundwater management strategies and estimate quantitative benefits through development of water budgets and application of water accounting. However, integrated hydrologic models have their limitations. Their complexity and often extensive data requirements can be resource-intensive and demand

PUBLIC DRAFT

specialized expertise. Consequently, a variety of analytical and modeling approaches have emerged over the years to meet California's water accounting needs. Regardless of the method used, proponents of sustainable water management, like the PPIC, have long advocated for the inclusion of water accounting into groundwater management. PPIC has recommended that local agencies should: "Improve groundwater accounting, including groundwater allocation and recharge crediting systems, to incentivize both demand reduction and supply enhancement" (Spencer et al. 2024). This recommendation has been well received by the California Legislature and water managers. As a result, water accounting, in its many forms, has found itself deeply embedded in the state's groundwater management practices.

4.4.1 Groundwater Accounting Applications in California

The passage of SGMA has reinvigorated California's attention to water accounting. However, SGMA is not the State's sole legal motivation for incorporating water accounting into groundwater management. Initially, water accounting was leveraged to support court rulings and adjudications on groundwater rights and groundwater management in specific areas. Applications of groundwater accounting in California predated SGMA by nearly a century, beginning with the adjudication of the Lytle Basin in 1924.

An overview of legislatively mandated applications of groundwater accounting is presented below along with a summary of the State and federal operations and studies that incorporate groundwater accounting.

Groundwater Accounting in Adjudicated Areas

Water accounting in adjudicated areas is conducted under the jurisdiction of a court, with a judge overseeing the adjudication process. Decisions are based on evidence such as hydrogeological studies, historical water use, land ownership, and other relevant data. The court establishes each party's groundwater extraction rights. Once the adjudication is finalized, the court typically appoints a Watermaster to oversee and enforce the adjudication terms and conditions to ensure compliance; however, in some cases, a watermaster may not be appointed.

Water accounting in adjudicated areas, if required by the court, typically involves systematically tracking groundwater extraction, recharge, and storage to ensure compliance with court-established rights and adjudication objectives. Many adjudicated basins incorporate mechanisms such as storage or recharge credits,

PUBLIC DRAFT

which can be banked, traded, or used to offset future groundwater pumping, providing greater operational flexibility. In most adjudicated areas, watermasters monitor groundwater levels, extraction, storage, and quality, compiling annual reports that detail compliance and water management activities in the adjudicated area. These reports, along with other relevant documents, are typically submitted to the court as part of its ongoing oversight.

Groundwater Accounting for Legislative Regulatory Compliance

Water accounting plays a critical role in ensuring compliance with legislative and regulatory requirements, providing a framework for tracking water use, promoting transparency, and supporting sustainable water management practices.

AGRICULTURAL WATER MANAGEMENT PLANS

California's Senate Bill X7-7, also known as the Water Conservation Act of 2009, requires that agricultural water suppliers who serve more than 25,000 irrigated acres — and those serving between 10,000 and 25,000 irrigated acres when sufficient State funding is available, prepare and adopt an Agricultural Water Management Plan (AWMP). These plans must be submitted to DWR and updated on a five-year basis. DWR is responsible for reviewing these plans and for reporting on plan compliance to the California Legislature.

Each AWMP must identify the agricultural water supplier and its service area, describe the quantity and quality of water resources, include an annual surface water budget, analyze the effect of climate change on future water supplies, outline past water management activities, set objectives, identify efficient practices, quantify water use efficiency, and present a drought response plan. The annual surface water budget must quantify all inflows and outflows within the supplier's service area. Inflows include effective precipitation, groundwater pumping, and surface inflows, while outflows include deep percolation, ET, and surface outflow. Additionally, annual surface water budgets must be reported on a water year basis.

The first AWMPs were due by December 31, 2012, followed by updates in 2015 and 2021. The next updates are due in 2026. The coverage area by those agencies that submitted plans represents 37% of the state's agricultural land.

URBAN WATER MANAGEMENT PLANS

In 1983, the California Legislature enacted the Urban Water Management Act, which required that every water supplier who provides water for municipal purposes to a minimum of 3,000 customers or 3,000 connections, or supplies at

PUBLIC DRAFT

least 3,000 acre-feet of water annually, to prepare and adopt an Urban Water Management Plan (UWMP). Urban water suppliers are required to submit UWMPs to DWR no later than 30 days after adoption and update them every five years. DWR is responsible for reviewing UWMPs and reporting to the California Legislature on the status of these plans and their contingency strategies for water shortages.

Each UWMP must include a comprehensive set of elements ranging from water supply analysis to water-related energy requirements. Key elements include:

- A description of the service area.
- An assessment of annual water demands and supplies including a breakdown of water use by sector.
- A discussion on potential water exchanges and/or transfers.
- An explanation of water demand management measures.
- A summary of water-related energy demands.
- An evaluation of developing desalinated and/or recycled water.
- A contingency plan for managing water shortages.

Through the quantification of water supplies and sector-specific water uses, UWMPs provide water suppliers and managers with a clear understanding of a service area's vulnerabilities and potential resources to address climatic change, as well as the seismic vulnerabilities of the area's water distribution system. As a result, UWMP's water accounting has played a pivotal role in managing California's urban water resources.

The first UWMPs were submitted for 1985 and have been updated every five years thereafter. The most recent UWMPs were prepared for 2020. In this update, DWR identified 438 water suppliers who are required to submit an UWMP. Of these, 417 suppliers (approximately 95%) submitted a plan. The next updates, for 2025, are due by July 1, 2026 (California Department of Water Resources 2023).

THE SUSTAINABLE GROUNDWATER MANAGEMENT ACT

With the passage of SGMA in 2014, the California Legislature established the requirement for local agencies and communities to form GSAs to sustainably manage the state's high- and medium-priority groundwater basins. SGMA requires that GSAs adopt a plan for reaching long-term sustainability within 20 years — known as either groundwater sustainability plans (GSPs) or Alternatives to GSPs

PUBLIC DRAFT

(Alternatives). These plans are submitted to DWR for evaluation of its compliance with the DWR's GSP Regulations (California Code of Regulations, Title 23).

GSPs must include water budgets for historical, current, and projected conditions and provide a total accounting of groundwater and surface water inflows and outflows to and from the basin or subbasin. Surface water and groundwater inflows must be reported by water source type while groundwater outflows must be reported by water use sector. The water budgets must also quantify the annual change in groundwater storage and must investigate if overdraft occurred during historical and current conditions. Additionally, the plans are required to define water year types associated with annual demand, supply, and change in groundwater storage, and to provide an estimate of sustainable yield for their respective basin or subbasin.

California Water Code (CWC) Section 10721 defines sustainable yield as "the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result."

GSP Regulation Section 354.24 requires that a GSA "establish in its Plan a sustainability goal for the basin that culminates in the absence of undesirable results within 20 years of the applicable statutory deadline. The Plan shall include a description of the sustainability goal, including information from the basin setting used to establish the sustainability goal, a discussion of the measures that will be implemented to ensure that the basin will be operated within its sustainable yield, and an explanation of how the sustainability goal is likely to be achieved within 20 years of Plan implementation and is likely to be maintained through the planning and implementation horizon."

As defined in the CWC and directed for use as indicated in the GSP Regulations, the sustainable yield is an estimate of the amount of water that can be withdrawn annually without causing an undesirable result. GSAs can use the estimate to identify the measures that will be implemented to operate the basin within its sustainable yield to reach the sustainability goal. Development of the sustainable yield is informed by a historical analysis of a groundwater basin's inflows and outflows, along with specific groundwater conditions, such as changes in groundwater levels and storage, seawater intrusion, the presence of water quality constituents of concern, land subsidence, and depletions of interconnected surface water.

PUBLIC DRAFT

By February 2024, 130 GSPs and Alternatives were submitted for 102 unique very low-, low-, medium-, and high-priority groundwater basins. A brief description of water accounting for these GSPs is provided below.

SPATIAL AND TEMPORAL COVERAGES IN GSPS

The spatial coverage and discretization of water budgets varies among GSPs and Alternatives. Of the 130 GSPs and Alternatives included in this investigation, 92, or approximately 71%, were found to include water budgets that they described as covering the entirety of their groundwater basin. Of those 92, 15, or approximately 16%, also provided additional water budgets aggregated to sub-area levels within their groundwater basins. The remaining 37, or 28%, described their water budgets as providing partial coverage of their respective basins.

Similar to spatial coverage, GSP water budget temporal coverage varies significantly. While GSAs submitted GSP water budgets for historical, current, and projected conditions, this investigation focused on historical water budgets. GSP water budgets for historical conditions were required to consist of either a 10-year minimum or a period of sufficient length to calibrate models and reduce uncertainty in developing water budgets and aquifer responses for projected conditions (California Code of Regulations, Title 23). GSP historical water budget periods ranged from 10 to 94 years. The earliest included year was 1921 with the most recent being 2021.

While all GSP historical water budgets exceed the 10-year minimum temporal coverage, this investigation was unable to determine if all historical period ranges were sufficient to adequately calibrate models (when modeling was applied) and reduce uncertainty in forecasting future water budgets and aquifer response. Furthermore, the temporal scale used in GSP historical water budgets was also found to vary significantly. While statistics were not calculated, historical water budgets temporal scales were found to include water budget flow term values reported at monthly and annual timesteps, as well as for average values for the entire historical period.

WATER BUDGET DEVELOPMENT METHODS IN GSPS

The 130 GSPs and Alternatives used various analytical tools and numerical models in the development of their water budgets:

- Numerical models were used to develop water budgets in 96 groundwater basins while analytical tools were used in eight — this includes three groundwater basins that used a combination of both methods. Sufficient

PUBLIC DRAFT

information to determine which method was used was not found for one groundwater basin (San Gabriel Valley). Refer to Figure 4-36.

- Thirty-two groundwater basins relied on a numerical model from the DWR. Specifically, 28 used some application of the Integrated Water Flow Model (IWFM) and/or IWFM Demand Calculator (IDC) — 17 of which used a version of DWR's California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) or the Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim) models — both of which are applications of IWFM and IDC. Of the remaining four groundwater basins, two used the Integrated Groundwater and Surface-Water Model (IGSM) while CALSim II (CALSim) and California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW) were each used in a single groundwater basin. Refer to Figure 4-37.
- Sixty-seven groundwater basins relied on a numerical model from the USGS. Specifically, one used the Basin Characterization Model and 66 used some version of MODFLOW. Of the 66 which used MODFLOW, seven groundwater basins also relied on the use of the Precipitation Runoff Modeling System. Refer to Figure 4-38.
- Notably, three groundwater basins used numerical models from both DWR and the USGS: Eel River Vally, San Joaquin Valley-Delta Mendota, and Ukiah Valley. While all three groundwater basins relied on a version of MODFLOW, Eel River Valley and Ukiah Valley used a combination of an unspecified version of MODFLOW with the Precipitation-Runoff Modeling System (PRMS), while San Joaquin Valley-Delta Mendota used MODFLOW-NWT. In terms of DWR tools, all three used different numerical models: Eel River Valley used Cal-SIMETAW, San Joaquin Valley-Delta Mendota used an unspecified version of C2VSim, and Ukiah Valley used IDC.

PUBLIC DRAFT

Figure 4-36 Methods used to Develop Water Budgets in GSPs and Alternatives

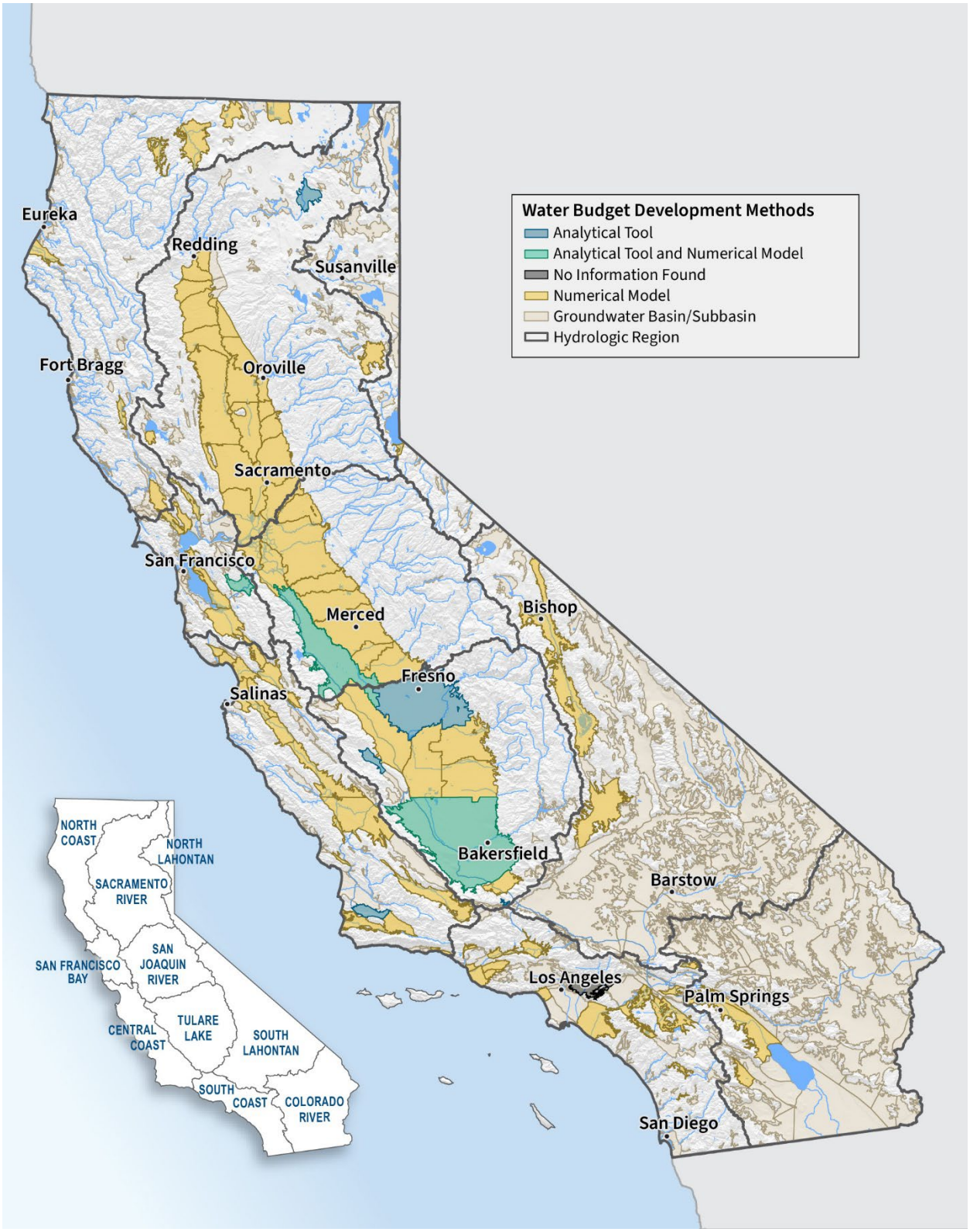


Figure 4-37 DWR Tools Used to Develop Water Budgets in GSPs and Alternatives

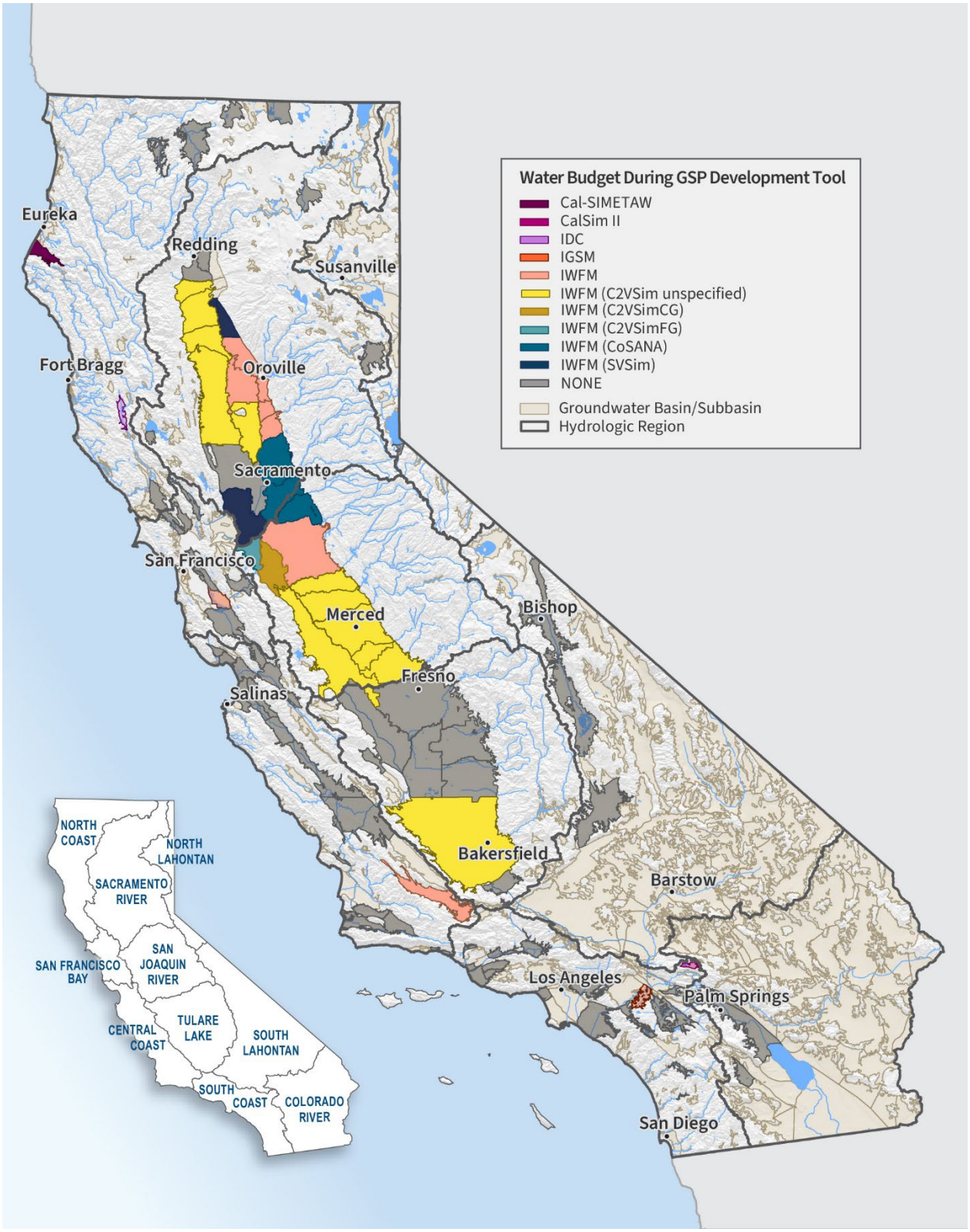
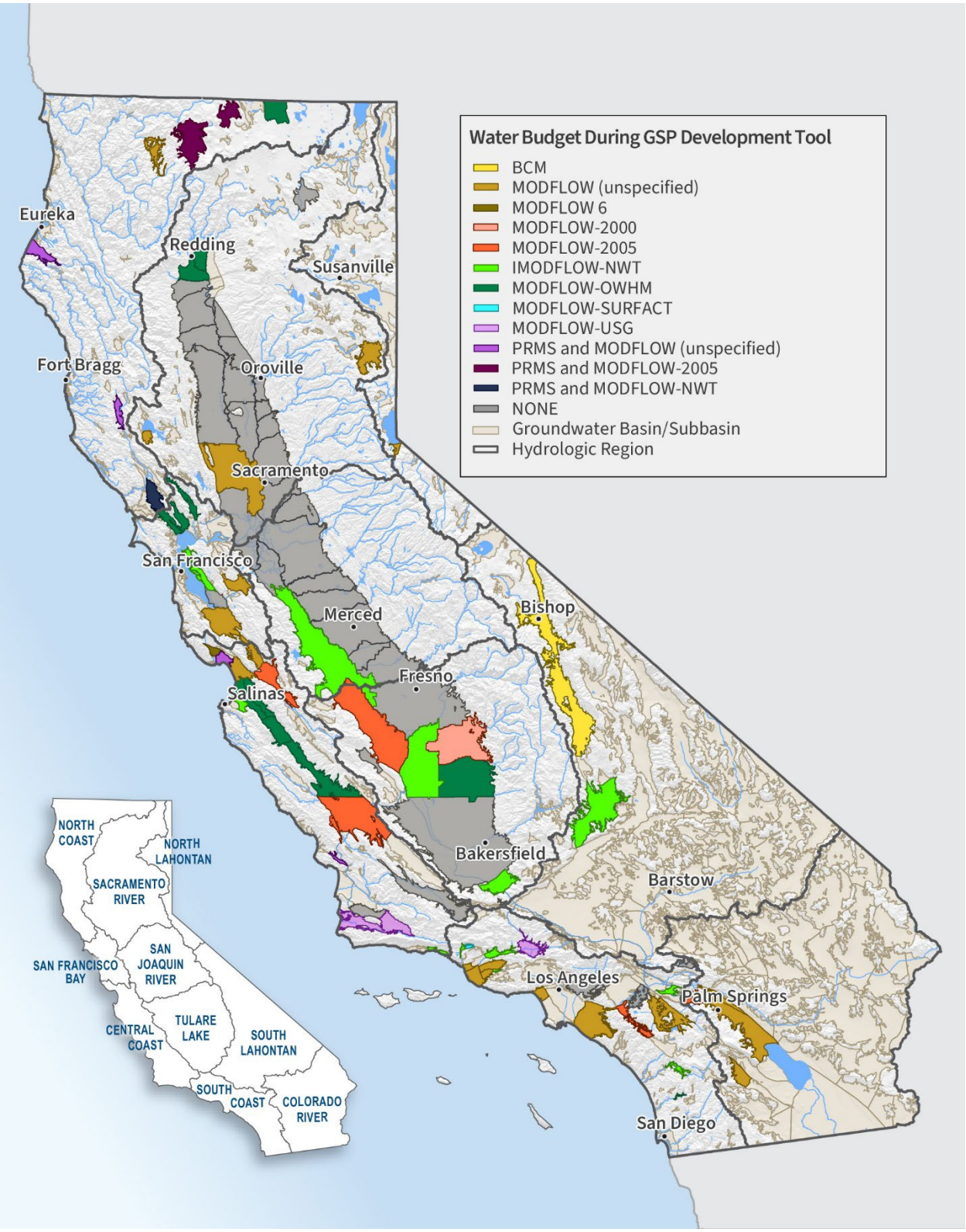


Figure 4-38 USGS Tools Used to Develop Water Budgets in GSPs and Alternatives



SUSTAINABLE YIELD AND CHANGE IN STORAGE

Sustainable yields from GSP and Alternative submissions were aggregated and compiled in Table 4-32 and are presented by hydrologic region. While 14 GSPs reported a range of sustainable yields, the remaining provided a single approximate value. Sustainable yield values for each basin are taken as either the single approximate value or the average of the reported range. A total 12.3 maf of sustainable yield was reported by GSAs that submitted a GSP or Alternative. This value is not representative of an estimate for statewide sustainable yield. Sustainable yield values provided in GSPs and Alternatives serve as an effective goal for sustainable groundwater management by linking the avoidance of undesirable results directly to groundwater pumping; however, there are considerations for the use of an aggregate of these values for statewide consideration. An aggregate value has some limitations. It underrepresents pumping by not including pumping in all portions of medium- and high-priority basins, low- or very low-priority basins, or areas outside of designated groundwater basins. It also may over-represent pumping in the basins that have calculated it, as some of the reported values are for basins that have been deemed inadequate.

Table 4-32 also includes the reported groundwater extraction volumes in taf for both a dry year (WY 2022) and wet year (WY 2023), sourced from annual report data submitted under GSPs and Alternatives. When comparing these extraction values to the sustainable yield values, some insights can be drawn. In WY 2022 (dry) the aggregated groundwater extractions exceeded the aggregated sustainable yield by 5.4 maf. The Central Valley hydrologic regions accounted for 88% of the sustainable yield exceedances. In WY 2023 (wet) aggregated groundwater extractions were 1.7 maf less than the aggregated sustainable yield. Change in storage for other years is discussed further in Chapter 6, "Groundwater Conditions."

PUBLIC DRAFT

Table 4-32 Sustainable Yield Reported in GSPs and Alternatives by Hydrologic Region

Hydrologic Region	Number of Basins Reporting	GW Basin Area (1,000 ac)	Reported Sustainable Yield[1] (taf)	Groundwater Extraction WY 2022[2] (dry) (taf)	Groundwater Extraction WY 2023[2] (wet) (taf)
North Coast	7	664	277	234	184
San Francisco Bay	7	532	195	161	131
Central Coast	19	1,834	794	935	859
South Coast	22	967	363	584	503
Sacramento River	21	4,248	3,083	3,724	2,461
San Joaquin River	10	3,642	3,306	4,456	3,023
Tulare Lake	9	4,990	4,218	7,186	2,828
North Lahontan	1	15	41	5	6
South Lahontan	2	1,042	8	119	19
Colorado River[3]	4	447	22	303	289
Basins with GSPs and Alternatives to GSPs	102	18,380	12,307	17,707	10,304

Table 4-32 Note:

1. *Reported sustainable yield are from GSPs and Alternatives submitted as of 07/29/2024.*
2. *Groundwater extraction data are from annual report data submitted under GSPs and Alternatives as of 08/19/2024.*
3. *Alternatives to GSPs for Coachella Valley Indio and Mission Creek basins did not include a quantified assessment of sustainable yield and are not included in this table.*

THE CALIFORNIA WATER PLAN AND WATER BUDGETS

The California Water Plan (CWP) is the State of California's strategic plan for sustainably managing and developing water resources for current and future generations. It presents the status and trends of California's water-dependent natural resources; water supplies; and agricultural, urban, and environmental water demands, covering the historical record from 1998 and projecting a range of plausible future scenarios. The CWP, updated and published every five years, includes water balances for agricultural areas, managed wetlands, surface water,

PUBLIC DRAFT

and urban areas, enumerating various inflows and outflows at different geospatial scales on a water year basis.

Since 1998, the CWPs Water Supply and Balance Team has collected, compiled, and maintained water balance data to characterize current conditions in accordance with CWC 10004. As the foundation of the CWP, this dataset provides the most detailed published data for statewide water supply and use. It estimates the balance between water supply and consumption, focusing primarily on the relationship between water sources and users in California.

Each water balance in the CWP is a simplified water budget for a specific water year, based on the analyses of developed and dedicated water supplies, sector-specific water use, water reuse, operational characteristics, and inflows and outflows within study areas above the root zone. The water balance data accounts for most, but not all, land system components. While the surface water supply used in the land system is well documented, groundwater use data is limited in large portions of the state and must be estimated by subtracting reuse and surface water supply from total water use.

The latest CWP update was Update 2023, which was released in 2024; the next update is scheduled for 2028.

Groundwater Accounting-Related State-Led Studies

WATER BALANCE TO WATER BUDGET PILOT STUDY

In 2022, DWR conducted an initial water balance to water budget pilot study. As part of the study, DWR mapped data from the CWP water balances to water budget components, using a pilot area in Merced County. This mapping was made consistent with the common vocabulary and water accounting templates of DWR's draft *Handbook for Water Budget Development: With or Without Models.*

The pilot study generally concluded that there is insufficient information on surface water and groundwater components to complete a comprehensive water budget for a CWP planning area. Without supplemental data and information from other sources, such as stream gage data, river water balances, and modeling results, the accuracy of water balance data related to the surface water and groundwater systems cannot be fully assessed. With new data streams now becoming available through SGMA implementation, the pilot study was revisited to determine whether these new data streams could improve the estimation of water budgets. Both GSPs and annual reports were evaluated for their potential to enhance the water budget information.

PUBLIC DRAFT

The review of GSPs provided the following key insights:

- Limited availability of annual data: Most water budget values are reported as average values for a range of years or grouped by water year type, rather than for individual years. This lack of annual water budget data severely limits the ability to analyze year-to-year groundwater conditions and develop water budgets for specific years. However, in cases where GSPs relied on model-generated water budget data, there was generally sufficient information to complete a water budget with major terms and mass balance errors within an acceptable margin.
- Challenges in combining water budget data across multiple GSPs: When multiple GSPs cover a single groundwater basin, integrating their data can be challenging. Some GSPs were found to use different terminology for their water budget flow components, and some report conflicting flow estimates, even when describing the same flow.
- Difficulties in developing water budgets for partial basin areas: Given the variation in water demand and supply across groundwater basins in California, developing accurate water budgets for partial areas is challenging unless water budgets are specifically reported for those areas or greater detail is provided for the individual flows. For example, this pilot study was unable to produce a water budget for one of its three subareas due to its overlap with a portion of the Eastern San Joaquin Subbasin and the lack of sufficient data to accurately develop a water budget for the partial area.

The review of the GSP Annual Report data provided the following key insights:

- Availability of annual data allows for water balance calculations for specific years.
- Most available data pertain to water use, with supply data often directly matching use, indicating a focus on developed supply rather than total supply.
- Reported data include changes in storage, groundwater extraction by water use sector, surface water supplies by source, and total water supply and use by source and sector. Key water budget terms tied to physical processes (e.g., precipitation, streamflow, runoff, return flows, and subsurface flows) are not provided. As a result, groundwater system balancing is not possible due to the lack of groundwater recharge estimates. The annual reports for 2021 documented 18.7 maf of groundwater extraction. Of this volume, 23.4% was measured through metering or electricity demand, while the remaining 76.6% was estimated primarily using land-use-based methods.

PUBLIC DRAFT

Discrepancies exist within individual annual reports, where the sum of reported values does not always match the stated total.

- "Total water use" figures in annual reports do not always match the reported surface water supply and groundwater extraction values.

4.4.2 Water Accounting Resources

To support the development of water budgets for compliance with SGMA, DWR develops and provides resources essential for integrated hydrologic models and water budgets. These resources include guidance documents, modeling-related datasets, the Groundwater Accounting Platform, and IWFM platform along with Central Valley-specific and Sacramento Valley-specific model applications. A brief description of these resources is provided below.

Guidance Documents

DRAFT HANDBOOK FOR WATER BUDGET DEVELOPMENT: WITH OR WITHOUT MODELS

The Draft Handbook for Water Budget Development: With or Without Models (available under the Reports tab) provides the California water resources community with a resource for water budget development using hydrologic models or analytical methods. Specifically, the Draft Water Budget Handbook presents a comprehensive water budget framework (Figure 4-39), decision trees to guide water budget development, an accounting template, case studies, and a data resources directory.

PUBLIC DRAFT

Figure 4-39 Total Water Budget

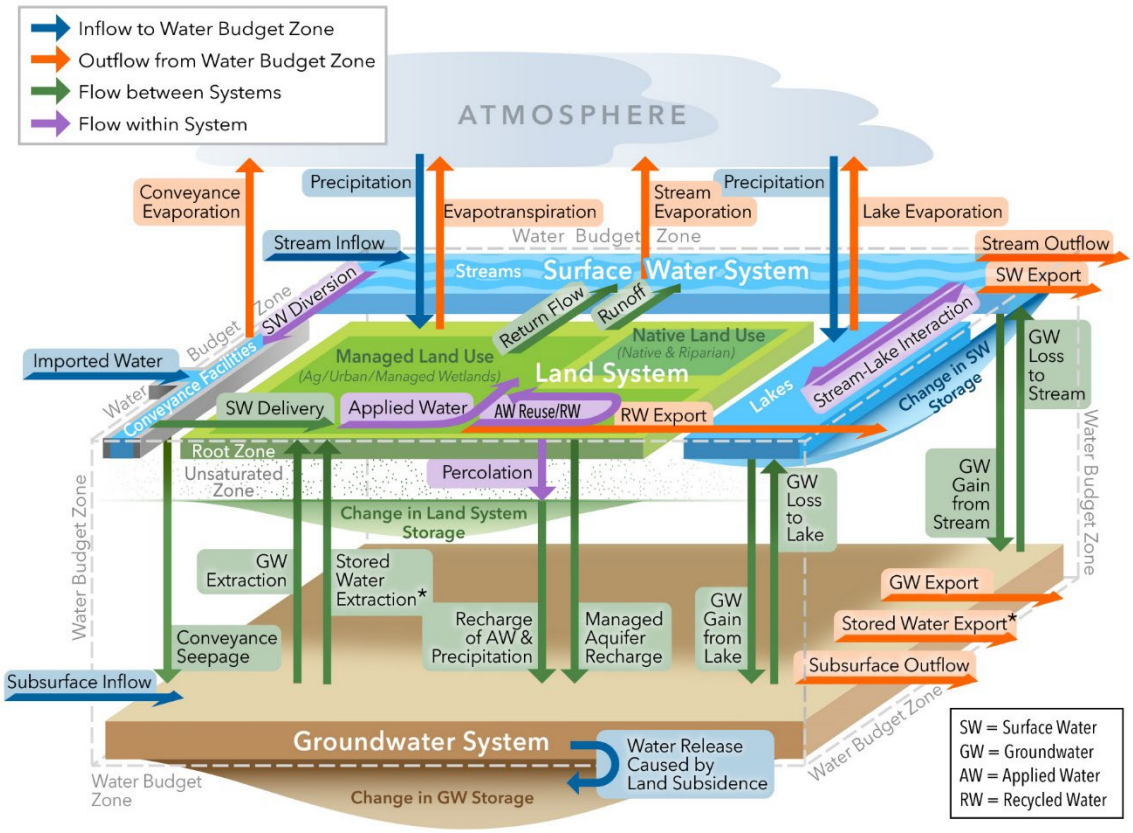


Figure 4-39 Note: Source: CA DWR's draft Handbook for Water Budget Development: With or Without Models.

SGMA BEST MANAGEMENT PRACTICES

With the passage of SGMA, DWR was directed by the Legislature to publish best management practices (BMPs) for the sustainable management of groundwater. In response, DWR published six BMPs, of which three are related to water budgets and modeling:

- BMP 3 Hydrogeologic Conceptual Model.
- BMP 4 Water Budget.
- BMP 5 Modeling.

State-Supported Data Resources Commonly Used in Water Accounting

State-supported data resources play a crucial role in water accounting by providing reliable datasets, tools, and platforms that help water managers track, analyze, and manage water supply, use, and sustainability in compliance with

PUBLIC

SGMA and other regulatory frameworks. Brief descriptions of these are provided below.

CALIFORNIA DATA EXCHANGE CENTER DATABASE SYSTEM

The California Data Exchange Center (CDEC), managed by DWR, collects, stores, disseminates, and exchanges hydrometeorological data and related information. Specifically, information on atmospheric pressure, humidity, rain, snow, stream stage and flow, temperature, and wind speed are collected from numerous sensors owned by federal, State, and local agencies. This data enables forecasters to prepare flood forecasts and water supply forecasts, reservoir and hydroelectric operators to schedule reservoir releases, and water suppliers to study historic water availability and forecast water availability. In the context of Integrated Hydrologic Modeling, this dataset has the potential to inform many hydrologic processes. Currently, over 140 agencies provide data to CDEC and also obtain data through CDEC's cooperative hydrologic database.

CDEC WATER YEAR TYPE DATASET

The CDEC Water Year Type Dataset consists of water year type hydrologic classifications based on measured unimpaired runoff for the Sacramento and San Joaquin valleys. Water year type classifications cover WYs 1906 through 2023 and 1901 through 2023 for the Sacramento and San Joaquin valleys, respectively.

CALIFORNIA GEOLOGIC ENERGY MANAGEMENT DIVISION DATA

California's Department of Conservation, the California Geologic Energy Management Division (CalGEM) uses science and sound engineering practices to regulate the drilling, operation, and permanent closure of energy resource wells. As part of its regulatory responsibility, CalGEM collects oil, gas, and geothermal well and extraction data. Additionally, it also collects downhole geophysical logs, oil and gas well completion reports, data on brine injections (i.e., waste disposal), periodic water level measurements, and conducts geochemical analyses of brine/connate/formation waters. To support improved electronic data management and transparency, CalGEM has increased the availability of online data applications in recent years.

DWR LAND USE ESTIMATES

For many years, DWR has collected land use data throughout the state and used this information to develop water use estimates for statewide and regional planning efforts, including water use projections, water use efficiency evaluation, groundwater model development, and water transfers. These data are essential for regional analysis and decision-making, which has become increasingly important

PUBLIC DRAFT

as DWR and other State agencies seek to address resource management issues, regulatory compliance issues, environmental impacts, ecosystem services, urban and economic development, and other issues. These efforts have resulted in the development of the County Land Use Survey Dataset which provides temporal coverage spanning WYs 1986 through 2015.

In turn, the county land use surveys were used to develop the Regional Crop Mapping Dataset which combines data from several counties to produce regional land use surveys for the California Bay Delta for WYs 2015 and 2017.

Increased availability of satellite imagery, aerial photography, and new analytical tools make remote sensing-based land-use surveys possible at a field scale that is comparable to that of DWR's historical ground-based field surveys. Current technologies allow accurate, large-scale crop and land-use identification to be performed at desired time increments and make possible more frequent and comprehensive statewide land-use information. Responding to this need, DWR sought expertise and support for identifying crop types and other land uses and quantifying crop acreages statewide using remotely sensed imagery and associated analytical techniques, which resulted in the creation of the Statewide Crop Mapping Dataset. Currently, statewide crop maps are available for WYs 2014, 2016, 2018–2021 and provisional statewide crop maps for 2022 and 2023.

The County Land Use Survey Dataset, Region Crop Mapping Dataset, and the Statewide Crop Mapping Dataset can be accessed through the CA DWR Land Use Viewer Browser-Based Application.

OPENET EVAPOTRANSPIRATION DATA

OpenET, a non-profit initiative, develops satellite-based estimates of actual evapotranspiration (ET) data for improved water management across the western United States. Data is available at the field scale for millions of individual fields or at the original quarter-acre resolution of satellite data. Actual ET data is currently available for six satellite-based models and a single "ensemble value" calculated from those models.

SGMA CLIMATE CHANGE RESOURCES

The GSP Regulations require GSAs to use projected water budgets to estimate future baseline conditions of supply, demand, and aquifer response to GSP implementation, and to identify the uncertainties of these projected water budget components. To better characterize future baseline conditions and account for potential deviations due to anticipated stressors, GSAs are required to use

PUBLIC DRAFT

projected data for climate change, population, population growth, and sea level rise from DWR or other data of comparable quality. To that end, DWR released the SGMA Climate Change Resources to aid GSAs in accounting for climate change under projected conditions.

The SGMA Climate Change Resources include processed climate change data related to climatology, hydrology, and water operations. The climatological data provided are change factors for precipitation and reference evapotranspiration gridded over the entire state. The hydrological data consists of projected stream inflows for major streams in the Central Valley and streamflow change factors for areas outside the Central Valley and smaller ungaged watersheds within the Central Valley. The water operations data provided are Central Valley reservoir outflows, diversions, State Water Project and Central Valley Project water deliveries, and select streamflow data. Most of the Central Valley inflows and all the water operations data were simulated using the CalSim II Model and produced for all projections.

Data are provided for projected climate conditions centered around 2030 and 2070. The climate projections are provided for these two future climate targets and include one scenario for 2030 and three scenarios for 2070: a 2030 central tendency, a 2070 central tendency, and two 2070 extreme scenarios (i.e., one drier with extreme warming and one wetter with moderate warming). The climate scenario development process represents a climate period analysis where historical interannual variability from January 1915 through December 2011 is preserved while the magnitude of events may be increased or decreased based on projected changes in precipitation and air temperature from general circulation models.

SGMA DATA VIEWER

DWR's SGMA Data Viewer provides access to groundwater related datasets that are organized by the requirements of SGMA and the GSP regulations for the purpose of supporting GSP development and implementation.

Specifically, the SGMA Data Viewer provides access to information under the following categories:

- Current Conditions (e.g., active groundwater level and subsidence network, locally reported dry wells, density of domestic wells susceptible to going dry).

PUBLIC DRAFT

- Groundwater Levels (e.g., continuous and periodic measurements from DWR, periodic measurements from the USGS, GSP monitoring sites, seasonal groundwater reports, well completion reports).
- Groundwater Storage (e.g., estimates from DWR's C2VSimFG model, estimates from the GSP annual reports).
- Water Quality (e.g., GAMA Program online tools and wells, SB-200 aquifer risk map).
- Land Subsidence (e.g., DWR and USGS extensometers, GPS stations, DWR's estimated vertical displacement within the San Joaquin Valley, TRE Altamira InSAR Dataset).
- Interconnected Surface Water (e.g., CDEC stations for air temperature, rain, reservoir levels, inflows, and outflows, snow measurements, and river and streamflow and stage).
- Water Budget (e.g., CIMIS, climate change data, land use data, water year data).
- Basin Characterization (e.g., geologic maps, lithology and geophysical data, well construction data, and hydrogeologic conceptual models).
- Reference Layers (e.g., groundwater management, hydrology, jurisdictions, political subdivisions, best available maps).

SGMA WATER YEAR TYPE DATASET

In accordance with the GSP Regulations (California Code of Regulations, Title 23), DWR is required to provide water year type classifications based on assessments of the amount of annual precipitation to aid GSAs in meeting compliance with SGMA. As a result, DWR developed the SGMA Water Year Type Dataset as an optional resource for the analysis of historical and current hydrologic conditions and the development of projected hydrologic conditions for the development and implementation of GSPs. The SGMA Water Year Type Dataset was initially released in 2021 and provided classifications for WYs 1931 through 2018 for 98 Hydrologic Unit Code (HUC) 8 watersheds within the state. These HUC 8 watersheds provide coverage of areas outside of the Sacramento and San Joaquin Valleys. The classifications were developed from monthly PRISM precipitation data collected from the Northwest Alliance for Science and Computational Engineering based at Oregon State University. Additionally, the input data and methodology used for the SGMA Water Year Type dataset was applied at the hydrologic region level and included in *California's Groundwater Update 2020*.

PUBLIC DRAFT

THE ONLINE SYSTEM OF WELL COMPLETION REPORTS

DWR's Online System of Well Completion Reports (OSWCR) is a digital repository that stores well completion reports for wells located within California. A description of this data resource is provided in Chapter 2, "Progress Toward Sustainable Groundwater Management."

Well completion reports provide a wealth of information that can be used in the development of integrated hydrologic models. Information from well completion reports, such as the borehole location and lithology, can be used to define the three-dimensional textural characteristics of the groundwater system by constructing a texture model. The texture model can be used to inform the spatial discretization of an integrated hydrologic model to develop the layering of aquifers and confining layers. Additionally, the borehole location, the depth to groundwater level, and the date which the depth to water level measurement was taken can be combined to create groundwater calibration points by providing groundwater modelers with discrete groundwater levels at specific times.

WATER DATA LIBRARY

DWR's Water Data Library (WDL) database includes all groundwater level measurements collected by DWR for the SGMA and the California Statewide Groundwater Elevation Monitoring (CASGEM) programs. The WDL provides public access to three separate datasets, including Groundwater Level Data, Water Quality Data, and Continuous Data. A description of these datasets is provided in Chapter 2, "Progress Toward Sustainable Groundwater Management."

Within the context of groundwater modeling, groundwater elevation data is a crucial source of information. Often, historical groundwater elevations are used when establishing initial conditions and calibrating groundwater models. Discrete or continuous, all groundwater elevation data are of tremendous importance when conducting model planning, development, calibration, and auditing.

State-Supported Tools Commonly Used in Water Accounting

State-supported tools are essential for water accounting, providing standardized methodologies, modeling platforms, and analytical frameworks to help water managers track and manage water supply, use, and sustainability. These tools support groundwater modeling, data visualization, water budget analysis, and other critical functions necessary for SGMA compliance and effective water resource management. By leveraging these resources, agencies and interested parties can inform decision-making, enhance transparency, and ensure long-term water sustainability.

PUBLIC DRAFT

Brief descriptions of these are provided below.

CALSIM

CalSIM is DWR's model for simulating the operations of the State Water Project and the Central Valley Project. It has been used in various planning studies since 2002.

CALIFORNIA SIMULATION OF EVAPOTRANSPIRATION OF APPLIED WATERS

The California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW) was designed to estimate daily soil-water balance for determining crop ET and ET of applied waters for CWP updates. This model requires climatological data, crop coefficients, soil data, and seepage, all of which influence crop water balance. In addition to historical simulations, Cal-SIMETAW can use near-real-time data from the Spatial California Irrigation Management Information System (CIMIS) — a DWR model that integrates weather station data and remote sensing to generate a statewide grid of reference ET.

INTEGRATED WATER FLOW MODEL

The Integrated Water Flow Model (IWFM) is an open-source computer program capable of simulating groundwater, surface water, and groundwater-surface water interactions. The program is composed of a pre-processor, simulator, and post-processor. Below is a brief description of IWFM's main components:

- Pre-Processor: The pre-processor reads and organizes user-defined time-independent data, such as the hydrologic, spatial, and stratigraphic characteristics specific to a simulation project. Specifically, those of the computational mesh, geologic stratigraphy, stream networks and lakes within the model domain.
- Simulator: The simulator mathematically simulates groundwater flow, surface water flow, and groundwater-surface water interactions with the use of a finite-element computational grid. Specifically, it accomplishes integrated hydrologic simulation by coupling the three-dimensional finite-element simulation of saturated groundwater flow with one-dimensional simulations of land surface hydrologic processes, surface water flow, vertical flow within the unsaturated zone, and ungauged watersheds adjacent to the model boundaries. Additionally, it simulates water demands based on agricultural management parameters, climatic conditions, land use, and soil properties while simulating water supplies in terms of groundwater pumping and surface water deliveries needed to meet its simulated demands.

PUBLIC DRAFT

- Post-Processor: The post-processor organizes and tabulates the results of the simulation (e.g., groundwater levels, land subsidence, water budget flows). It is capable of developing results on various scales, ranging from the element-level of the computational grid to those of the entire model domain with flexibility for user-defined zonal budgets of sizes in between.

As of 2024, the application of IWFM for water resources management has become a common practice within California's Central Valley. To support this effort, in compliance with the California Water Code (23 CCR § 354.18), DWR provides the IWFM as a potential resource for GSAs to use in the development of their water budgets.

CALIFORNIA CENTRAL VALLEY GROUNDWATER-SURFACE WATER MODEL SIMULATION

The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) is an application of IWFM, which simulates groundwater and surface water movement within California's Central Valley. This model utilizes a hydrogeological conceptual model, which is structured into a four-layer finite element grid for simulating land surface processes, root zone, vadose zone, groundwater, and surface water processes. C2VSim dynamically simulates historical water demands for agricultural, native and urban land uses; allocates root zone and surface water supply contributions from precipitation, soil moisture, and surface water diversions; and calculates groundwater pumping volumes required to meet water demands after accounting for root zone and surface water supplies. By simulating the Central Valley's response to historical stresses, C2VSim is able to quantify historical changes in groundwater elevations and volumes, exchanges between interconnected surface water and groundwater, and land subsidence. Additionally, C2VSim can also be used to simulate the Central Valley's potential responses to projected anthropogenic and climatic changes. Currently, there are two separate versions of C2VSim which use similar data and provide similar spatial coverage: the coarse-grid version (C2VSimCG, Figure 4-40) and the fine-grid version (C2VSimFG,
Figure 4-41).

In compliance with the California Water Code (23 CCR § 354.18), DWR provides the C2VSimFG as a potential tool for GSAs to use in the development and implementation of their GSPs. Currently, C2VSimFG Version 1.5 is available to the public. This version contains monthly historical stream inflows, surface water diversions, precipitation, ET, and land use acreages from October 1973 through September 2021. DWR plans to continue developing and refining C2VSim-FG to

PUBLIC DRAFT

reflect the most recent data and information on hydrogeology, water use, stream conditions, and surface water.

SACRAMENTO VALLEY GROUNDWATER-SURFACE WATER MODEL SIMULATION

The Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim) is an application of IWFM covering the Sacramento Valley. SVSim was developed to meet two main goals:

- Support the DWR Water Transfer Program by developing a tool that meets essential modeling requirements for evaluating project-specific impacts of groundwater substitution transfers on stream depletion in the Sacramento Valley.
- Support compliance with SGMA by developing a tool for evaluating water budgets, groundwater-surface water interactions, and sustainable groundwater management scenarios in the Sacramento Valley.

Currently, version 1.0 of SVSim (SVSim Version 1.0) is available to the public. The model domain includes the Sacramento Valley Groundwater Basin, the Redding Area Groundwater Basin, and the Sacramento-San Joaquin Delta (Figure 4-42). The simulation period covers WY 1973 through 2015.

PUBLIC DRAFT

Figure 4-40 Simulation Geometry for C2VSimCG

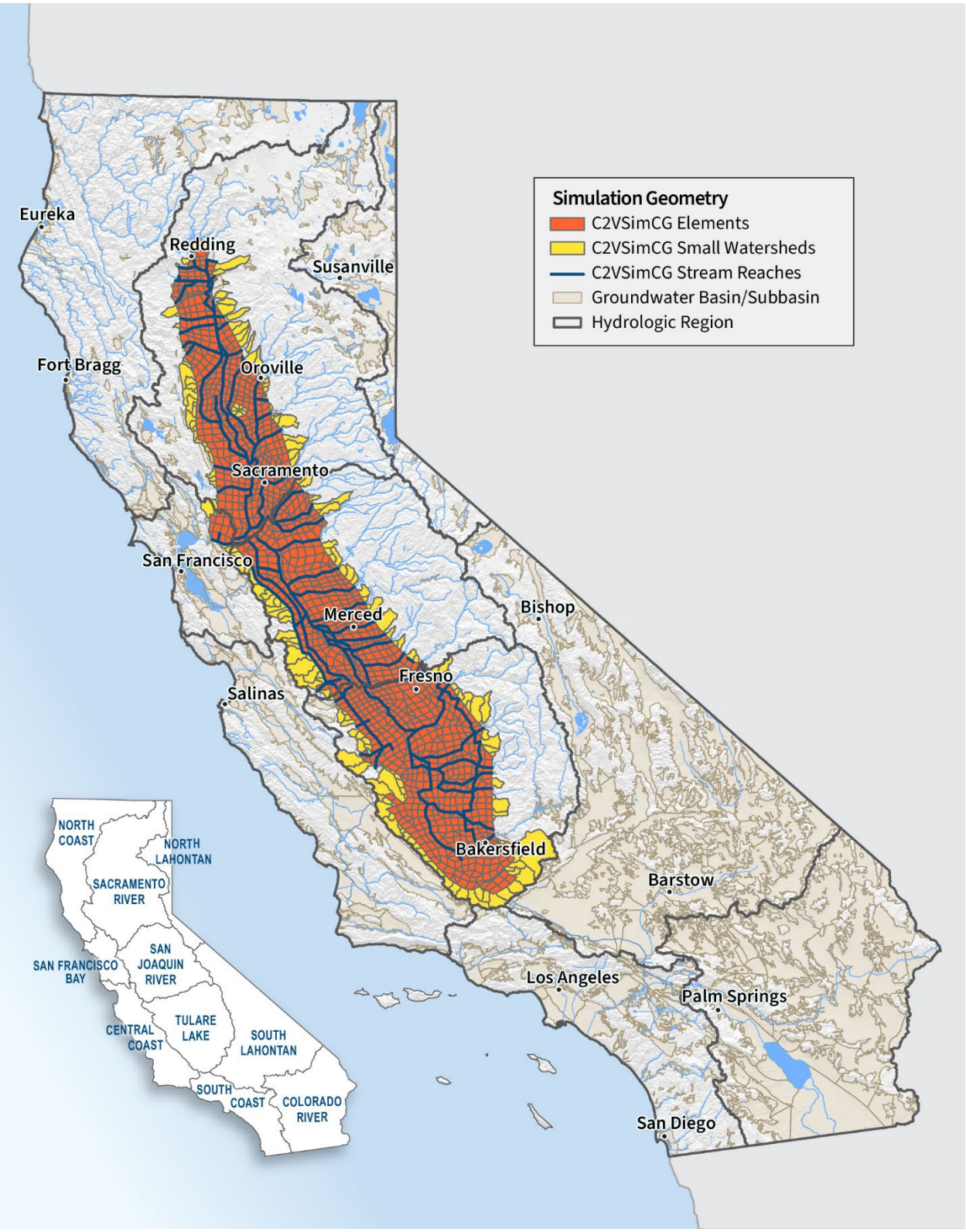


Figure 4-41 Simulation Geometry for C2VSimFG

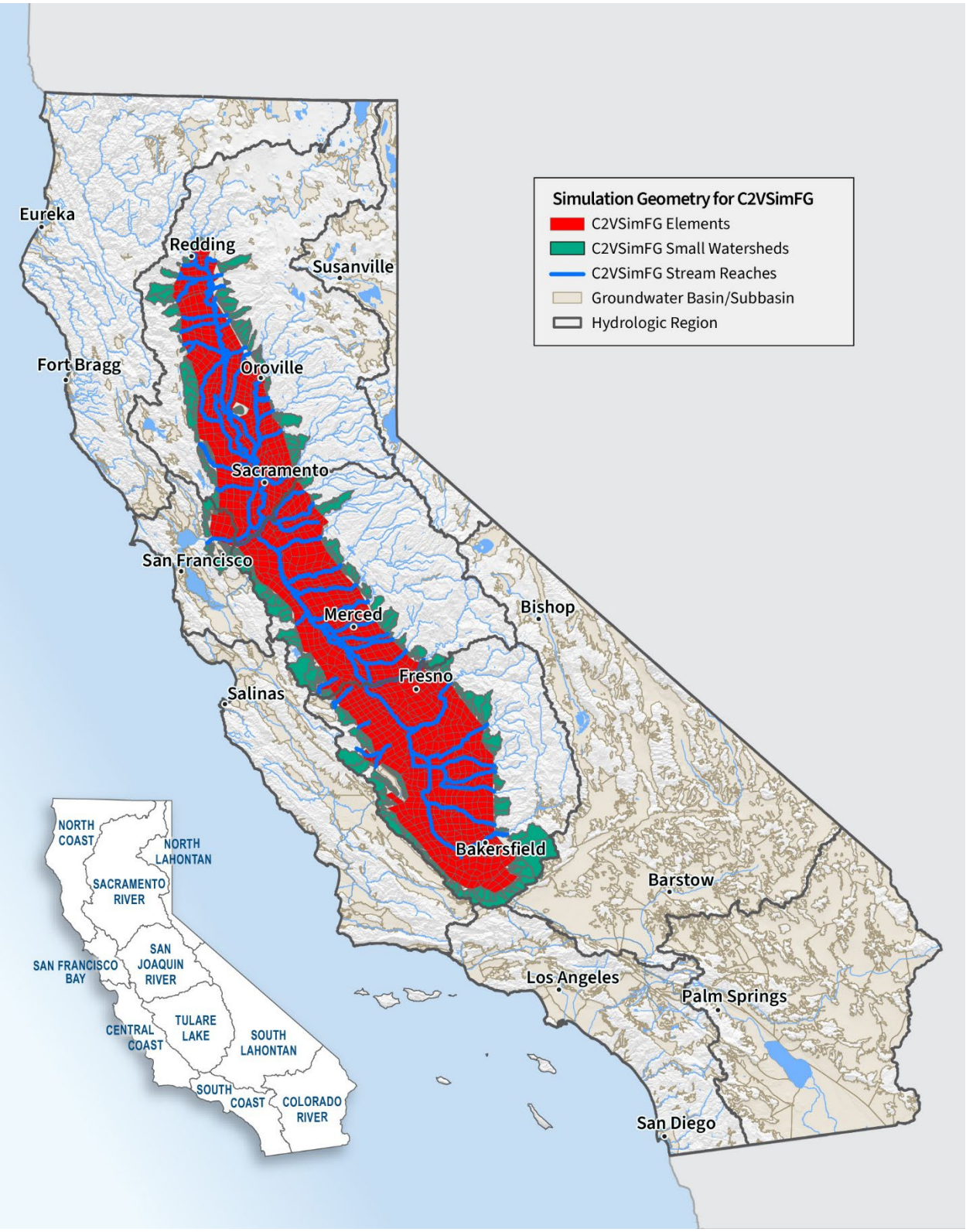
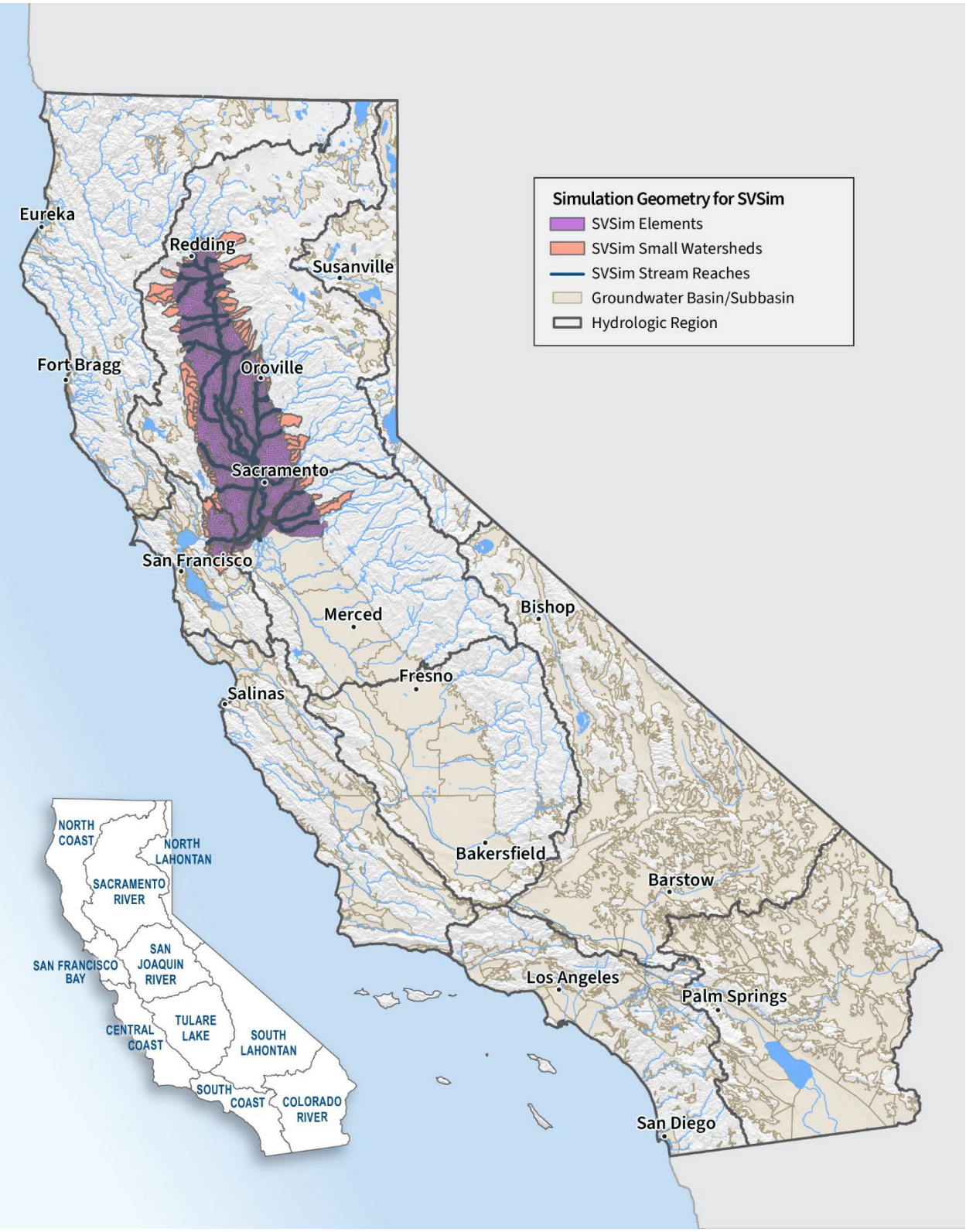


Figure 4-42 Simulation Geometry for SVSim



GROUNDWATER ACCOUNTING PLATFORM

The Groundwater Accounting Platform was developed to provide an easy-to-use, cost-effective, and open-source option for groundwater accounting. It is a data-driven tool that enables water managers to track water availability and usage with user-friendly dashboards and workflows. The platform can integrate data from various sources, including satellite imagery, flow meters, and sensor networks. This consolidation of water supply and usage information allows for accurate tracking of water budgets at the parcel level. The platform features a comprehensive water manager dashboard to account for water distribution across districts and regions, informing crucial management decisions such as billing and allocation planning. In addition to supporting water accounting, the tool enables users to assess the impacts of groundwater pumping, water trading, groundwater recharge, and other management scenarios through its scenario planning capabilities. Utilizing open-source code, the platform offers flexibility for water districts to develop and customize their unique software solutions.

Groundwater Accounting-Related Federal-Led Studies

USGS GROUNDWATER MODELING

Over the years, the United States Geological Survey (USGS) has been at the forefront of investigating groundwater nationwide. As a result of its efforts, it has developed several tools which have proven instrumental in investigating California's groundwater conditions and incorporating water accounting into groundwater management. Three of its most prominent resources are the Basin Characterization Model, MODFLOW, and the Precipitation Runoff Modeling System:

BASIN CHARACTERIZATION MODEL

The Basin Characterization Model (BCM) is a computer program that uses a gridded approach to conduct water balances for a soil profile at any spatial and temporal scale. The model's main inputs are climate, soil, and topographic data. Prior to conducting the water balance, the BCM calculates the amount of water that enters the soil profile by accounting for precipitation, snow accumulation and melt, and sublimation and potential ET considering air temperature, cloudiness, and topography. The water holding capacity and water available for plants are estimated for each cell's soil profile by considering soil data. From the water balance, the BCM produces estimates for sublimation, snow accumulation, snowmelt, watershed available water, adjusted simulated actual ET, climatic water deficit, local groundwater recharge, and local runoff.

PUBLIC DRAFT

MODFLOW

The MODFLOW framework refers to a suite of computer software used to support the simulation of hydrologic processes. The suite's modular structure provides a robust framework capable of simulating coupled groundwater/surface water systems, solute transports, variable density flow (including saltwater), aquifer-system compaction and land subsidence, parameter estimation, and groundwater management. MODFLOW offers a three-dimensional simulation of groundwater flow using a finite difference computational grid. MODFLOW has multiple versions and GSAs were found to have used the following versions:

- MODFLOW 2000 — 2000 version of the core MODFLOW version.
- MODFLOW 2005 — The 2005 version of the core MODFLOW version.
- MODFLOW-NWT — Uses a Newton-Raphson formulation to improve simulation of unconfined groundwater flow problems.
- MODFLOW-OWHM — The One-Water Hydrologic Flow Model (MODFLOW-OWHM) is an integrated hydrologic model based on MODFLOW 2005 and designed for analysis of conjunctive-use management. MODFLOW-OWHM tight couples groundwater flow, surface water flow, landscape processes, aquifer compaction and subsidence, reservoir operations, and conduit (karst) flow.
- MODFLOW-USG — Uses an unstructured grid approach for simulation of groundwater flow and tightly coupled processes using a control volume finite-difference formulation.
- MODFLOW 6 — The sixth core version of the core MODFLOW version.
- GSFLOW — The Coupled Groundwater and Surface-Water Flow Mode (GSFLOW) is an integrated hydrologic model based on the integration of the USGS Precipitation-Runoff Modeling System, MODFLOW-2005, and MODFLOW-NWT. GSFLOW was developed to simulate coupled groundwater/surface-water flow in one or more watersheds on a daily timestep.

PRECIPITATION RUNOFF MODELING SYSTEM

The Precipitation-Runoff Modeling System (PRMS) is a computer program composed of a deterministic and parameterized hydrologic modeling system. Its simulated hydrologic processes include evaporation, infiltration, interflow, runoff, and transpiration. PRMS is also capable of preparing water budgets at the watershed scale for a variety of temporal scales.

PUBLIC DRAFT

The California Water Science Center (CWSC) has developed several MODFLOW-based groundwater models within California.

One of the USGS' most well-known hydrologic models is its simulation of California's Central Valley, known as the Central Valley Hydrologic Model (CVHM). The CVHM simultaneously accounts for changing water supply and demand across the landscape and simulates surface water and groundwater flow across the entire Central Valley. CVHM2 is the USGS's current version of CVHM. Though similar to the previous version, CVHM2 differs in its simulation period, discretization of its spatial domain, inclusion of drain flows, and enhancements to tidal effects. Notably, the model layering has been increased from 10 to 13 layers, and the simulation period has been extended from WY 1962 through WY 2003 to WY 1962 through WY 2019.

CVHM has played a significant role in water resource management within California's Central Valley. Additionally, historic and on-going collaboration efforts for model development exist between DWR's C2VSimFG development team and the USGS's CVHM development team.

The Future of Groundwater Accounting in California

Addressing California's current and future water challenges, including interbasin flows, environmental management, water trading, and voluntary agreements — requires a comprehensive understanding of the state's water supplies and demands. The implementation of SGMA has played a pivotal role in advancing this effort by enhancing data availability, regulatory oversights, and sustainable water management practices. Data from GSPs and annual reports provide essential annual water budget data for specific groundwater basins. GSPs also provide detailed information on the state's hydrogeology and water resources in the form of hydrogeologic conceptual models, water budgets, monitoring data, and groundwater conditions. Additionally, water budgets from annual reports have been particularly valuable because of their consistent format and broad spatial coverage. Water budget information from annual reports and water use and supply balances from the CWP forms the foundation for understanding California's water resources.

Despite the wealth of new information provided by the GSPs and annual reports developing a comprehensive understanding of groundwater resources at the regional or statewide level remains challenging. Two key areas face significant obstacles: quantification of groundwater supplies and regional coordination. In

PUBLIC DRAFT

most parts of the state, direct metering is not used to measure groundwater extractions. To address this data gap, many groundwater managers estimate groundwater usage as the closure term for water accounting efforts, relying heavily on estimates of ET demand and local irrigation data. As a result, these estimates, when coupled with an insufficient understanding of the groundwater system, may hinder the ability to sustainably manage California's water resources.

Regional coordination presents another major challenge when attempting to integrate water accounting efforts at a regional or statewide level. The level of detail in water budgets, as well as the tools and methods used to develop them, varies across GSPs. Additionally, the spatial coverage of water accounting efforts differs among AWMPs, UWMPs, and GSPs. As a result, few watersheds are fully covered by water accounting efforts that are compatible in both detail and quality. This inconsistency poses significant challenges, even when sophisticated spatial rescaling techniques are applied, because the distribution of water demands and supplies in California is not uniform.

Many of these challenges could be remedied over time through the continued development and enhancement of monitoring networks, water accounting tools, creation of water accounting standards, and ongoing technical assistance. Increased spatial resolution and temporal frequency of data collection can improve the detail and utility of water budgets by producing estimates for flows at finer spatial and temporal scales. This, in turn, will refine groundwater models and groundwater pumping estimates while allowing greater flexibility in regional coordination, even when only partial spatial and temporal coverage are available for analysis.

Additionally, efforts should focus on standardizing key aspects of data reporting — such as format, quality, and spatial and temporal resolution — to streamline compliance with legislative requirements. Many water accounting tools, including groundwater models and their scenario-specific datasets (e.g., those accounting for climate change and population growth), would benefit from continued refinement and expansion. As groundwater management progresses in California, the understanding of the state's water resource systems is expected to improve, and these advancements should be reflected in water accounting tools to enhance their effectiveness.

While efforts to establish water accounting frameworks are well underway, many of the challenges associated with water accounting and its reporting remain. Continued standardization of water accounting methods will help mitigate common

PUBLIC DRAFT

issues, such as contradicting interbasin flow estimates, double counting, and communication gaps related to water budget flows. Continued technical assistance will not only help to ensure the continuation of the best available science but will also serve to reinforce the need for improved data, tools, and standardization.

Although many of these improvements should be implemented at the local and interbasin levels, their cumulative benefits will be realized statewide, ultimately enhancing the long-term management of California's water resources through more robust and reliable water accounting practices.

PUBLIC DRAFT

5 . Groundwater Monitoring

Chapter Summary

Chapter 5, "Groundwater Monitoring," of *California's Groundwater: Bulletin 118 — Update 2025* (CalGW Update 2025), outlines California's comprehensive approach to monitoring groundwater conditions, essential for understanding groundwater resources across the state and supporting various beneficial users. Furthermore, it provides critical data to implement and enhance sustainable water management practices under the Sustainable Groundwater Management Act (SGMA).

This chapter begins by setting the stage for groundwater monitoring, emphasizing its role in assessing and managing groundwater resources effectively. This underscores the importance of comprehensive monitoring programs in supporting data-driven groundwater management and safeguarding California's water resources. Groundwater level monitoring is explored first, detailing the monitoring networks, data collection, and reporting practices that provide insights into groundwater conditions across the state. Next, monitoring of change in groundwater storage is discussed to enhance understanding of groundwater resource trends. This is followed by an overview of groundwater quality monitoring, including efforts to assess the base of freshwater, which helps identify water quality thresholds and maintain standards crucial to sustainable groundwater use.

This chapter then addresses land subsidence monitoring, highlighting various techniques like using continuous global positioning systems (GPS), satellite-based Interferometric Synthetic Aperture Radar (InSAR), and borehole extensometers. These tools allow for accurate tracking of ground-level changes resulting from groundwater extraction, which help inform management actions for mitigating land subsidence risks. Finally, interconnected surface water monitoring tools are assessed to evaluate the relationship between surface water and groundwater systems. Seawater intrusion monitoring techniques are reviewed to protect coastal aquifers from saline intrusion, which can degrade water quality and threaten freshwater supplies.

Chapter 5, "Groundwater Monitoring," connects closely with the themes of CalGW Update 2025, including Theme 4, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support" by emphasizing the role of comprehensive monitoring programs, from groundwater levels and quality to subsidence and

PUBLIC DRAFT

seawater intrusion, in supporting informed resource management. This chapter also aligns with Theme 2, "Accelerating Momentum for Sustainability," as effective monitoring provides essential data for ensuring long-term groundwater availability and resilience under SGMA.

5.1 Introduction

It's been said that you can't manage what you can't measure, and this is true with California's groundwater. Groundwater monitoring has been conducted in California for more than a century, with the earliest groundwater monitoring data in the Department of Water Resources' (DWR's) data systems dating back to around 1900. Today, groundwater monitoring has evolved into an extensive network in which State agencies, federal agencies, local authorities, and individuals contribute data to DWR through various monitoring programs. Current groundwater monitoring efforts include networks of wells for collecting groundwater levels and water quality data, as well as surveying and remote sensing to measure minute changes in land elevation. The need to monitor groundwater in California is increasing because of its growing importance as a resource and the need to improve our understanding of water conditions throughout the state.

Robust data systems and powerful analysis tools use these data to assess groundwater conditions, seawater intrusion, water quality, and land subsidence as well as to model groundwater and interconnected surface water systems. Additionally, data collected through groundwater monitoring are used to support sustainable water management and help avoid undesirable results attributed to groundwater overdraft, loss of storage, degraded groundwater quality, land subsidence, depletion of interconnected surface water, and seawater intrusion.

As climate change intensifies in California, groundwater monitoring has become increasingly critical for managing California's water resources. Rising temperatures, shifting precipitation patterns, and prolonged droughts threaten groundwater availability and quality, making continuous monitoring essential for informed decision-making. Figure 5-1 presents a conceptual representation of climate change impacts and statewide monitoring efforts. This figure illustrates how various climate-related stressors, such as changes in precipitation patterns, prolonged droughts, and rising temperatures, impact both surface water and groundwater systems. It also highlights the role of statewide monitoring efforts in tracking and mitigating these vulnerabilities and underscores the importance of a

PUBLIC DRAFT

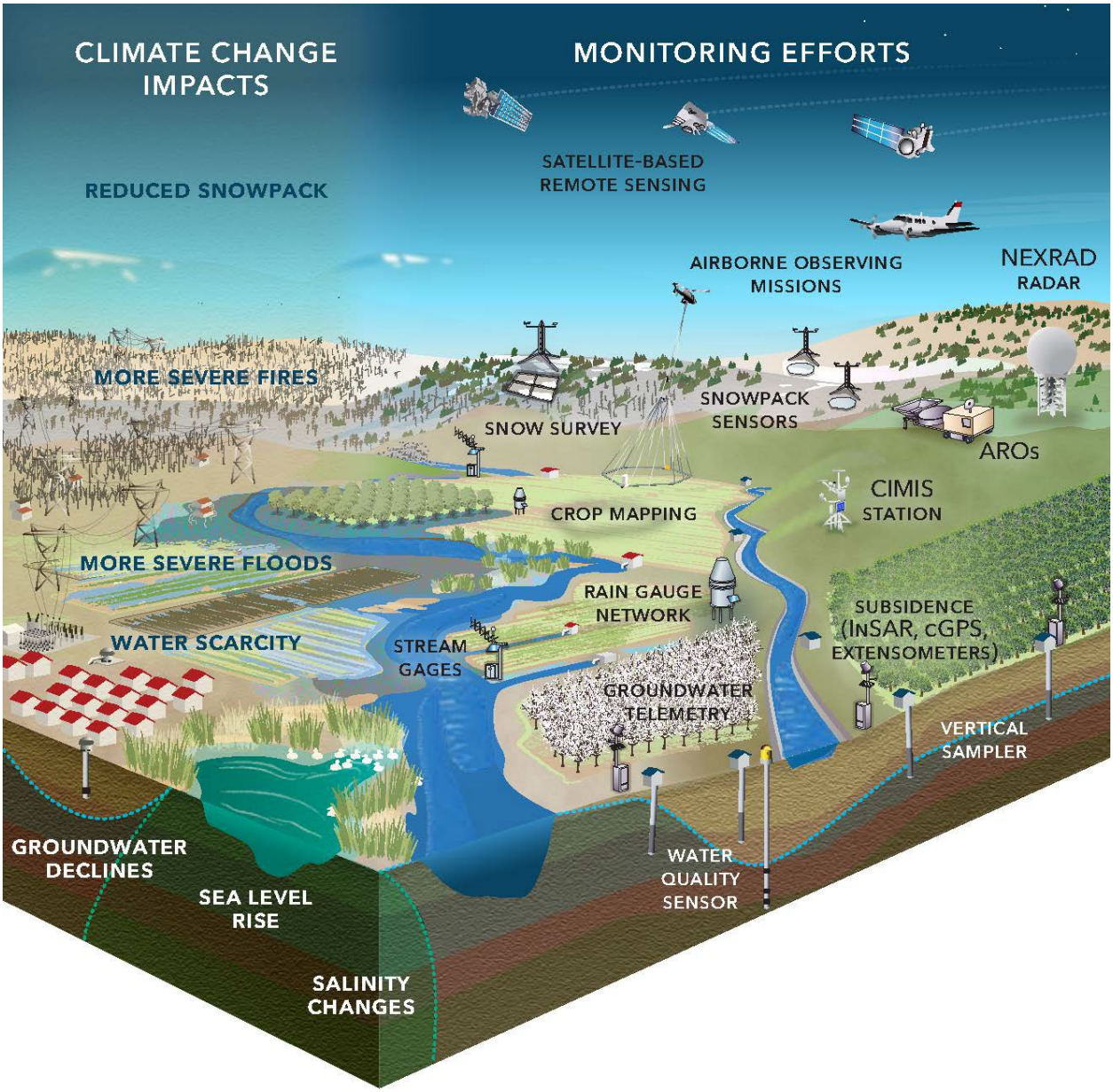
comprehensive, data-driven approach to sustainable groundwater management in California.

In recognition of the significance of groundwater monitoring, the State has been collaborating closely with local agencies to enhance and modernize groundwater monitoring programs. These partnerships aim to improve the collection of groundwater level and quality data, ensure timely reporting, and assess recharge patterns and opportunities. By providing a clearer picture of regional vulnerabilities, these efforts help inform adaptive management strategies tailored to local needs.

The data and analysis presented in Chapter 5, "Groundwater Monitoring," provide valuable insights into how climate change affects groundwater conditions and will enhance our understanding of its broader impacts. This chapter also helps identify areas across the state with physical and social vulnerabilities and ensure that monitoring efforts are directed toward these regions to effectively address existing data gaps.

PUBLIC DRAFT

Figure 5-1 Climate Change Impacts and Statewide Monitoring Efforts



Legislatively mandated statewide programs aimed at groundwater monitoring began with the establishment of the California Statewide Groundwater Elevation Monitoring Program (CASGEM) in 2009 under Senate Bill X7-6. The SGMA, enacted in 2014, further emphasized the importance of groundwater monitoring and mandated it as a key element of the development and implementation of Groundwater Sustainability Plans.

These legislative efforts have led to significant advancements in groundwater monitoring and data management across the state. Building on this foundation,

key updates since California's Groundwater Update 2020 include the implementation of the SGMA Portal for data submissions, enhancements to the (OS), and the introduction of real-time groundwater data telemetry and the DWR Groundwater Monitoring Initiative. DWR makes all groundwater-related data publicly available through various resources, including the California Natural Resources Agency (CNRA) Open Data website, the SGMA Portal, the SGMA Data Viewer, California's Groundwater Live, and the Water Data Library (WDL).

The following sections present statewide groundwater monitoring data and information, organized by the topics listed below, which correspond to the six sustainability indicators of SGMA:

1. Groundwater Levels.
2. Change in Groundwater Storage.
3. Groundwater Quality.
4. Land Subsidence.
5. Interconnected Surface Water.
6. Seawater Intrusion.

Information about groundwater conditions based on data collected through 2023 can be found in Chapter 6, "Groundwater Conditions," organized by the topics listed above. A summary of monitoring activities occurring in each hydrologic region can be found in Chapter 7, "Groundwater at a Glance: Hydrologic Region Summaries." Information regarding the methods, assumptions, and data used in compiling this section are provided in Appendix C, "Methods and Assumptions." Links to the references, various tools, interactive maps, and datasets discussed in this chapter are included in Appendix D, "Citations, Reference Materials, and Links." Basin-specific data used for this report, including the number of groundwater monitoring sites, are available in Appendix G, "Hydrologic Region, Basin, and County Data."

5.2 Groundwater Level Monitoring

Groundwater level data provide important information about groundwater conditions and how these conditions change over time. These data can show how the groundwater system responds to drought, flooding, groundwater pumping, land use changes, farming practices, urban evolution, and local and distant natural and artificial recharge. Short-term groundwater level records are used to evaluate changes in groundwater elevation caused by seasonal fluctuations, groundwater

PUBLIC DRAFT

extraction, changes in streamflow, and natural and artificial groundwater recharge. Long-term data show trends in groundwater levels and storage over time.

Groundwater level monitoring networks are designed to collect and share information to assess conditions. These monitoring networks consist of groups of wells that are organized by basin, region, project or program, and collecting agency. For example, Groundwater Sustainability Agencies (GSAs) use groundwater monitoring networks, identified as part of SGMA compliance, to support management of groundwater within their basin(s). Groundwater levels can also be used by the GSAs as a proxy for water quality, land subsidence, surface water interaction, and seawater intrusion management criteria, provided agencies can demonstrate there is a significant correlation between groundwater levels and these sustainability indicators.

Groundwater levels can be measured manually or autonomously. Manual measurements use tools such as electric sounders or steel tape and are taken by technicians visiting each site, allowing them to observe conditions firsthand. Manual groundwater level measurements give reliable and accurate results but are typically time-consuming and costly because they require visiting each monitoring location.

Autonomous groundwater level measurements are collected with a water-level sensing device that is paired with a datalogger programmed to collect and record the water level at a set interval defined by the user, ranging from minutes to days. While these devices operate independently, they still require occasional site visits for maintenance, calibration, and data retrieval. Although this method is still time-consuming and costly because of equipment costs and a requirement for periodic site visits, the benefit is the significant increase in groundwater data collected.

Groundwater level data can also be transmitted through satellite, radio, or cell-based systems for near real-time monitoring. This is referred to as *telemetry* and is achieved by connecting telemetry systems that incapsulate telecommunications equipment to dataloggers at an individual well site. Telemetry allows groundwater data retrieval without needing to visit the well site. Telemetry can also provide information about problems with the equipment installed at the site so that issues can be addressed more quickly. Telemetering has higher upfront costs for telecommunications, but it provides the benefit of having access to large quantities of groundwater data in near real-time while minimizing the cost of on-site visits.

PUBLIC DRAFT

The two primary statewide DWR programs supporting groundwater level monitoring are the Sustainable Groundwater Management Program (SGMP) and the California Statewide Groundwater Elevation Monitoring (CASGEM). Currently, DWR manages the data collected for these programs, which include contributors such as DWR and local agencies like GSAs, CASGEM monitoring entities, and cooperators via enterprise data management systems. These systems are also designed to receive groundwater level data outside the SGMP and CASGEM programs, as needed, through "voluntary" data submittals. Public access to this groundwater level data is available through the SGMA Portal and CASGEM Online System, as well as other web-based platforms such as the SGMA Data Viewer, DWR Water Data Library, and CNRA Open Data website. In 2024, DWR started the DWR Groundwater Monitoring Initiative that will improve the current programs for easier submittal and access of data.

The National Water Information System (NWIS) is a separate enterprise data system managed by the United States Geological Survey (USGS) that provides access to a comprehensive nationwide database of water data, including groundwater level data. NWIS wells within California are shown on the SGMA Data Viewer. Some NWIS well data are used for DWR reports and analysis, including this report; however, most of the NWIS network data are not included in DWR analyses because they are not linked to DWR data systems.

Groundwater level monitoring wells can include dedicated monitoring wells, constructed specifically for collecting groundwater data, and production wells that are also used for agriculture, domestic water supply, stock watering, or municipal purposes. In some instances, retired production wells are repurposed as monitoring wells.

The physical characteristics and extent of aquifers within California's groundwater basins and non-basin areas are highly variable because of differences in geology, aquifer thickness, quantity of aquifers, unconfined and confined aquifers, recharge sources, and hydraulic connectivity. Aquifers that are shallow and unconfined are more susceptible to surface contamination and seasonal water level fluctuations. Deep aquifers, such as confined aquifers, store large volumes of groundwater over long timeframes and are less susceptible to surface contamination. For more information about groundwater aquifers, see Chapter 3, "California's Natural and Built Groundwater Infrastructure."

Groundwater monitoring networks are multifaceted and serve multiple purposes such as monitoring for groundwater levels, water quality, and seawater intrusion.

PUBLIC DRAFT

To effectively manage California's varied aquifer systems, it is essential to collect groundwater level measurements from monitoring wells that represent a wide range of scenarios. These include varying depths, locally important aquifers, and considerations for vertical and horizontal variability in groundwater conditions that are influenced by pumping, recharge, and subsurface flow. The following sections describe California's groundwater monitoring networks in various ways, based on factors including an evaluation of the collection and submittal timing of groundwater level data, the monitoring program, the collecting agency, the primary use or type of well, and the depth of the wells used for data collection. Understanding these distinctions is useful for interpreting groundwater data and supporting sustainable groundwater management.

5.2.1 Groundwater Level Monitoring Well Summary

The sources that inform the DWR groundwater database contain millions of groundwater level measurements from all over California. Water level data from some wells date back to the early 1900s, including several wells that are still being monitored. Groundwater level data collected for basins by DWR, GSAs, and other entities are consolidated in DWR's centralized data systems through the CASGEM Online System and the SGMA Portal. These data were queried on September 27, 2024, for all active monitoring wells. Actively monitored wells provide the best information about current conditions. Active monitoring wells in this report include those that have been recently monitored and those with a consistent track record of at least two measurements per year since 2019. Wells recently added to the monitoring network database are also included as active wells. The queried dataset includes 8,980 active wells statewide within groundwater basins, which were used in the analyses presented in this Chapter. This queried dataset includes 191 wells in the non-basin areas.

The total number of active monitoring wells varies significantly across California's hydrologic regions. The Sacramento River Hydrologic Region has the highest number of active monitoring wells, with 1,824 wells, while the Colorado River Hydrologic Region has the fewest, with 195 wells. Details of the distribution of active wells by hydrologic region and monitoring program are provided in Table 5-1. Figures 5-4 through 5-9 show the network of actively monitored wells by program, collecting agency, well type, and depth.

5.2.2 Frequency of Groundwater Level Measurements

This section examines the frequency of groundwater level data collection and its role in effective groundwater management. Understanding how often groundwater

PUBLIC DRAFT

levels are measured — and the timing of data submission — is critical for tracking aquifer conditions, identifying trends, and making informed decisions.

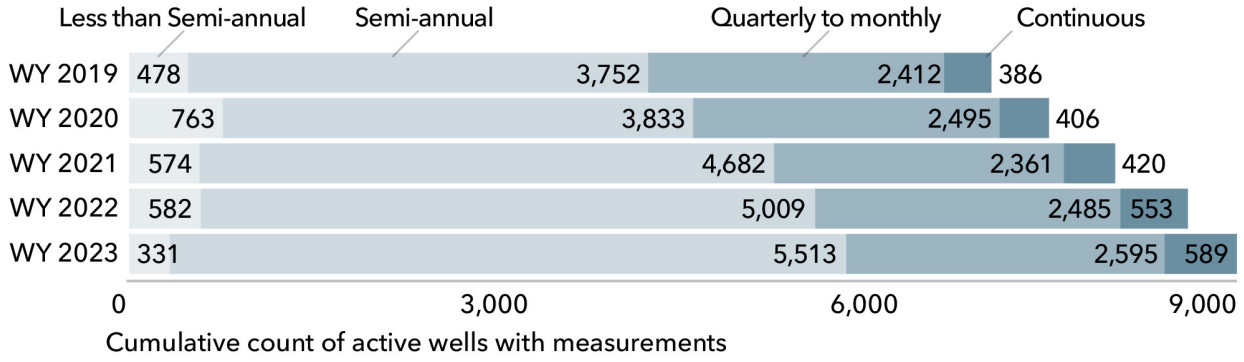
In California, groundwater level measurements are collected at varying frequencies, with most wells measured manually between twice per year to monthly or quarterly, while some are equipped with data loggers that provide continuous daily or more frequent measurements. This diversity in monitoring frequency reflects the various needs and purposes for groundwater data collection across the state. Local monitoring needs, data program requirements and budgets, and weather all play roles in determining how often groundwater levels are measured.

Monthly or continuous data collection through data loggers and telemetry significantly improves the ability of groundwater managers and analysts to understand groundwater systems. More frequent measurements can reveal seasonal patterns, identify causes for fluctuations in groundwater levels (such as pumping), provide insight into recharge, enhance the ability to detect trends, enable timely notification of potential issues, and provide more robust data for groundwater modeling.

Analysis of groundwater level measurement collection frequency of Water Years (WYs) 2019–2023 for the active wells is shown in Figure 5-2. There was a steady increase in the number of active wells monitoring semi-annually during the five years, from 3,752 wells in WY 2019 to 5,513 wells in WY 2023. The number of wells with quarterly to monthly monitoring slightly increased from 2,412 to 2,595 over the same time period. Continuous monitoring wells using data loggers have also gradually increased, from 386 wells in WY 2019 to 589 wells in WY 2023, indicating a growing focus on collecting more frequent data. Additionally, in WY 2023, the number of wells with less than semi-annual monitoring reached its lowest level.

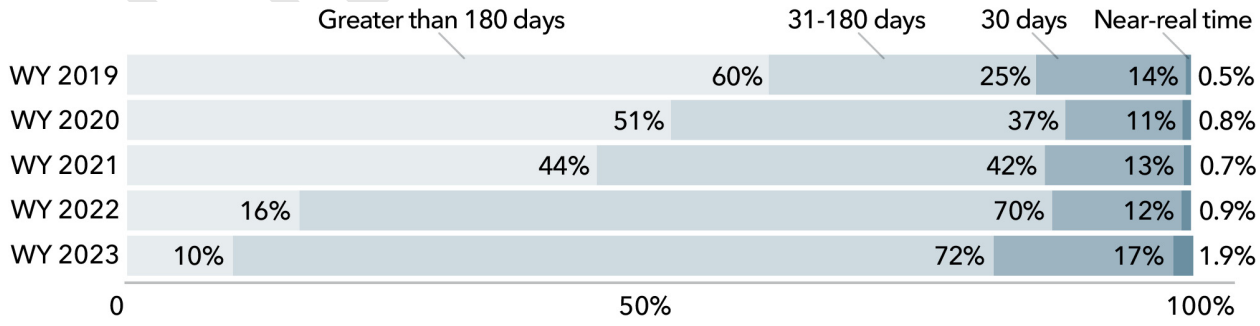
PUBLIC DRAFT

Figure 5-2 Groundwater Level Measurement Collection Frequency (Water Years 2019-2023)



The timely submittal of groundwater level data, or minimal data submittal latency, improves real-time decision-making, especially during critical periods such as droughts, peak water demand seasons, and flooding events that may support recharge efforts. Figure 5-3 summarizes the data submission latency for measurements collected from active monitoring wells for WYs 2019–2023. There has been a notable improvement in the timeliness of data submission, with the percentage of submissions within 31 to 180 days increasing from 25% to 72%, and a corresponding decrease in submissions exceeding 180 days, from 60% to 10%. The average submittal of data within 30 days of measurement has remained relatively stable over the years, consistently making up 11% to 17% of the total measurements annually. Continuous monitoring, using data loggers with near real-time reporting, is the least common, accounting for only 0.5% to 1.9% of measurements each year. However, this increase is not trivial as it shows a quadrupling of wells with near real-time reporting.

Figure 5-3 Groundwater Level Data Submission Latency (Water Years 2019-2023)



The advantages of high-frequency data and prompt reporting ultimately enhance the ability of both State and local agencies to make proactive, informed management decisions that align with California's groundwater sustainability

PUBLIC DRAFT

goals. Furthermore, consistent and frequent data collection, combined with timely submissions, helps build a more robust historical dataset that supports comprehensive trend analysis and predictive modeling.

5.2.3 Groundwater Level Data Submission

Frequently measured groundwater levels provide valuable insights into current groundwater conditions and are essential for understanding the effects of events such as drought or extreme precipitation on groundwater resources. Access to near real-time and real-time groundwater data enhances the ability to make effective management and planning decisions. Groundwater level data, aggregated in DWR's data systems, are collected and submitted on various schedules depending on the program and the entity collecting the data.

For this report, groundwater level data collection and reporting are categorized into four groups: continuous near real-time data (telemetered), quarterly or monthly data submitted within 30 days of collection, biannual data submitted within 30 days of collection, and any measurements submitted more than 30 days after collection.

Operational data refer to measurements collected monthly or more frequently and submitted within 30 days of collection and made available to the public. This type of data is useful for water managers as it provides a near real-time understanding of groundwater conditions. Telemetered data are considered the best option for groundwater management, as telemetering offers continuous data that are submitted in real time, providing timely information critical for informed decision-making, assessing the success of active water management practices, and identifying areas for improvement. Data collected quarterly or more frequently provide insights into seasonal groundwater level. Most wells across the state are monitored twice a year, typically capturing seasonal highs (spring) and lows (fall). While this biannual frequency is adequate for tracking long-term trends, more frequent monitoring is necessary to understand seasonal groundwater level fluctuations in greater detail.

Figure 5-4 summarizes monitoring well data collection frequency and the data submittal timing for wells reporting groundwater-level measurements collected during WY 2024. Data from 8,980 wells, submitted by the end of September 2024, were included in the analysis. Of these, operational data were reported for 423 active wells, representing approximately 5% of total wells. This subset of wells includes 261 wells (3%) with measurements collected quarterly or at least ten

PUBLIC DRAFT

times a year and submitted within 30 days and 162 wells (2%) that are equipped to collect continuous real-time telemetered measurements.

There are 2,574 wells with measurements submitted within 30 days of collecting the well data, including the operational data from 423 active wells discussed above and 2,151 wells (24%) for which groundwater level measurements were collected at least twice a year and reported within 30 days of collection. There are 6,274 wells where measurements are submitted 31 days or longer after collection. The longer delays in submitting groundwater level data are because of GSAs being required to submit measurement data only by the April annual report, in accordance with SGMA Regulations (23 CCR Section 354.40).

PUBLIC DRAFT

Figure 5-4 Statewide Groundwater Level Data Reported for WY 2024

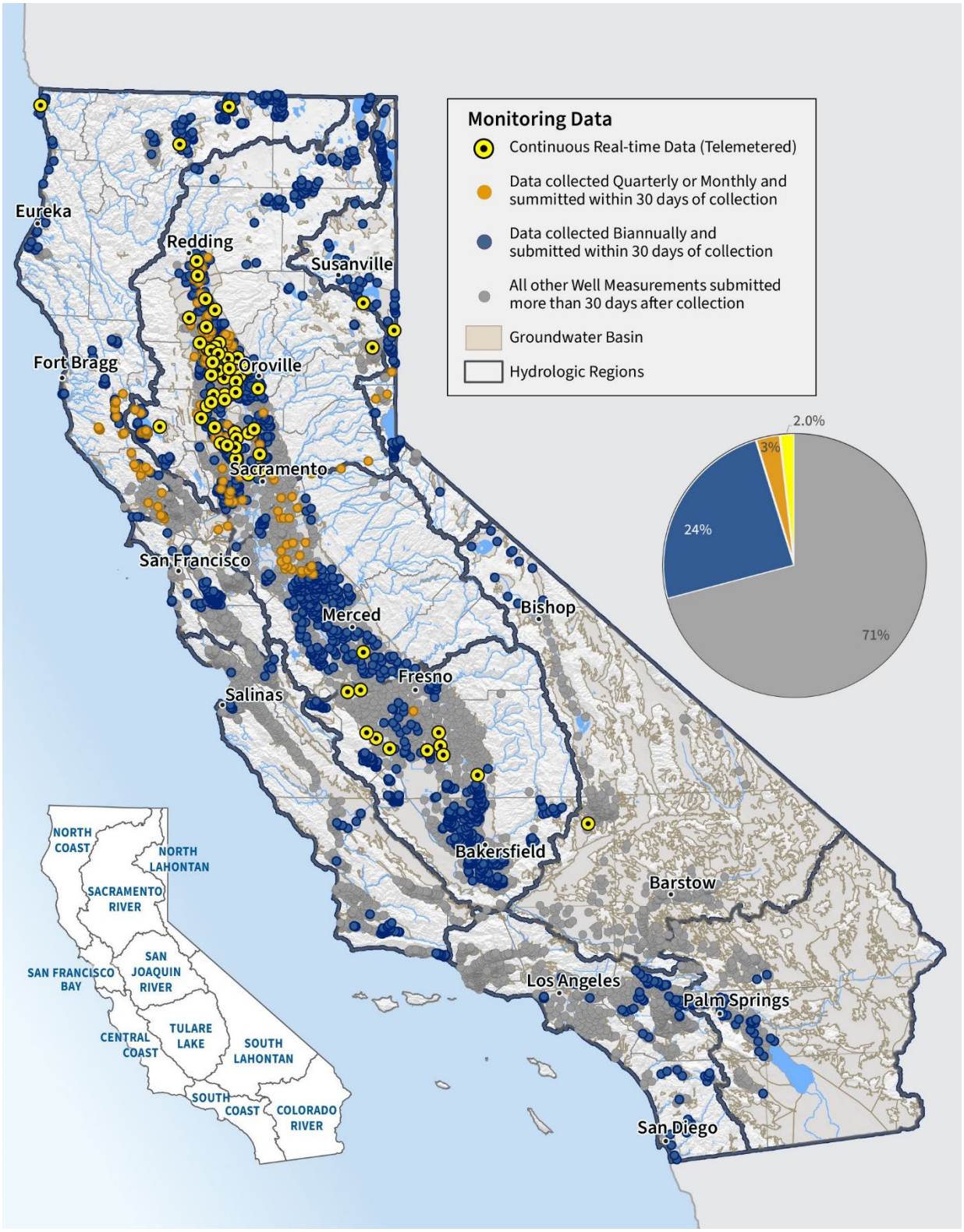
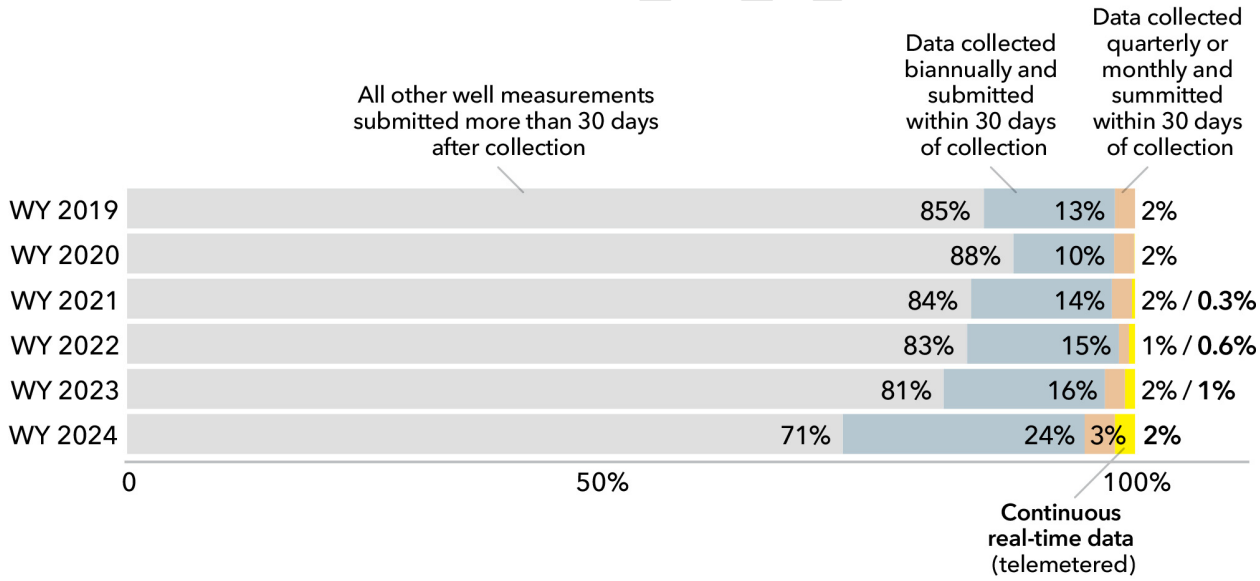


Figure 5-5 compares the collection and submission dates for groundwater level data for WYs 2019–2024. The data reveal a gradual shift toward more timely data submissions and an increase in real-time monitoring — thereby reflecting a trend toward more operational data. Semiannual data submissions within 30 days have shown a steady increase, rising from 13% in WY 2019 to 24% in WY 2024, reflecting an improvement in timely reporting practices. Quarterly or Monthly data submissions within 30 days have remained fairly consistent but show a slight increase from 2% in early years to 3% by WY 2024. Continuous real-time telemetered data, initially non-existent in WYs 2019–2021, began appearing in WY 2022 at 1% and has since doubled to 2% by WY 2024. The majority of well measurements in each WY are still being submitted more than 30 days after collection, though this proportion has decreased from 85% in WY 2019 to 71% in WY 2024.

Figure 5-5 Statewide Groundwater Level Data Statistics Based on Data Collection and Submission (Water Years 2019-2024)



5.2.4 Groundwater Level Monitoring Wells by Program

Various State, federal, and local programs throughout California support groundwater level data collection. Within DWRs statewide data systems, groundwater level data submitted to DWR is organized by the two primary groundwater level data collection programs, SGMA and CASGEM. Data collected outside of these programs is considered "Voluntary" data and are an important component of statewide groundwater level monitoring, analysis, and reporting.

The implementation of SGMA has expanded the local networks and groundwater data reporting to DWR. Many groundwater-level monitoring wells, previously part of the CASGEM network, were transferred to the SGMA Groundwater Sustainability Plan (GSP) and Alternative Plan networks. During the implementation of these plans, additional wells have also been added, improving data gaps in monitoring California's groundwater conditions. Figure 5-6 displays the statewide distribution of actively monitored groundwater monitoring wells by program, and Table 5-1 provides a summary of the number of actively monitored wells by program in each hydrologic region.

SGMA monitoring wells include GSP representative monitoring wells that track Sustainable Management Criteria information such as minimum thresholds and measurable objectives. Currently, the total number of SGMA wells accounts for nearly 63% (5,638) of all monitoring wells statewide, with 2,615 wells reported as representative monitoring wells. CASGEM wells represent nearly 14% (1,221) of the wells of the state's monitoring network. Nearly 24% (2,121) are contributed through voluntary or other groundwater programs.

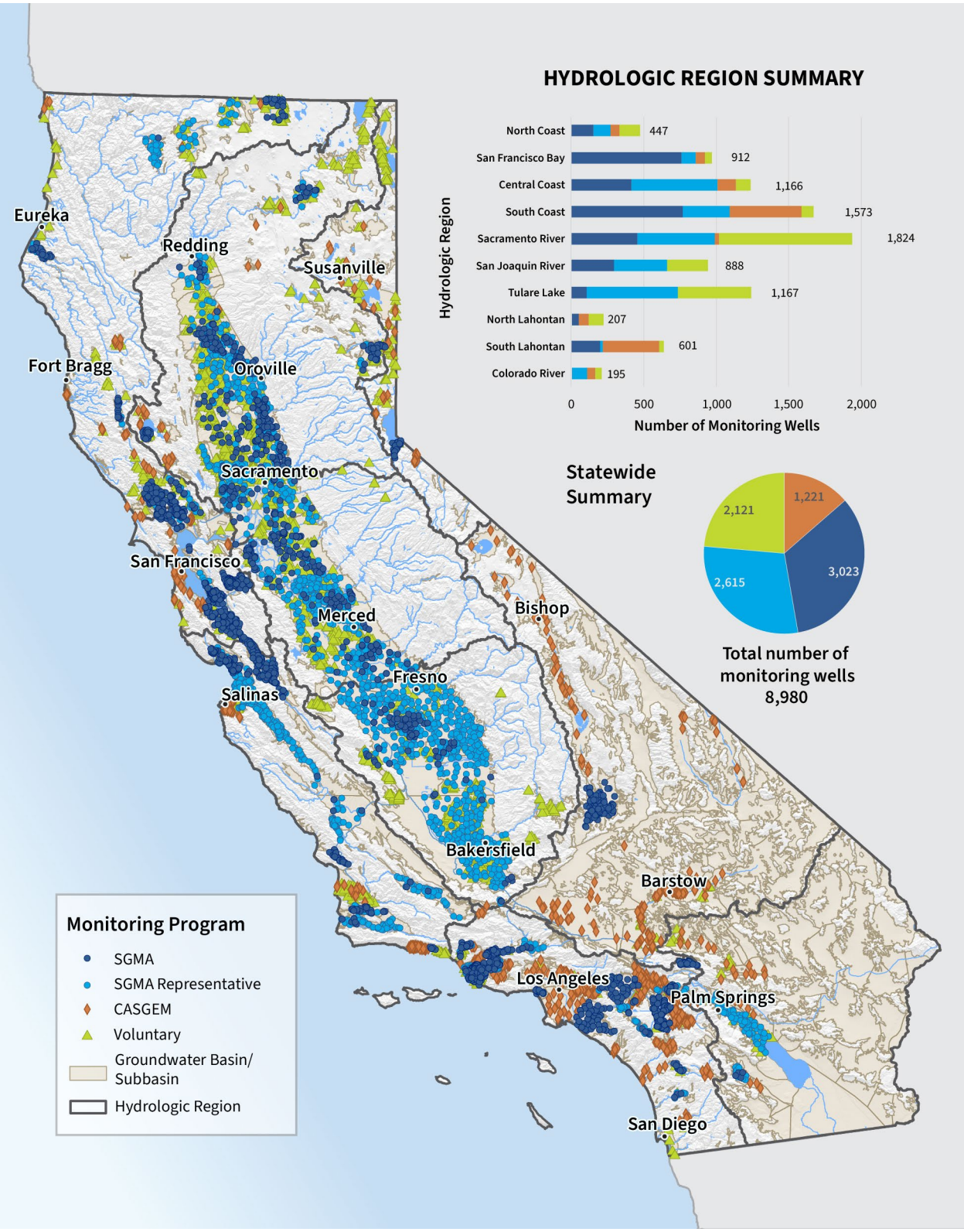
PUBLIC DRAFT

Table 5-1 Actively Monitored Groundwater Level Monitoring Wells by Monitoring Program and Hydrologic Region (Water Years 2019–2024)

Hydrologic Region	SGMA	SGMA Representative	CASGEM	Voluntary/ Other Programs	Total
North Coast	145	111	56	135	447
San Francisco Bay	716	91	61	44	912
Central Coast	390	559	120	97	1,166
South Coast	724	303	467	79	1,573
Sacramento River	429	502	30	863	1,824
San Joaquin River	278	344	0	266	888
Tulare Lake	101	592	1	473	1,167
North Lahontan	47	0	64	96	207
South Lahontan	188	18	367	28	601
Colorado River	5	95	55	40	195
Total	**3,023**	**2,615**	**1,221**	**2,121**	**8,980**

PUBLIC DRAFT

Figure 5-6 Groundwater Level Monitoring Wells by Monitoring Program (Water Years 2019–2024)



5.2.5 Groundwater Level Monitoring Wells by Collecting Agency

Coordinated monitoring efforts by multiple entities enhance the quality and coverage of groundwater level data by helping to fill data gaps, reduce redundancies, and ensure that groundwater management decisions are based on the best available information.

Through this statewide collaboration, DWR collects and manages groundwater level data and receives and maintains data from local and federal agencies (Figure 5-7 and Table 5-2). Local agencies consist of counties, water districts, and other organizations. Federal agencies include the U.S. Bureau of Reclamation (USBR) and the USGS. Between WY 2019 and WY 2024, DWR contributed groundwater level data from 18% (1,606) of the wells, while local agencies monitored 57% (5,113) of wells, and federal agencies contributed data from less than 2% (130) wells. The USGS monitors more groundwater wells than reported; however, DWR does not receive data from those additional wells. Although it is common for measurements to be collected by a single agency, there are cases where data is collected from a well by multiple agencies. From WY 2019 to WY 2024, approximately 24% (2,131 wells) were measured by more than one agency, which was typically a local water agency or county working in partnership with a GSA or DWR.

As can be seen in Table 5-2, the Sacramento and Tulare Lake hydrologic regions have the highest percentage of wells monitored by DWR, accounting for 35% (1,824) and 40% (1,573) of the wells in these regions, respectively. The South Coast hydrologic region has the largest number of wells (1,063) monitored by local agencies, while Central and South Coast hydrologic regions have the highest number of wells monitored by multiple agencies, with a combined total of 1,082 wells (51%) of the 2,131 statewide wells with partnering agencies.

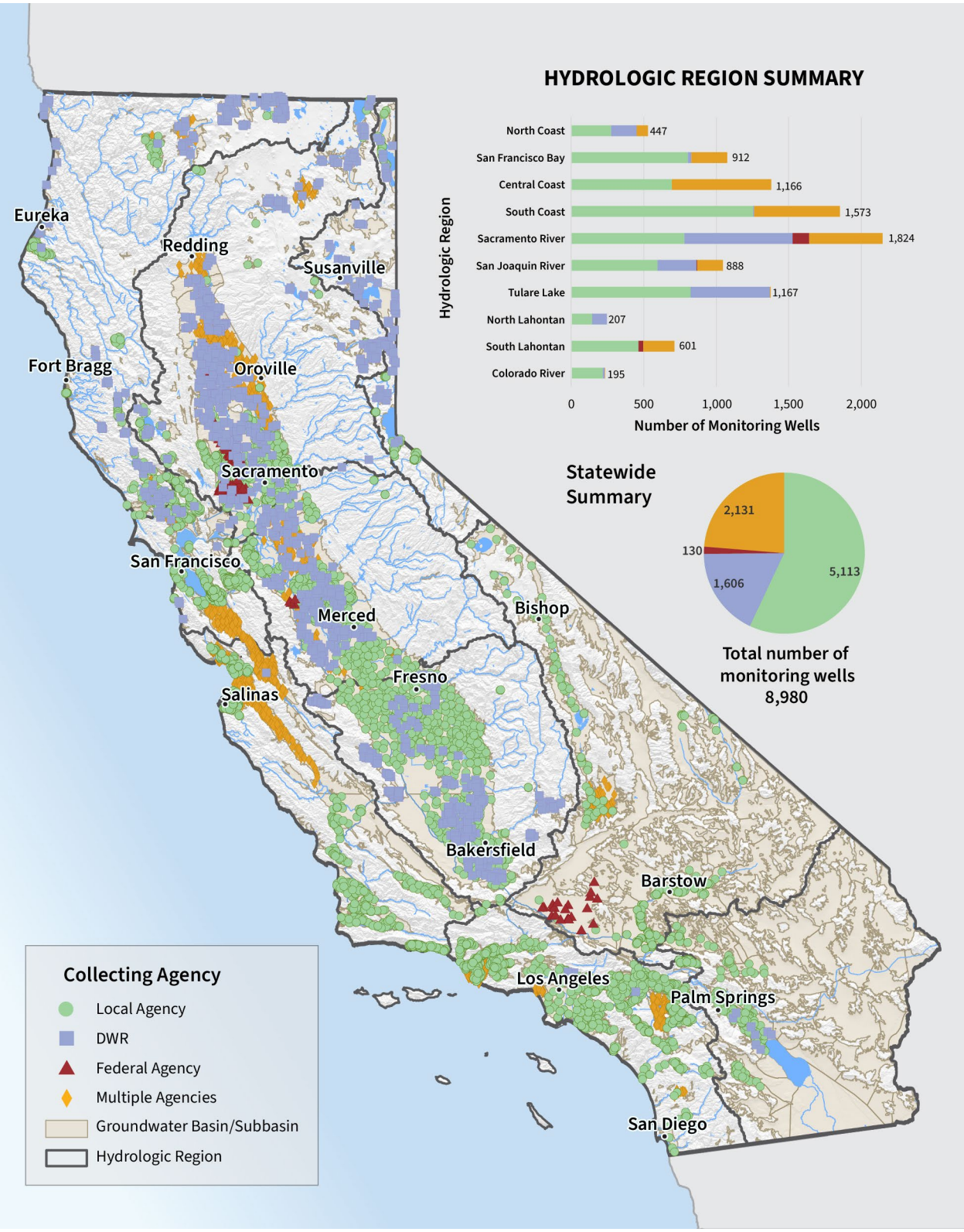
PUBLIC DRAFT

Table 5-2 Actively Monitored Groundwater Level Monitoring Wells by Collecting Agency and Hydrologic Region (Water Years 2019–2024)

Hydrologic Region	Measured by a Local Agency	Measured by DWR	Measured by a Federal Agency	Measured by Multiple Agencies	Total
North Coast	230	151	0	66	447
San Francisco Bay	681	20	0	211	912
Central Coast	586	1	0	579	1,166
South Coast	1,063	7	0	503	1,573
Sacramento River	661	634	98	431	1,824
San Joaquin River	503	229	4	152	888
Tulare Lake	696	465	0	6	1,167
North Lahontan	119	88	0	0	207
South Lahontan	391	0	28	182	601
Colorado River	183	11	0	1	195
Statewide	**5,113**	**1,606**	**130**	**2,131**	**8,980**

PUBLIC DRAFT

Figure 5-7 Groundwater Monitoring Wells by Collecting Agency (Water Years 2019-2024)



5.2.6 Groundwater Level Monitoring Wells by Well-Use Type

Groundwater level data is collected from a variety of well types, as described below:

Dedicated observation wells encompass all wells identified for "monitoring" or "observation" purposes. Observation wells are specifically installed or designated to track groundwater levels, water quality, or both, often as part of regional groundwater management or scientific studies. They are crucial for long-term groundwater sustainability planning and serve as the backbone for statewide monitoring networks.

Irrigation wells are used primarily for agricultural purposes, providing groundwater to support crop irrigation and can be completed to access the deeper aquifers. Owing to their high pumping volumes and frequent usage, irrigation wells can significantly impact local groundwater levels. When used as monitoring wells, they provide valuable insights into the effects of agricultural water use on groundwater availability and trends. Their inclusion in groundwater monitoring efforts can offer a perspective on deeper aquifer conditions.

Domestic (residential) wells are typically installed to supply drinking water to households. These wells are generally less deep and have lower extraction rates compared to agricultural or industrial wells. Their inclusion in groundwater monitoring efforts can offer a perspective on shallow aquifer conditions and the availability of potable water in rural areas.

Other wells include a range of wells that serve various purposes, such as stock wells for livestock, test wells for exploration purposes, and municipal and industrial wells for manufacturing or processing needs. Wells with insufficient information to determine their specific use type are also included in this category. The varied nature of these wells can complicate their data interpretation in monitoring programs.

Figure 5-8 displays the statewide distribution of groundwater level monitoring wells by well-use type. A summary of monitoring wells by well-use type within each hydrologic region is presented in Table 5-3. The most common well-use type used for monitoring groundwater levels statewide is *dedicated observation*, which accounts for nearly 45% (4,022) of total groundwater level monitoring wells. Presently, irrigation wells are the second most common well-use type for groundwater level observations and measurements, accounting for 28% (2,519) of

PUBLIC DRAFT

total monitoring wells. Domestic and other well use types combined account for nearly 21% (1,857), and wells with an unknown well use type represent the remaining 6% (582), down from 19% in 2018 as reported in California's Groundwater Update 2020.

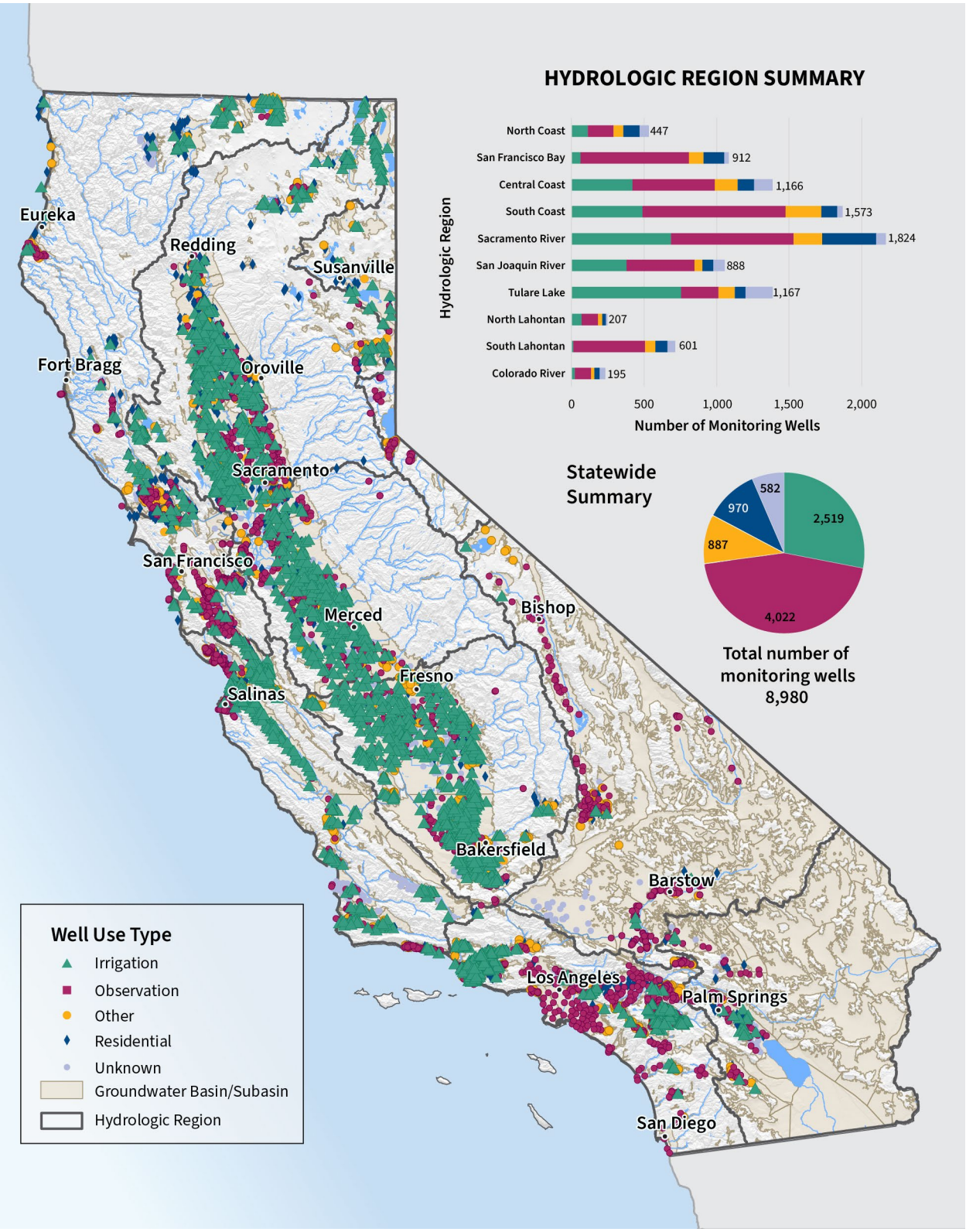
In the Central Valley, which includes portions of Tulare Lake, San Joaquin River, and the Sacramento River hydrologic regions, irrigation wells are used for nearly 61% (1,529) of the monitoring wells. In contrast, the coastal regions — comprising the San Francisco Bay, Central Coast, and South Coast hydrologic regions — have the highest number of dedicated observation wells, accounting for approximately 48% (1,940) of all monitoring wells.

Table 5-3 Number of Groundwater Level Monitoring Wells by Well-Use Type and Hydrologic Region (Water Years 2019–2024)

Hydrologic Region	Dedicated Observation	Irrigation	Domestic	Other Use Types	Unknown Use Type	Total
North Coast	150	93	94	57	53	447
San Francisco Bay	631	50	122	84	25	912
Central Coast	478	353	96	132	107	1,166
South Coast	831	411	93	207	31	1,573
Sacramento River	712	576	314	166	56	1,824
San Joaquin River	395	318	64	45	66	888
Tulare Lake	217	635	63	95	157	1,167
North Lahontan	96	57	22	23	9	207
South Lahontan	417	9	71	59	45	601
Colorado River	95	17	31	19	33	195
Statewide	**4,022**	**2,519**	**970**	**887**	**582**	**8,980**

PUBLIC DRAFT

Figure 5-8 Groundwater Level Monitoring Wells by Well-Use Type (Water Years 2019-2024)



5.2.7 Groundwater Level Monitoring Wells by Well Depth

Monitoring networks in California's groundwater basins and non-basin areas can be very different from each other mostly because of variations in geology, groundwater pumping locations (land use), available resources, and the presence of interconnected surface water. Some basins consist of single aquifer systems, while others are highly complex, with multiple stacked aquifers separated by impermeable layers or lenses. In addition, monitoring in non-basin areas can be particularly challenging as these areas often lack discernible aquifer systems, with groundwater moving through fractures in bedrock or bedrock-like material.

Throughout the state, groundwater level measurements are collected from monitoring wells with variable depths, ranging from less than 30 feet to more than 2,000 feet below the ground surface. These wells target different zones or aquifers and serve various purposes, such as monitoring interconnected surface water, assessing water quality, and other groundwater related studies. Depending on the complexity of the basin, measuring wells at varying depths provide a more comprehensive understanding of groundwater dynamics, such as the interaction between different aquifer layers, groundwater-surface water exchanges, and the impacts of groundwater pumping at different depths. Figure 5-9 displays the depth of actively monitored groundwater wells according to the defined well-depth categories. Table 5-4 provides a summary of monitoring wells by well depth and hydrologic region. Shallow monitoring wells, with depths less than 200 feet, account for 30% (2,716) of the monitoring wells, emphasizing the importance of capturing data on near-surface groundwater conditions and shallow aquifers. Intermediate monitoring wells are the most common depth or zone monitored, with depths ranging from 200 to 600 feet. These wells account for 37% (3,327) of the monitoring wells.

Deep monitoring wells provide insights into the conditions of deeper aquifer zones that are often isolated from surface influences. Wells with depths ranging from 601 to 1,000 feet account for nearly 13% (1,139), wells with depths ranging from 1,001 to 1,500 feet account for 5% (452), and wells with depths of 1,501 feet or more account for nearly 2% (171) of the monitoring wells. Deep monitoring wells tend to be more expensive to construct, which might explain the lower overall number of deep monitoring wells. Deeper monitoring wells help identify long-term trends, such as declining groundwater levels from over-pumping, which might not be evident in shallower wells.

PUBLIC DRAFT

The reported totals and percentages above could significantly change if the monitoring wells with unknown depths were known. Statewide, 13% (1,175) of the monitoring wells are reported with unknown well depths. Although there are still a high percentage of monitoring wells with unknown depths, the percentage of monitoring wells with unknown well depths is down from 26% (2,911) in 2018.

For shallow groundwater monitoring, the Sacramento River hydrologic region has the highest number of shallow wells with 670, indicating a strong focus on monitoring groundwater conditions in the upper aquifer layers in this area. In contrast, regions like the Tulare Lake and Colorado River hydrologic regions have only 79 and 12 shallow monitoring wells respectively, which may be attributable to different hydrogeologic conditions or monitoring priorities.

For deep monitoring wells of 1,001 feet or more, the South Coast, Tulare Lake, and South Lahontan hydrologic regions have the highest quantities, with 200, 191, and 104 deep wells respectively. In comparison, the Central Coast, Colorado River, North Coast, North Lahontan, San Francisco Bay, and San Joaquin River hydrologic regions collectively account for 81 deep monitoring wells, indicating a lesser emphasis on tracking conditions in the deeper aquifer zones in these areas.

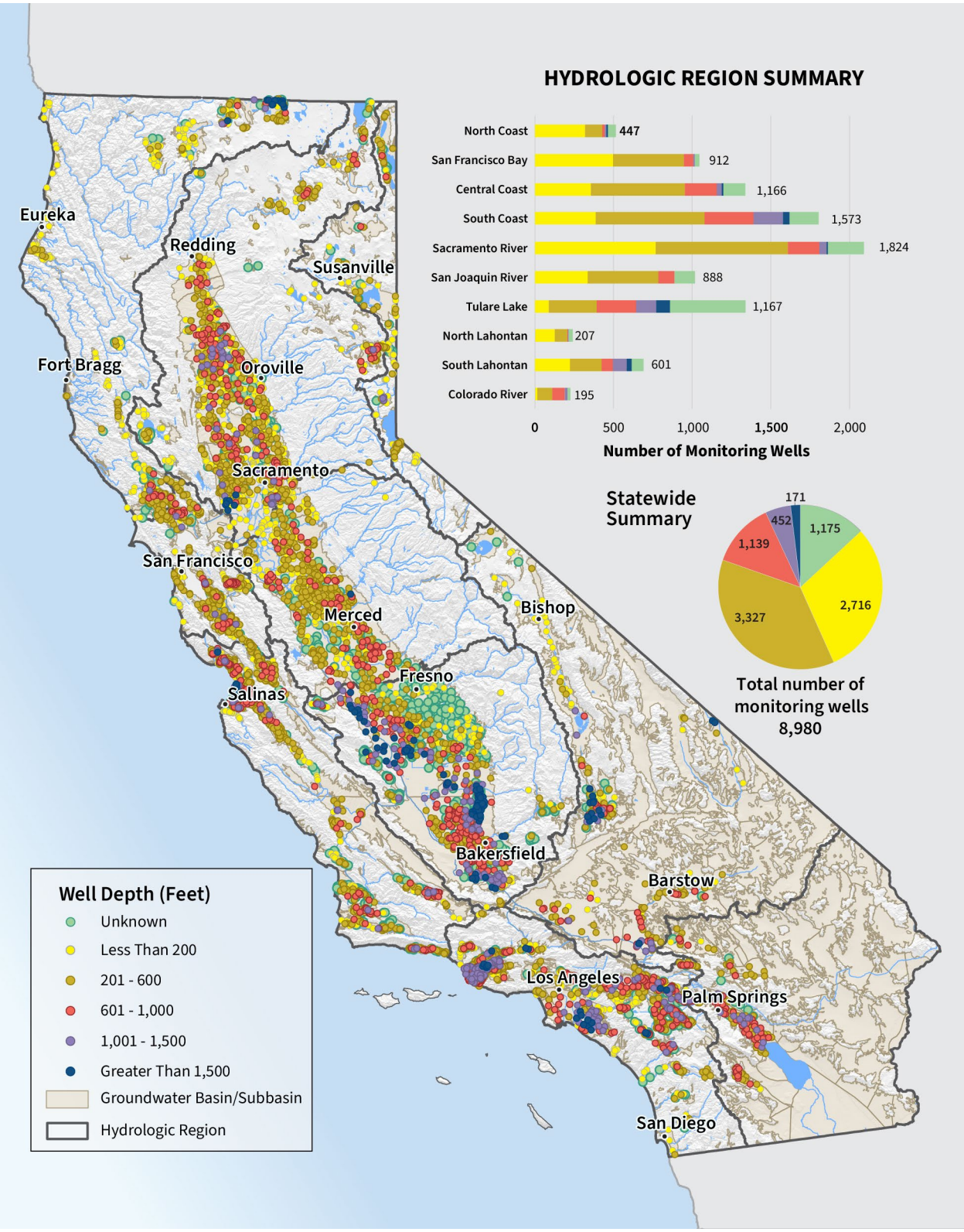
PUBLIC DRAFT

Table 5-4 Number of Groundwater Monitoring Wells by Well Depth in each Hydrologic Region (Water Years 2019–2024)

Hydrologic Region	Less than 200 ft	201–600 ft	601–1,000 ft	1,001–1,500 ft	Greater than 1,500 ft	Unknown Depth	Total
North Coast	278	95	16	5	11	42	447
San Francisco Bay	433	393	54	6	0	26	912
Central Coast	310	521	178	28	9	120	1,166
South Coast	337	604	271	164	36	161	1,573
Sacramento River	670	732	176	40	7	199	1,824
San Joaquin River	293	391	89	1	1	113	888
Tulare Lake	79	263	220	111	80	414	1,167
North Lahontan	110	68	4	3	0	22	207
South Lahontan	194	177	62	77	27	64	601
Colorado River	12	83	69	17	0	14	195
Statewide	**2,716**	**3,327**	**1,139**	**452**	**171**	**1,175**	**8,980**

PUBLIC DRAFT

Figure 5-9 Groundwater Level Monitoring Wells by Well Depth, in Feet (Water Years 2019-2024)



5.3 Change in Groundwater Storage Monitoring

Change in groundwater storage is one of the six sustainability indicators under SGMA used to assess the balance between groundwater recharge and extraction and ensure a basin's long-term sustainability. It refers to the difference in the volume of groundwater in an aquifer between two specified time periods. Understanding changes in groundwater storage is essential for assessing the balance between inflows and outflows in a groundwater system, which serves as a critical measure of groundwater conditions. For example, a negative change in groundwater storage, especially over extended periods, signals an imbalance where pumping exceeds recharge. This imbalance can lead to negative consequences, such as declining groundwater levels and land subsidence, which undermine the groundwater sustainability of the basin.

Direct measurement of changes in groundwater storage is not possible; therefore monitoring efforts focus on estimating these changes using indirect methods. One of the most common approaches is analyzing groundwater levels from two different time periods to approximate changes in storage. This method assumes a relationship between water level fluctuations and the volume of water stored within an aquifer, which is determined by aquifer parameters; however, to improve accuracy and account for spatial variations, other estimation methods are also utilized. These include numerical models, which simulate groundwater flow and storage dynamics; remote sensing technologies, which use satellite-based observations to determine gravimetric changes and/or detect land surface changes related to groundwater depletion; and water balance calculations, which assess the difference between inflows and outflows within a groundwater system. By combining multiple methods, agencies can develop a more comprehensive understanding of groundwater storage trends and sustainability. These methods and estimates of change in groundwater storage for various periods are presented in Chapter 6, "Groundwater Conditions."

GSAs have been reporting changes in groundwater storage as part of the GSP annual reporting requirements since 2020 (covering WY 2019 and later). Initially, these reports only covered basins subject to critical conditions of overdraft. By 2022, all remaining high- and medium-priority basins subject to SGMA began providing change in groundwater storage estimates, starting with WY 2021. This data is summarized in Chapter 6, "Groundwater Conditions."

PUBLIC DRAFT

5.4 Groundwater Quality Monitoring

Groundwater quality monitoring is essential for detecting and evaluating chemical concentrations in groundwater, assessing potential contamination risks, ensuring water safety for various uses, and supporting sustainable groundwater management by identifying trends and emerging water quality concerns. Groundwater quality monitoring is performed for many reasons and at thousands of locations throughout California. Both anthropogenic (those originating from human activities) and naturally occurring chemicals can be found in groundwater. Drought and excessive groundwater extraction, exacerbated by climate change, can influence groundwater quality by mobilizing and increasing the concentration levels of both anthropogenic and naturally occurring chemicals (Haugen et al. 2021; Levy et al. 2021; Levy et al. 2024).

Degraded groundwater quality presents significant challenges for water managers in California, including the need to install treatment systems, blend water sources, abandon wells, and seek alternative water supplies. In areas where groundwater is used as a potable water source, monitoring chemical concentrations is especially important because certain chemicals can be harmful to human health if consumed above safe levels. Elevated chemical concentrations in groundwater can also impact irrigation practices and crop productivity, reduce groundwater availability for urban and domestic users, and disrupt other beneficial uses of groundwater. Additionally, degraded groundwater quality can introduce harmful chemicals into interconnected surface waters, causing serious harm to groundwater dependent ecosystems.

To monitor groundwater quality, DWR and other organizations and agencies test well water using various methods. The simplest method involves inserting a probe directly into a well to measure parameters such as temperature, pH, dissolved oxygen, and nitrate. However, probes can measure only a few constituents in a limited range of values, so water samples are often collected for more detailed analysis. This can be done using a water sleeve or a submersible pump, depending on the required water volume and constituent of interest. Samples are stored in clean containers and transported to a laboratory for comprehensive testing. Laboratory analysis provides the most accurate data but can be costly and often requires prompt chemical analysis to prevent sample degradation. DWR frequently uses the Bryte Chemical Laboratory for groundwater quality analysis and makes the results publicly available through the Water Data Library.

PUBLIC DRAFT

The State Water Resources Control Board (State Water Board) has the primary responsibility for monitoring and regulating groundwater quality in the state. It operates various programs to detect, evaluate, and remediate groundwater contamination. Groundwater quality monitoring data collected by the State Water Board are stored in the Groundwater Ambient Monitoring Assessment (GAMA) Geographic Information System (GIS) database, the largest groundwater quality monitoring repository in California. GAMA includes groundwater quality data from numerous regulatory and non-regulatory programs across the state, including DWR data from the Water Data Library. Water quality monitoring wells include dedicated monitoring wells as well as domestic, irrigation, municipal, and other supply wells that take water quality measurements.

As of July 2024, the GAMA database contains more than 25 million individual records from nearly 116,000 unique wells used for municipal, domestic, irrigation, and industrial water supply purposes. To evaluate this data, a subset of wells monitored for any of the eight constituents of concern (COC) is considered because they are commonly found in groundwater, frequently measured, and identified as concerns for groundwater sustainability (see Chapter 6, "Groundwater Conditions," for detailed water quality conditions). These constituents are: 1,2,3-trichloropropane (1,2,3-TCP), nitrate as nitrogen (NO3N), arsenic (As), uranium (U), total dissolved solids (TDS), hexavalent chromium (Cr(VI) or Cr6), perfluorooctanoic acid (PFOA), and perfluorooctane sulfonate (PFOS). Figure 5-10 shows the locations of the 33,922 monitoring wells in GAMA that track these eight COCs.

For these COCs, the Central Coast Hydrologic Region has more wells with measurements (11,822 wells) than any other hydrologic region, accounting for 35% of the groundwater quality wells analyzed here. The San Joaquin River and Tulare Lake hydrologic regions have the second and third highest number of wells, with approximately 5,000 wells each. Table 5-5 displays the number of groundwater quality monitoring wells in GAMA that monitor any of the eight COCs, categorized by hydrologic region, as well as basin and non-basin areas.

PUBLIC DRAFT

Table 5-5 Number of Groundwater Quality Monitoring Wells in GAMA Database that Monitor at Least One of the Eight COCs by Hydrologic Region and Basin and Non-Basin Area (Water Years 2014–2023)

Hydrologic Region	Basin	Non-Basin	Total
North Coast	784	417	1,201
San Francisco Bay	742	417	1,159
Central Coast	10,204	1,618	11,822
South Coast	2,614	637	3,251
Sacramento River	2,438	1,098	3,536
San Joaquin River	4,234	1,041	5,275
Tulare Lake	4,650	438	5,088
North Lahontan	208	122	330
South Lahontan	1,193	261	1,454
Colorado River	719	87	806
Total	**27,786**	**6,136**	**33,922**

Table 5-5 Note: GAMA = Groundwater Ambient Monitoring Assessment.

PUBLIC DRAFT

Figure 5-10 Groundwater Quality Monitoring Wells in GAMA Database that Monitor at Least One of the Eight COCs (Water Years 2014–2023)

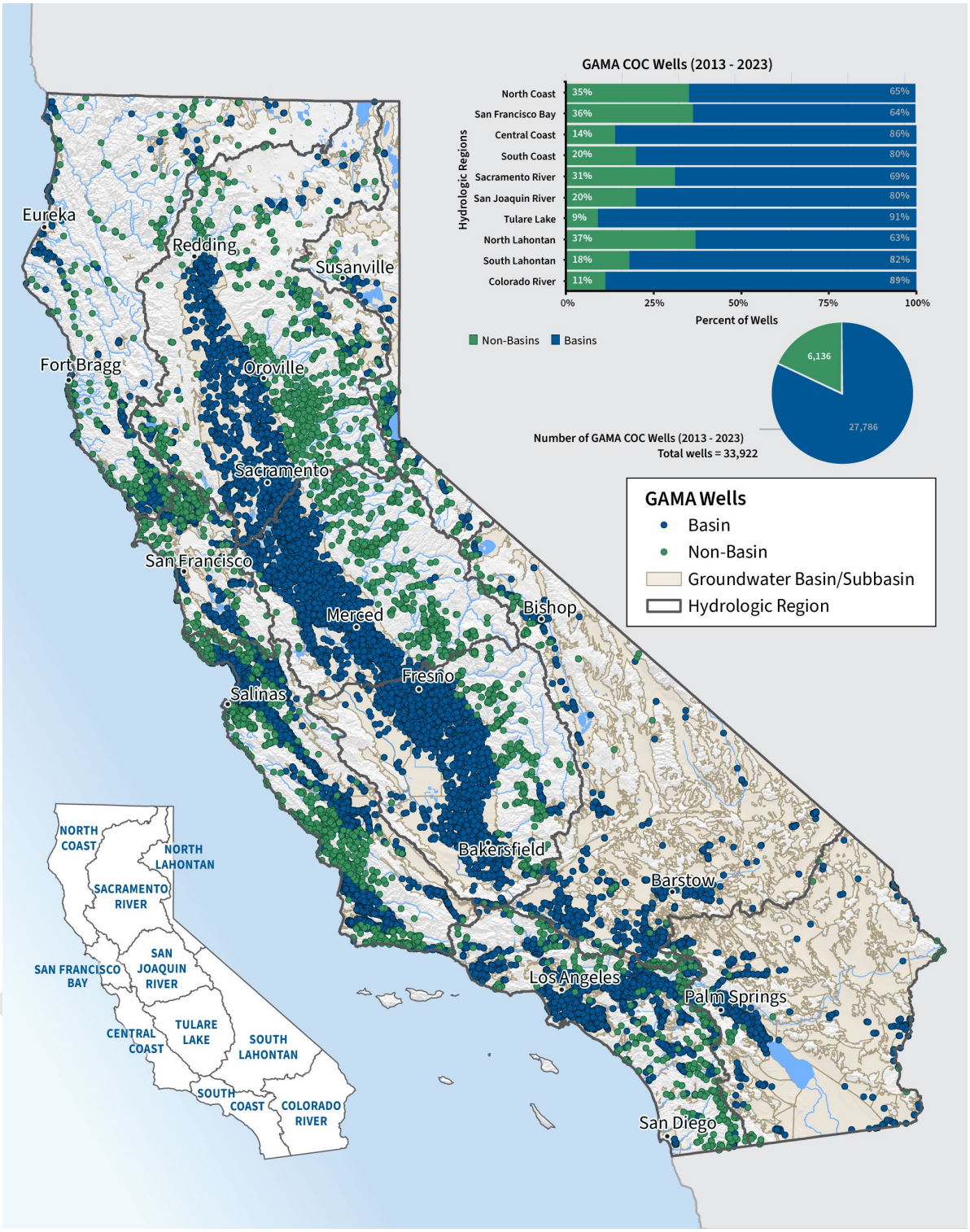


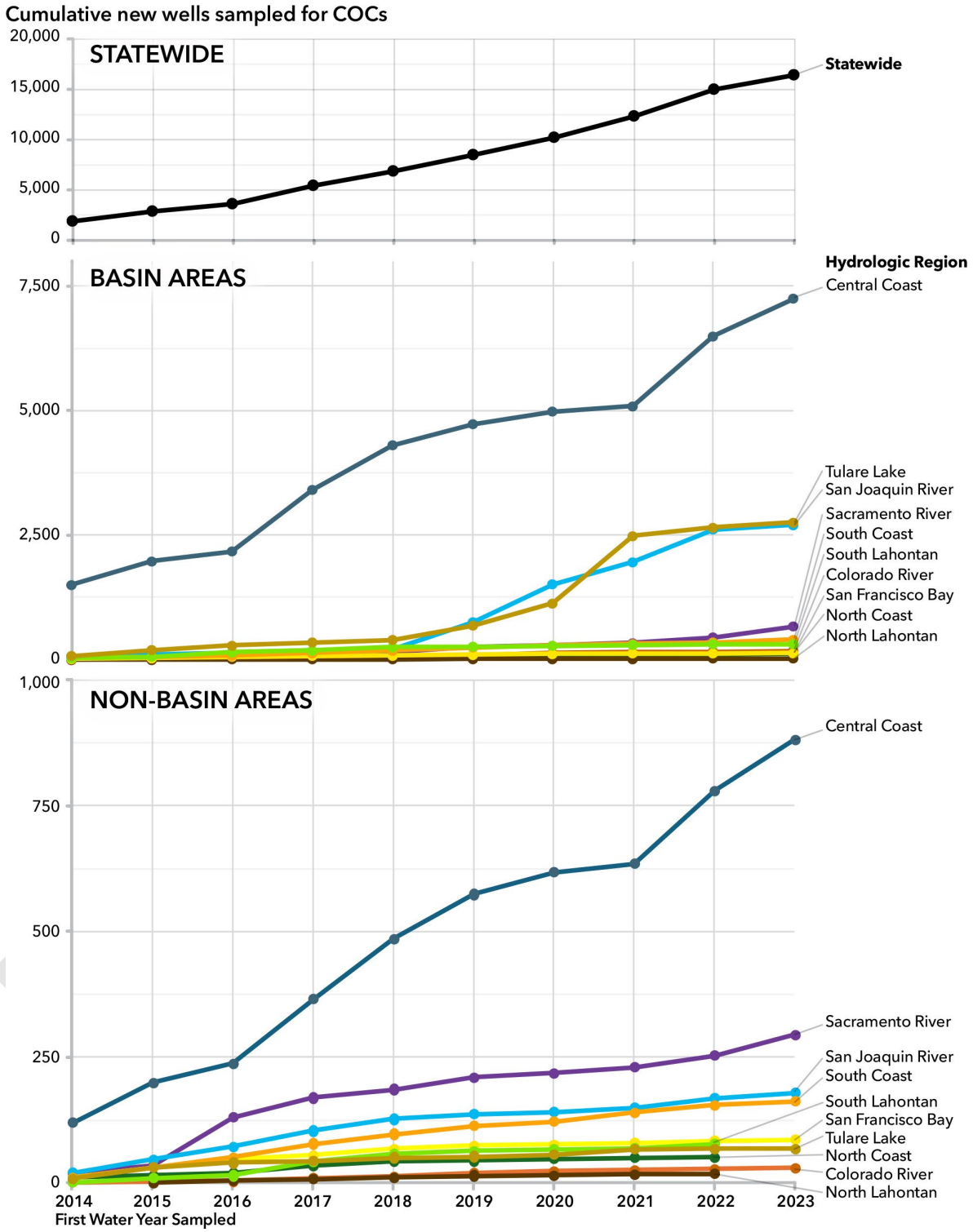
Figure 5-10 Note: GAMA = Groundwater Ambient Monitoring Assessment.

Some water quality monitoring wells have been sampled for decades, while others are more recent additions. These may include older wells that were previously unsampled or newly drilled wells added to the monitoring network. Newly sampled wells may be tested for just one of the eight key constituents of concern, but any new data contributes to progress toward sustainability. This updated information helps local water managers make informed decisions. Tracking the number of newly sampled wells across different hydrologic regions provides valuable insight into the pace of progress in expanding groundwater quality monitoring and filling data gaps.

Of the 33,922 wells evaluated for the eight COCs, 16,419 wells (about 48%) had not been sampled prior to WY 2014 for any of the eight COCs. Figure 5-11 shows the cumulative sum of newly sampled wells for these COCs added to GAMA each year from Water Years 2014–2023. Newly sampled wells include wells used for municipal, domestic, irrigation, industrial, and water supply purposes. The annual growth (indicated by change in the slope of the cumulative curve) of new wells sampled varies by hydrologic region. The Central Coast Hydrologic Region had the greatest number of new wells sampled (8,134) since 2014, followed by the San Joaquin Hydrologic Region (2,884) and the Tulare Lake Hydrologic Region (2,826). Additionally, the rate of new wells sampling differs between basin and non-basin areas. The non-basin areas of the Central Coast Hydrologic Region had the greatest number of new wells sampled (881) since 2014, followed by the Sacramento River Hydrologic Region (295) and the San Joaquin River Hydrologic Region (180). For additional information on well sampling and data, see the Aquifer Risk Map and other tools developed by the State Water Board as part of the Safe and Affordable Funding for Equity and Resilience Program.

PUBLIC DRAFT

Figure 5-11 Cumulative Count of Groundwater Quality Monitoring Wells in the GAMA Database Sampled for the First Time for at Least One of Eight COCs (WY 2014–WY 2023)



Wells sampled for the first time help fill data gaps in both space and time. When these wells are located in frontline communities, they support evaluation of vulnerability and equity in regard to groundwater quality. Historically, these communities have experienced a disproportionate amount of impacts caused by degraded water quality and may not have the necessary monitoring to detect such changes or the tools to access relevant information. A precondition for achieving equity in water quality monitoring is ensuring adequate sampling across a wide geographic area that includes frontline communities, with sufficient frequency and access to tools. This ensures that the necessary data are available to assess groundwater quality and inform planning and any necessary management actions.

Groundwater quality monitoring is also essential for defining the Base of Freshwater (see Chapter 3, "California's Natural and Built Groundwater Infrastructure"). In many groundwater basins, including the Central Valley, fresh groundwater lies above deeper saline groundwater. As freshwater is extracted, moderately saline groundwater may migrate upward, raising the base of freshwater and reducing the total volume of fresh groundwater storage. Some GSAs use the Base of Freshwater to define volumes of groundwater storage for sustainable management. By systematically measuring salinity levels at different depths over time, groundwater quality monitoring helps identify shifts in the freshwater-saline water interface in the aquifer, track long-term changes, and refine the definition of the base of freshwater. This information enables GSAs to more accurately assess groundwater availability and support sustainable management efforts.

5.4.1 Groundwater Quality Monitoring Under SGMA

As part of SGMA, GSAs are required to define and monitor degraded water quality as an undesirable result. Additionally, alternative plans monitor basins for specific constituents of concern. Because different basins have different geology, agriculture, and industry, GSAs have identified different constituents to monitor; however, several constituents are commonly measured across hydrologic regions. Table 5-6 provides a summary of the three most common constituents monitored by GSAs by Hydrologic Region. The North Lahontan Hydrologic Region is listed as "No GSPs" because no basin in the region submitted a GSP. The alternative plans were not included in this analysis. In the South Lahontan Hydrologic Region, constituents such as arsenic, chlorine, and sodium occur with equal frequency across the plans analyzed.

PUBLIC DRAFT

Table 5-6 Three Most Commonly Monitored Constituents by GSPs by Hydrologic Region

Hydrologic Region	Constituents	Number of Plans Monitoring
North Coast	NO3N	6
	SC	4
	As	3
San Francisco Bay	TDS	4
	NO3N	4
	As	4
Central Coast	TDS	22
	NO3N	20
	Cl	18
South Coast	TDS	14
	NO3N	14
	Cl	6
Sacramento River	TDS	13
	NO3N	5
	SC	5
San Joaquin River	TDS	16
	NO3N	8
	As	6
Tulare Lake	As	21
	NO3N	20
	1,2,3-TCP	17
North Lahontan	No GSPs	No GSPs
South Lahontan	TDS	4
	As, Cl, Na	3
	NO3N	3
Colorado River	TDS	1
	NO3N	1

Table 5-6 Notes: Plans that did not define specific constituents are excluded. SC = specific conductivity, As = arsenic, Na = sodium, NO_3N = nitrate as nitrogen, Cl = chlorine, TDS = total dissolved solids, 1,2,3-TCP = 1,2,3-trichloropropane.

Constituents that contribute to undesirable results are defined at the local level but they generally correspond to or overlap with with the eight COCs identified in this report. For more detailed information regarding other constituents, refer to individual GSPs and Alternative Plans on the SGMA Portal. Figure 5-12 shows the water quality monitoring networks for GSPs and Alternative Plans as of July 2024.

PUBLIC DRAFT

The networks are reviewed and updated on an annual basis and are important for informing the projects and management actions for sustainable groundwater management. Projects such as managed aquifer recharge can impact water quality by transporting constituents or introducing reactive oxygen, necessitating continuous monitoring to detect changes and ensure effective management. The extent of change in water quality from managed aquifer recharge remains an active area of research (Harkness et al. 2023; Haugen et al. 2021). Results from these studies will assist in improving sustainable groundwater management practices across California.

PUBLIC DRAFT

Figure 5-12 Groundwater Quality Monitoring Wells Available in the Monitoring Network Module for GSPs and Alternatives

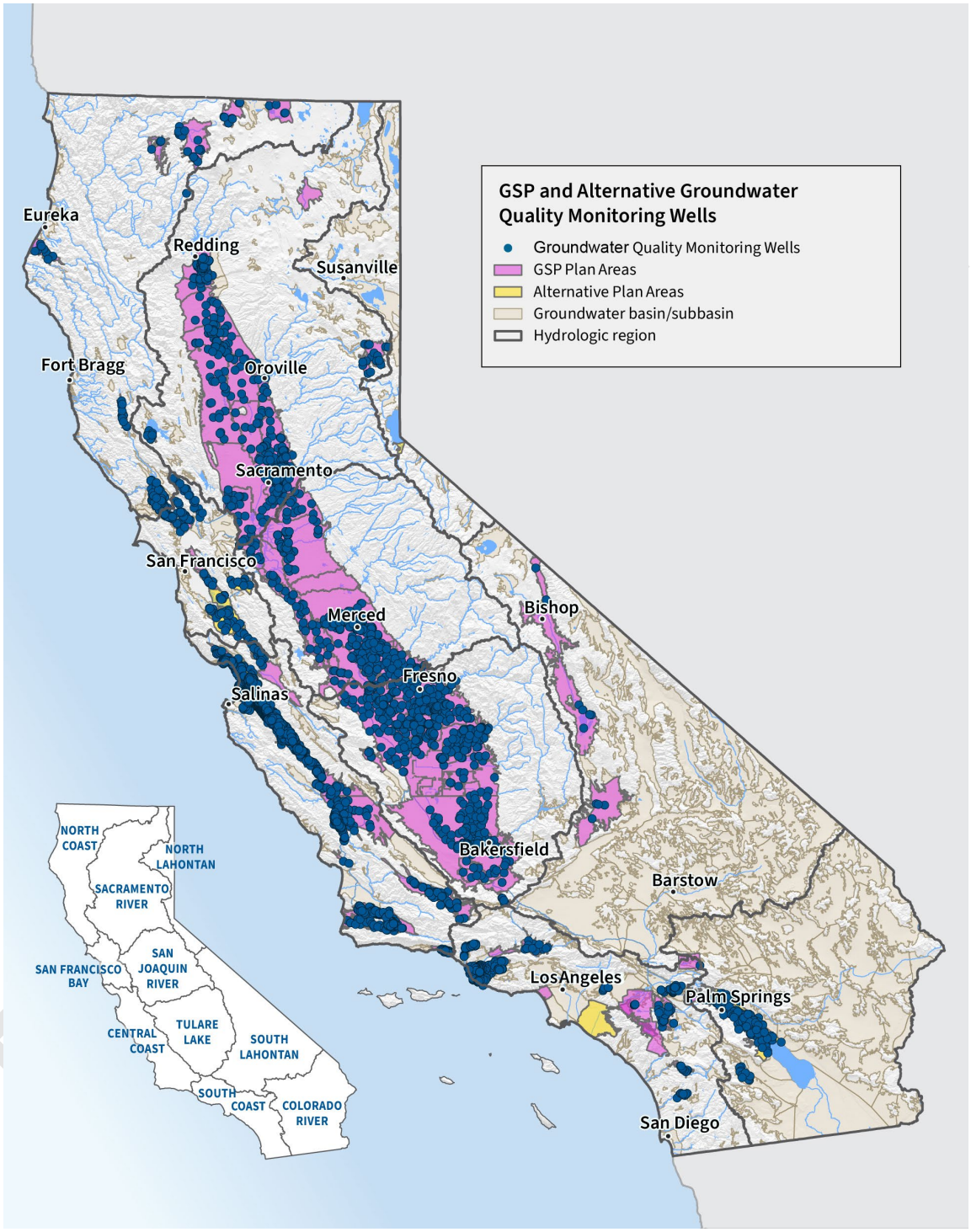


Figure 5-12 Notes: Monitoring wells as reflected by the GSP Monitoring Network Module as of July 2024, which includes some Alternative Plans. Some networks were provided to DWR directly as part of outreach in August 2024.

5.5 Land Subsidence Monitoring

Land subsidence is a gradual settling or sudden sinking of the Earth's surface resulting from removal or displacement of subsurface earth materials. Land subsidence in California can be caused by compaction associated with groundwater level declines, oil and natural gas withdrawals, and the drainage of organic soils. In some parts of the state, tectonic activity can also play a role by raising or lowering the ground surface. When groundwater is extracted from aquifers in excessive quantities, the groundwater levels decline and water pressure decreases, causing more of the weight of the overlying sediments to be supported by the aquifer's skeletal framework (the remaining sediment structure after the removal of water). If these sediments have not previously been stressed, such as from a previous lowering of groundwater levels, the overlying sediments may compact or compress the aquifer skeleton and cause the land surface to subside. The magnitude and permanence of subsidence (whether it is elastic or inelastic) depend on several factors, including the volume, duration, and timing of groundwater extraction and recharge, as well as sediment type and the extent of sediment beds. Subsidence can cause damage to existing surface and subsurface infrastructure, cause groundwater wells to fail, reduce available groundwater storage, alter the natural water flow patterns, and affect groundwater dependent ecosystems.

Subsidence monitoring has been conducted sporadically since the 1950s in select locations across the state. Because of advances in technology, such as satellite imagery and remote sensing, land subsidence monitoring coverage has expanded since the 1990s. Initially, there were two primary methods for detecting and monitoring subsidence: spirit-level surveying and borehole extensometers. Spirit-level surveying measures changes in the land surface elevation using established reference locations called *benchmarks*. Borehole extensometers, on the other hand, measure aquifer compaction by using a specialized well casing that compresses vertically as land subsidence occurs. In the 1980s, the introduction of *total stations,* devices that combine an electronic distance measuring system with an electronic theodolite and computer software-enhanced subsidence monitoring, providing precise horizontal distance measurements to complement spirit-level surveying.

In the 1990s, researchers began using global positioning system (GPS) array monitoring, which can be used in small areas (portions of a basin) or on a regional scale (multiple basins). During this time, satellite-based remote sensing using interferometric synthetic aperture radar (InSAR) also emerged as a method to

PUBLIC DRAFT

detect deformation of the ground surface and has been found to be useful for basin analysis and monitoring. In 2019, DWR began providing public access to monthly statewide InSAR-based land subsidence data. Repeated light detection and ranging (LiDAR) is also employed to measure changes in the ground surface elevations. However, LiDAR measurements have a lower vertical resolution compared to other methods of measuring the elevation of land surface (Borchers and Carpenter 2014). Satellites and other remote-sensing-based monitoring cannot always differentiate between subsidence and changes in ground surface elevation resulting from activities such as farming practices or construction. Field verification may be needed to verify that the reported subsidence is actually occurring.

Subsidence monitoring data are publicly available from non-profit organizations such as the Scripps Orbit and Permanent Array Center and UNAVCO, a university-governed non-profit consortium for geosciences research using geodesy. Data are also provided by public agencies, including DWR, USGS, and other State and federal agencies.

This section discusses publicly available statewide DWR InSAR subsidence datasets, selected regional subsidence monitoring networks, continuous global positioning system (CGPS) stations, and borehole extensometer stations. Figure 5-13 displays the distribution of GPS stations, InSAR data coverage, borehole extensometers, and regional subsidence networks. A more comprehensive description of subsidence networks in operation throughout the state was compiled in the 2014 report, *Land Subsidence from Groundwater use in California* (Borchers and Carpenter 2014). Appendix I, "Update on Land Subsidence in California," of CalGW Update 2025 builds on that work and provides an updated analysis of land subsidence conditions across California.

PUBLIC DRAFT

Figure 5-13 Distribution of Continuous GPS Stations, Borehole Extensometers, InSAR Data Coverage, and Selected Regional Subsidence Networks

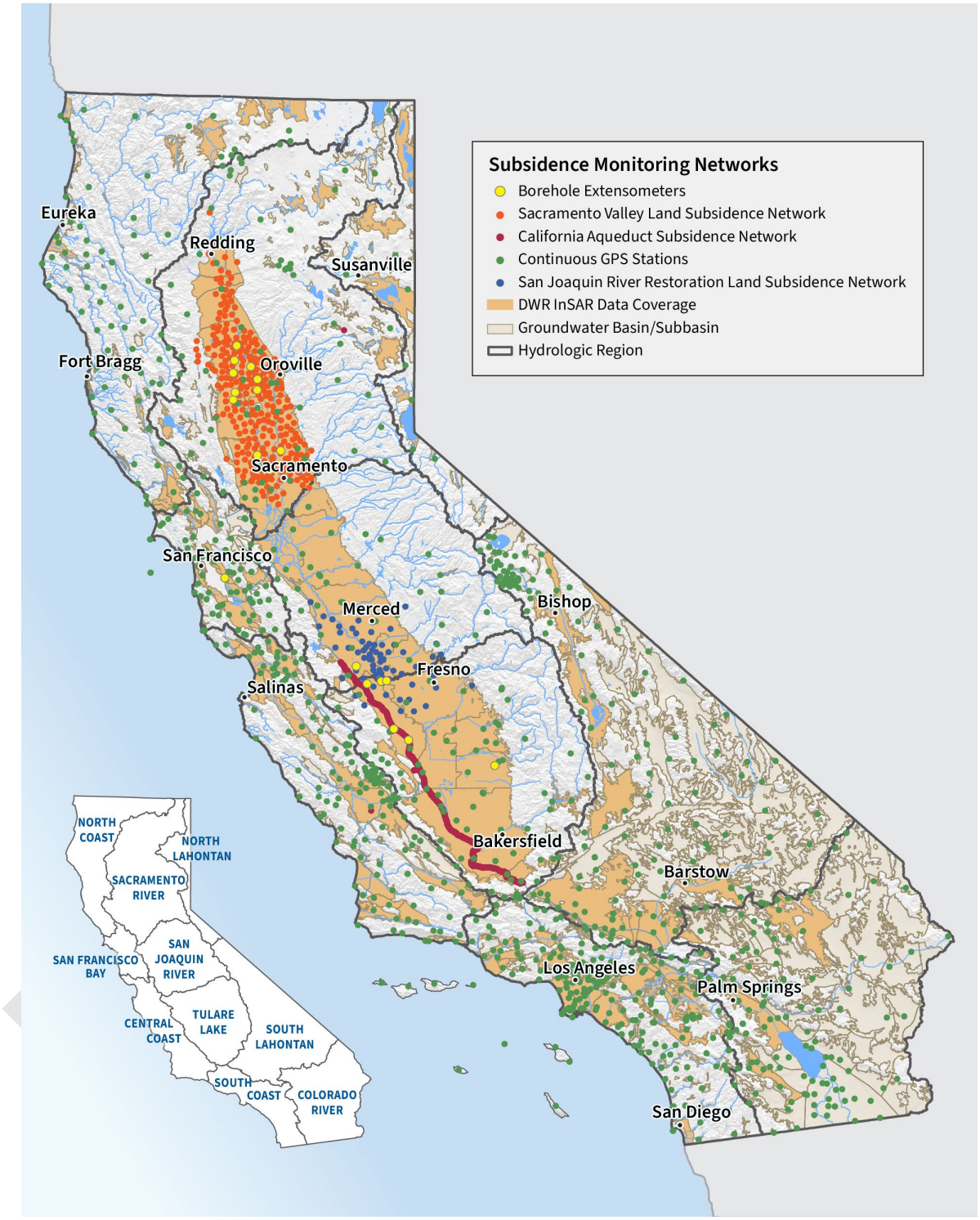


Figure 5-13 Note: GPS = global positioning system, InSAR = interferometric synthetic aperture radar.

5.5.1 Monitoring by Borehole Extensometer

A borehole extensometer records compaction within a portion of the aquifer by measuring changes in the distance from the ground surface to the depth in the subsurface where the extensometer is anchored. Earlier extensometers were typically built using a steel cable with an anchor weight at the bottom of the borehole and a counterweight at the surface to keep the cable under tension (Lofgren 1961). More recently, the cable has been replaced by a continuous steel pipe that rests on the bottom of the borehole that is often counterweighted to prevent the pipe from collapsing under its own weight. Many of the borehole extensometers in California were constructed in the 1950s and 1960s during the planning and construction of State and federal water projects. After completion of the water projects, and when groundwater levels recovered, funding for subsidence monitoring ended and borehole extensometer sites fell into disrepair or were abandoned (Borchers and Carpenter 2014).

As of November 2024, seven USGS borehole extensometers are recording compaction measurements in the San Joaquin Valley (six in Tulare Lake, one in San Joaquin hydrologic regions). Since 2020, these extensometers have been fitted with telemetry capabilities for near real-time data uploads and are operated and maintained by the USGS California Water Science Center. Five existing extensometers (two previously refurbished, and three additional "legacy" extensometers originally installed as early as 1958) are slated for refurbishment by the USGS in cooperation with DWR. Refurbishment includes repairs and improvements to reference tables and replacing the outdated cable systems with counterbalanced pipe-style extensometers. For locations of these active borehole extensometers, as well as 11 active DWR borehole extensometers in the Sacramento Valley, see Figure 5-13.

5.5.2 Monitoring by Leveling

Historically, monitoring subsidence in California was achieved through leveling techniques. Leveling is the oldest method used to precisely measure elevation and was commonly performed along linear infrastructure including roads and railroad tracks as part of initial construction or ongoing maintenance (U.S. Geological Survey 2018). The installation of benchmarks (or "monumenting") in California was generally first performed in 1901 by the U.S. Geological Survey and in 1906 by the U.S. Coast and Geodetic Survey (predecessor to the National Geodetic Survey [NGS]). The leveling technique allows the surveyor to carry an elevation from a known reference point (such as a benchmark) to other points by use of a precisely leveled telescope and a graduated rod resting vertically on temporary or

PUBLIC DRAFT

permanent benchmarks. Repeated surveys of the same benchmarks over time yield a series of elevations from which elevation changes are calculated. *Subsidence* is then the net negative change in elevation of the land surface between the surveys. Information on this survey type and measurement uncertainty is available in *Standards and Specifications for Geodetic Control Networks* (Federal Geodetic Control Committee 1984).

An extensive network of benchmarks was monumented and resurveyed in California by the NGS and other agencies primarily during 1906–1975. These surveys form the basis of the subsidence maps published in many historical reports. Figure 5–14 shows the distribution of leveling lines throughout California from 1901 through 2004. The spatial extent for an individual survey can be on the order of tens of miles with 10–100 measurements collected (examples of survey designs shown in Figure 5-15).

Leveling surveys can be labor intensive and are limited in their spatial extent as the line of sight between the instrument and location of interest needs to be maintained. Nowadays, GPS-based technologies are often used to measure subsidence in California rather than leveling surveys.

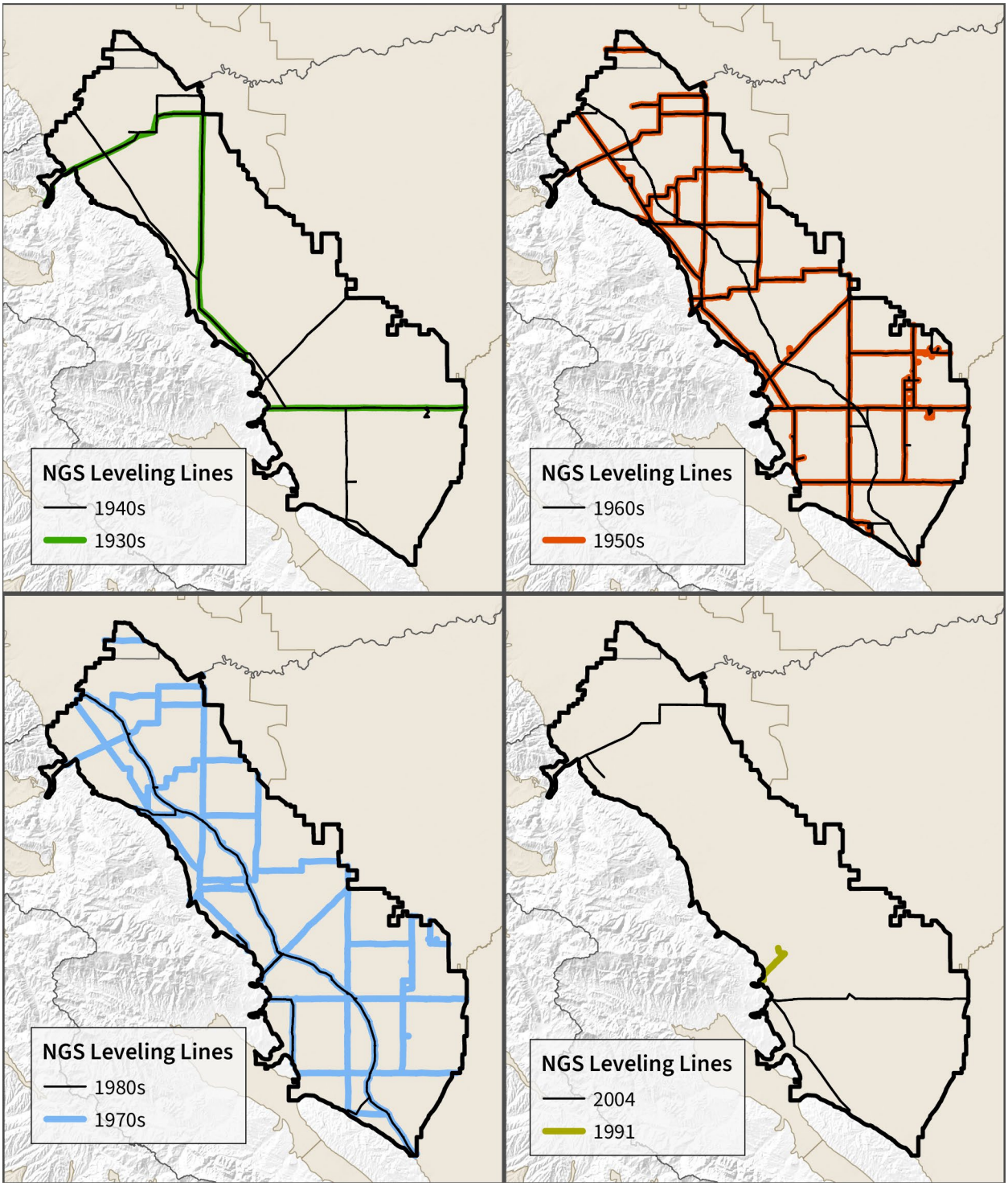
PUBLIC DRAFT

Figure 5-14 Distribution of Leveling Lines Throughout California from 1901 through 2004



Figure 5-14 Notes: NGS data: 1930s–1970s, USGS: early 1900s, USBR: 1960s–1970s, CalTrans: 1973 and 2004.

Figure 5-15 **Distribution of Historical Leveling Lines in the Westside Subbasin**

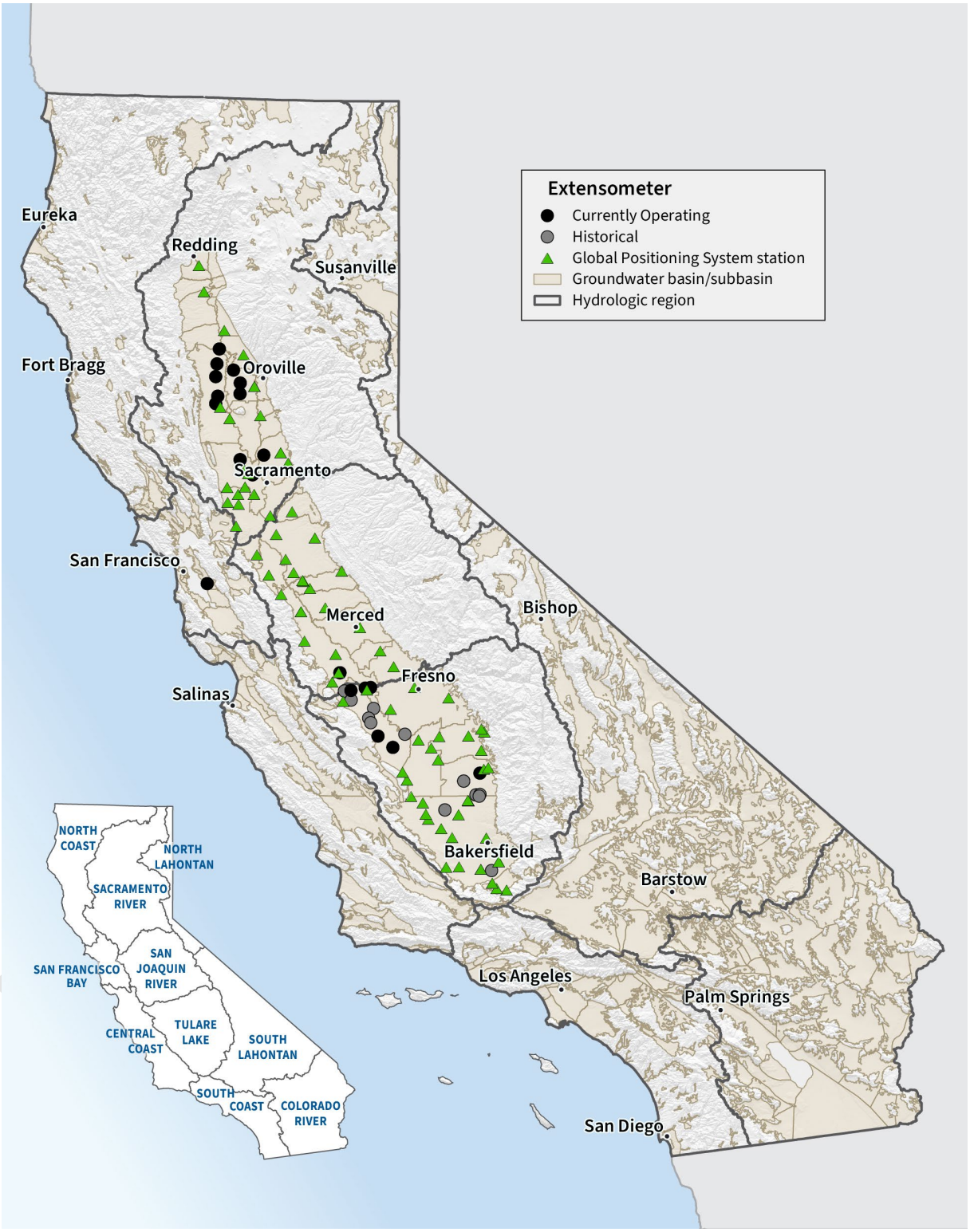


5.5.3 Monitoring by Continuous Global Positioning System

Continuous Global Positioning System (CGPS) monitoring stations record horizontal and vertical ground surface displacement with high frequency. Scripps Orbit and Permanent Array Center (SOPAC) and UNAVCO maintain statewide networks of CGPS stations that record the real-time GPS data, which is available online. As of November 2024, the SOPAC network includes 398 CGPS stations within California groundwater basins. Figure 5-16 shows the location of borehole extensometers and GPS stations in the Central Valley.

PUBLIC DRAFT

Figure 5-16 Location of borehole extensometers and Global Positioning System stations in the Central Valley



In 2023, DWR started installing Continuous GPS Stations in groundwater basins to further improve the statewide subsidence monitoring network. As of November 2024, eight stations producing daily subsidence measurements have been installed in the following basins: Kern County, Tule, Kaweah, and Westside, and DWR is planning additional stations to be installed statewide. All GPS Stations installed by DWR will be added to the SOPAC network.

5.5.4 Monitoring by Interferometric Synthetic Aperture Radar

InSAR is a remote sensing technique that uses satellite radar images taken at different times to measure the deformation of the Earth's surface at a high degree of spatial detail and measurement resolution (U.S. Geological Survey 2000). In 2018, DWR contracted with TRE Altamira to process and evaluate InSAR data collected by the European Space Agency's Sentinel remote sensing satellites from January 2015 through June 2018 for more than 150 groundwater basins and subbasins, with a geographical coverage of about 40,000 square miles. DWR has since released annual updates and in 2022 increased the reporting frequency from annually to quarterly to provide more up-to-date information. The TRE Altamira InSAR dataset has a horizontal resolution of 100 meters and provides land subsidence measurements in monthly timesteps. InSAR's data quality is influenced by changes at the land surface over time, including agricultural cropping practices. Low-quality data were removed from the dataset by TRE Altamira; areas associated with the low-quality data appear as blank areas in Figure 5-13.

Quarterly InSAR dataset updates are released to the public on the California Natural Resources Agency's (CNRA) Open Data website and on the SGMA Data Viewer. As of December 2024, DWR's statewide InSAR coverage extends through October 2024. DWR will coordinate with other State Agencies on maintenance and improvements to InSAR-based subsidence monitoring. When it becomes available, DWR's subsidence monitoring program will incorporate InSAR data from the upcoming NISAR mission, a partnership between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO).

InSAR data from past satellite missions can be processed to provide historical subsidence data. Spatial coverage, monitoring frequencies, and accuracy of resulting subsidence data products vary by satellite. DWR released subsidence data from the Envisat satellite for years 2003–2010 and from the Radarsat-2 Satellite acquired between 2011 and 2015 on the CNRA Open Data website.

PUBLIC DRAFT

Along with the installation of continuous GPS stations, DWR will begin the installation of InSAR corner reflectors that improve InSAR data coverage and fill subsidence monitoring data gaps in 2025.

5.5.5 Regional Monitoring Networks

Regional land subsidence monitoring networks with publicly available data are discussed below.

GPS Survey of the Sacramento Valley Land Subsidence Network

In 2008, DWR developed a series of survey monuments (markers that define a geographic position) in the Sacramento Valley to create a regional land subsidence monitoring network. The network encompasses all or part of 11 counties, from Shasta County at the north end of the valley to Solano and Sacramento counties on the south end. The network includes more than 300 monuments with an average spacing of 4.3 miles (7 kilometers). During the spring and summer of 2008, DWR, along with 25 local, State, and federal cooperators, performed an initial survey of the GPS network to establish a measurement baseline.

DWR resurveyed the regional subsidence monitoring network in 2017 with assistance from 19 State, county, and local agencies, and one private entity. The methods and equipment were similar to those used in the 2008 survey. The results were analyzed by comparing the measured height of each monument in the grid recorded in 2008 with the measured height of the same monuments in 2017 and reporting the detected differences. The results, released in 2019, reported the change in height from 2008 to 2017 at each of the monuments and are included in the Sacramento Valley GPS Subsidence Network Report (California Department of Water Resources 2019).

California Aqueduct Land Subsidence Monitoring Network

DWR conducts periodic land surface elevation surveys along the California Aqueduct to estimate the extent of land subsidence. Repeated surveys compare elevations along specific portions of the aqueduct in Fresno and Kings counties to the 1967 baseline survey. Fifteen surveys occurred from 1968 through 2015 on approximately three-year intervals. DWR's California Aqueduct survey results are reported after each survey. The most recent results are available in the 2017 *California Aqueduct Subsidence Study* and the 2019 *California Aqueduct Subsidence Study: Supplemental Report.* California Aqueduct Subsidence Study

PUBLIC DRAFT

data through 2024 are available on the California Natural Resources Agency's Open Data website.

San Joaquin River Restoration Program Land Subsidence Monitoring Network

The U.S. Bureau of Reclamation surveys a network of more than 70 control points for land subsidence across the San Joaquin Valley as part of the San Joaquin River Restoration Program. Under the existing program, each control point is measured every July and December to monitor land subsidence. Results are reported biannually.

GSP Land Subsidence Monitoring Networks

As part of SGMA compliance, GSAs have established monitoring networks for each sustainability indicator, including land subsidence. GSP land subsidence monitoring networks need to be designed to identify the rate and extent of land subsidence, which may be measured by extensometers, surveying, remote sensing technology, or other appropriate methods. GSAs have developed measurable objectives, interim milestones, and minimum thresholds for each monitoring site. GSAs submit annual reports to DWR that include a description of progress toward implementing the plan, including achieving interim milestones for each applicable sustainability indicator.

Groundwater Level Monitoring in Support of Land Subsidence Management

Groundwater level declines drive land subsidence in susceptible areas. While land subsidence monitoring frequency has improved through the availability of telemetered data from extensometer sites and continuous GPS stations, as well as statewide monthly InSAR data, groundwater levels are only collected semi-annually and reported after 30 days of collection for most monitoring sites. Since inelastic compaction is irreversible, groundwater level measurements should be taken at a higher frequency and reported with minimal lag time to support adaptive land subsidence management. It is recommended that groundwater level measurements be taken at least monthly, or more frequently, to capture seasonal lows and support analysis of the relationship between groundwater levels and land subsidence trends. Groundwater level monitoring networks should be designed to provide sufficient coverage in areas where groundwater extractions occur and at locations and depths susceptible to compaction, especially near infrastructure vulnerable to land subsidence.

PUBLIC DRAFT

5.6 Interconnected Surface Water Monitoring

Monitoring interconnected surface water (ISW) requires knowledge of the groundwater system, surface water bodies, and the earth material connecting the two water sources. It is critical to have a sound understanding of the hydrogeology of the aquifer and hydrology of the surface water when interpreting the data. A common approach for identifying locations of ISW involves comparing groundwater elevations from a network of shallow monitoring wells with surface water flow or stage measurements, such as stream gauge data.

In general, an interconnected stream provides stability for beneficial uses and users of the surface water. For example, groundwater contributions to surface water can sustain baseflow, provide cooler temperatures to support aquatic species, and provide a buffer for riparian ecosystems during drier conditions when surface flow is reduced. In contrast, disconnected streams lack these benefits, leaving the beneficial uses and users to rely solely on the surface water as a source.

Understanding the location, quantity, and timing of depletion by groundwater pumping can help to avoid undesirable results that can be impactful to beneficial uses and users, such as downstream water rights and ecosystems.

This section begins with a general explanation on what an ISW is, followed by identifying ISWs through a shallow well monitoring network, and concludes with a short discussion and considerations for groundwater managers on depletion of ISW (California Department of Water Resources 2024). A more in-depth discussion on each of these topics can be found in DWR's technical papers on ISW and Depletion of ISW (available under the Guidance Documents tab).

5.6.1 Interconnected Surface Water

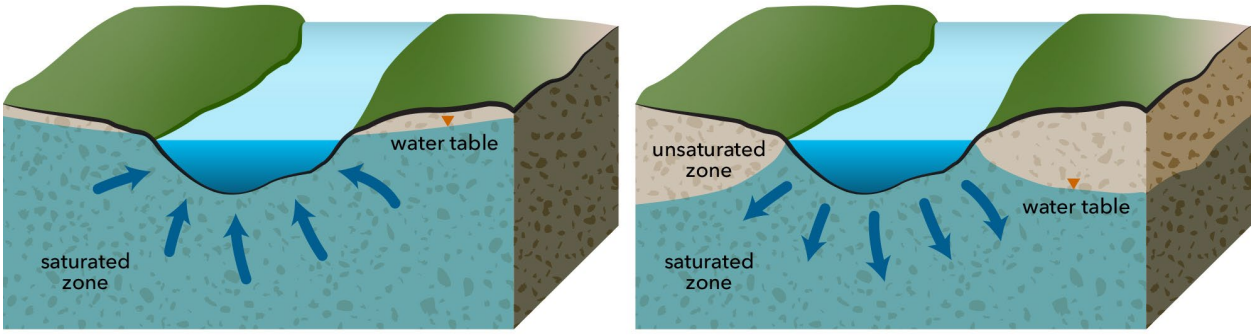
The Groundwater Sustainability Plan Regulations (23 CCR Section 351[o]) define interconnected surface water (ISW) as "surface water that is hydrologically connected at any point by a continuous saturated zone to the underlying aquifer, and the overlying surface water is not completely depleted." Therefore, ISW conditions exist when the saturated zone beneath the surface water body extends to groundwater and results in the movement or exchange of a volume of water between surface water and groundwater. Precipitation, climate, season, geology, and water management affect surface water and groundwater interactions. This water exchange may also include an exchange of chemistry and temperature, which can affect the water quality and temperature of the receiving system.

PUBLIC DRAFT

The interaction between groundwater and surface water can occur in three primary ways:

- Surface water gains water from groundwater (Figure 5-17a).
- Surface water loses water to groundwater (Figure 5-17b).
- Both, gaining in some locations and losing in other locations or gaining at some times and losing at other times.

Figure 5-17 Interconnected Surface Water Body – Gaining and Losing

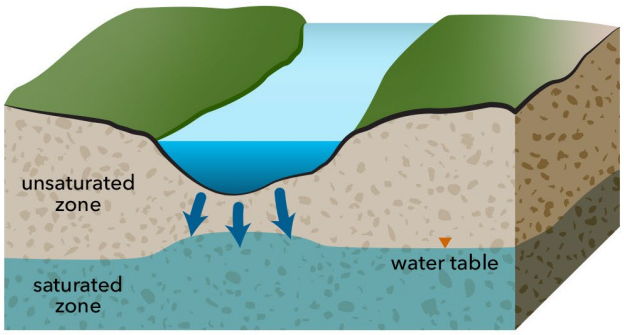


(a): Gaining - Groundwater elevation is higher than surface water elevation.

(b): Losing - Surface water elevation is higher than groundwater elevation.

In other cases, an unsaturated zone exists beneath the surface water body and can extend hundreds of feet above the groundwater. This condition is referred to as a *disconnected surface water body* (Figure 5-18), where groundwater levels do not impact the interaction.

Figure 5-18 Disconnected Surface Water Body – Unsaturated Zone is Below the Surface Water Body



The location of these conditions (gaining, losing, and disconnected) can change over time depending on various factors, such as changes in pumping, land use,

precipitation, or climate. When the surface water body becomes disconnected, it is very rare for reconnection to be reestablished along an entire surface water body's disconnected segment. However, the extent or edges of the disconnection can expand or contract over time.

5.6.2 Identifying ISW via Monitoring Nearby Groundwater Elevations

Determining if a surface water body is an ISW can be challenging. A common method compares groundwater elevation data with the nearby surface water body. In this case, it is important to use wells near the surface water body and preferably shallow wells, as they are most suited for analyzing connectivity between the two systems. While the discussion below uses streams and streambeds as examples, the same principles are also applicable for lakes and lakebeds, wetlands, or other forms of surface water bodies. This listing is not exhaustive and other appropriate methods may be used based on the best available science and information for their area.

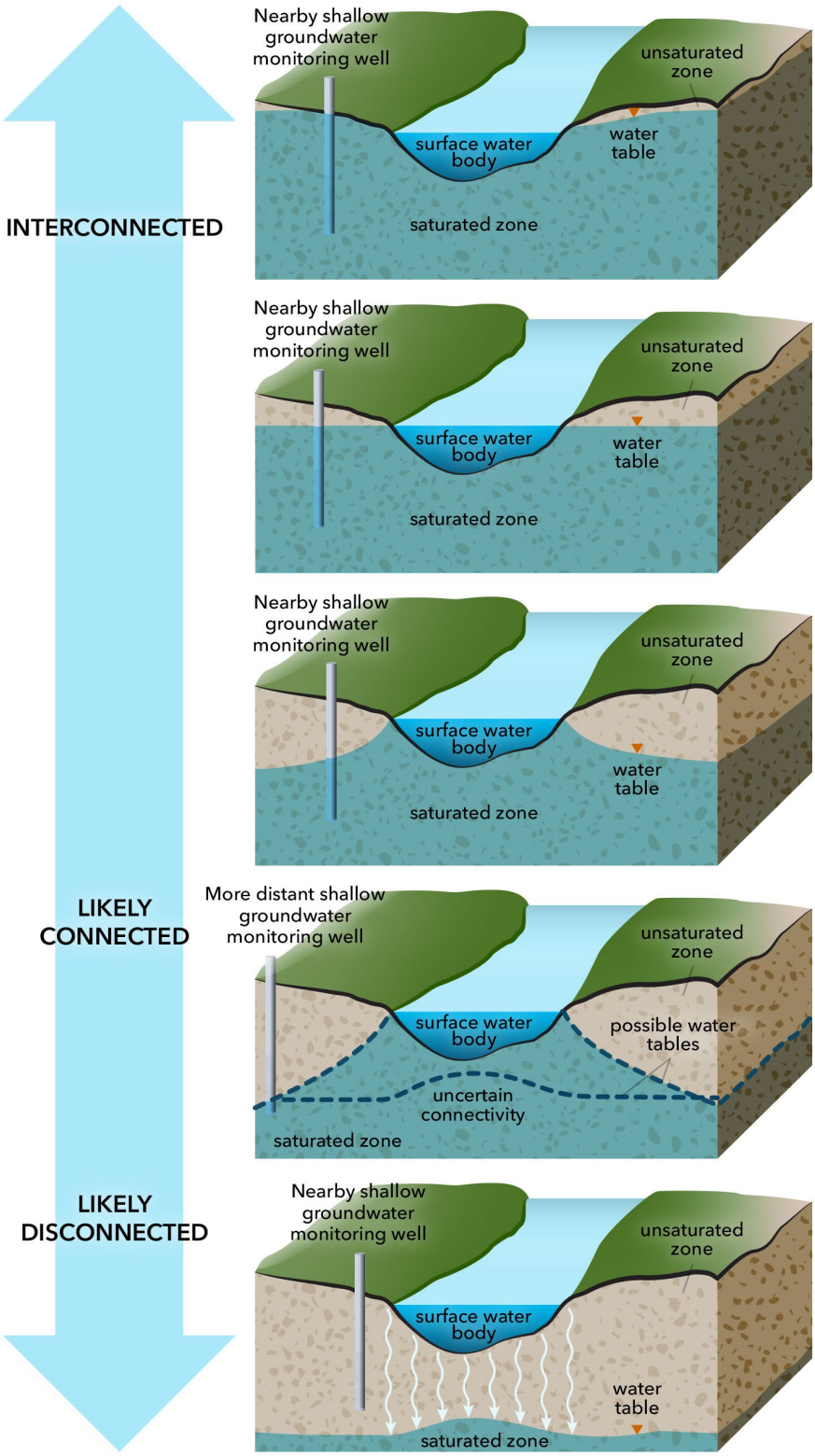
Nearby shallow groundwater elevations that are similar to the streambed elevation may suggest connectivity through a saturated zone (Figure 5-19). Careful consideration of distance between the surface water body and the screened interval of the well is needed. Although more distant wells may show groundwater elevations below streambed elevation, there is greater uncertainty regarding whether the surface water body may or may not be hydraulically connected, as shown in Figure 5-19.

While groundwater level data can provide evidence of possible interconnection (or disconnection), the certainty of this data depends on the well's distance from the stream and the difference between elevation in surface water bodies and groundwater elevation. Care should be taken with the information used in evaluating the hydraulic connection between the two systems. Available data may often be incomplete and uncertain, and professional judgment using the best available science should be used along with the identification of data gaps and data uncertainties.

Monitoring wells adjacent to the surface water body is the key to understanding ISW and if there are gaining or losing conditions. More monitoring points along the surface water body provides higher confidence, and with a sufficient density of monitoring wells, preferably shallow wells, groundwater contours could be developed and used to fill monitoring well data gaps.

PUBLIC DRAFT

Figure 5-19 Considerations and Interpretation of Interconnected Surface Water Based on Five Example Cases of Nearby Groundwater Elevation Data



A stream and a nearby shallow monitoring well with a groundwater elevation above the bottom of the streambed and above the elevation of the surface water, strongly suggesting an ISW.

A stream and a nearby shallow monitoring well with a groundwater elevation above the bottom of the streambed and similar to the elevation of the surface water, suggesting an ISW.

A stream and a nearby shallow monitoring well with a groundwater elevation similar to the bottom of the streambed, suggesting a likely ISW.

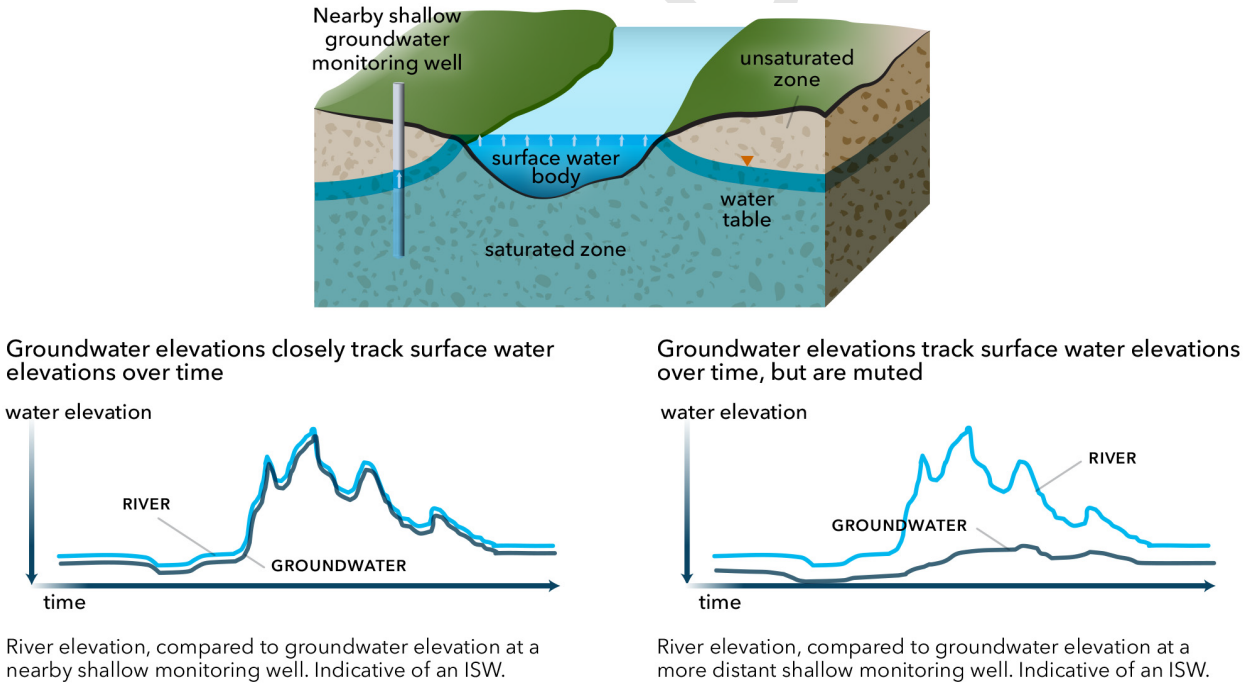
A stream and a more distant shallow monitoring well with a groundwater elevation below the bottom of the streambed. Without additional data it is difficult to determine if the stream is an ISW.

A stream and a nearby shallow monitoring well with groundwater elevation substantially below the bottom of the streambed, suggesting a disconnected stream, not an ISW.

Groundwater elevations in nearby shallow wells that mirror changes in water levels in the adjacent surface water body may indicate a connection at that location (Figure 5-20). Nearby stream gages can provide estimates for surface water elevations and fluctuations, which can be compared to changes in groundwater elevation in the monitoring well during the same period. The stream gaged data can also assist in validating whether the groundwater elevations being measured in the nearby monitoring well are connected to the surface water body.

The graph on the lower left in Figure 5-20 below shows that surface water elevation changes over time are mimicked by groundwater elevation changes in a nearby shallow monitoring well, indicating ISW. However, this mimicking effect in a monitoring well diminishes with distance from the surface water body, as shown in the graph on the lower right. Another consideration is that the elevation in monitoring wells can easily be impacted by nearby pumping, so careful interpretation of the data is needed.

Figure 5-20 Groundwater Elevations Tracking Stream Stage Elevation are a Potential Condition of ISW



In some cases, shallow monitoring wells may not be available, representing a data gap. Relatively deeper wells may be used to aid in identifying ISW, but consideration should be given to the possibility that shallow groundwater may interact with the surface water body even if groundwater elevations in the deeper wells are lower than the streambed elevation.

5.6.3 Depletion of Interconnected Surface Water by Groundwater Use (Pumping)

Depletion of interconnected surface water from groundwater use can occur in two ways, the interception of groundwater that would have normally discharged to the surface water body, or the drawing of water directly from the surface water body. The GSP Regulations require plan managers to report the location, quantity, and timing of depletion on surface water bodies that are interconnected with groundwater resulting from groundwater use. DWR's technical papers on ISW and Depletion of ISW, provide the reasoning for developing a numerical model that uses the available information on groundwater levels, stream gauges, pumping, land use, and other hydrogeologic parameters collected throughout the basin and in some cases beyond the basin's boundaries.

While monitoring surface water depletion is crucial for sustainable groundwater management, there are several limitations associated with this process:

- Depletions cannot be directly measured: Unlike groundwater levels or land subsidence, surface water depletions cannot be directly measured. This is because depletion represents the difference between surface water flows with and without groundwater pumping. The latter scenario cannot be directly observed, making direct measurement impossible.
- Reliance on estimation methods: Because of the inability to directly measure depletions, professionals must rely on estimation methods, such as groundwater and surface water models. These models, while valuable, depend on simplifying assumptions and available data, which introduces uncertainty into the depletion estimates.
- Data gaps and uncertainties: Accurately estimating depletions requires extensive data on pumping, aquifer characteristics, surface water features, and historical hydrologic conditions. Data gaps in any of these areas can significantly impact the reliability of depletion estimates. Additionally, uncertainties in data, such as estimations of pumping rates, can propagate through the models, further affecting the accuracy of depletion assessments.
- Complexity of groundwater systems: Groundwater systems are inherently complex, influenced by various factors such as geology, hydrology, and human activities. Capturing this complexity in models can be challenging. Factors like variable aquifer properties, dynamic stream-aquifer interactions (e.g., shifting between gaining and losing conditions), and the presence of confining layers can complicate the estimation process.

PUBLIC DRAFT

- Delayed nature of depletions: The effects of groundwater pumping on surface water depletions can be delayed by years, decades, or even centuries (Barlow and Leake 2012). This time lag makes it difficult to assess the full impact of current pumping practices on surface water resources and complicates the development of management strategies, as actions taken today may not manifest in reduced depletions for a considerable amount of time.
- Spatial and temporal scale considerations: Depletions can vary significantly across different segments of a river or different portions of a lake or wetland. Estimating depletions at a localized level requires high-resolution data and modeling capabilities. Similarly, the timescale of analysis is crucial. Short-term monitoring may not capture the long-term effects of pumping, while long-term historical data may be limited or unreliable.
- Resource constraints: Developing and implementing robust monitoring and modeling programs for surface water depletions can be resource-intensive due to the costs associated with data collection, model development, and expert analysis. Resource constraints may limit the scope and accuracy of depletion assessments, especially in basins with limited funding or technical expertise.

DWR advocates for the continuous improvement of ISW monitoring and estimation methods. This involves:

- Addressing data gaps: Prioritizing data collection efforts to fill critical gaps in pumping information, aquifer characteristics, and surface water features.
- Refining modeling techniques: Utilizing advanced modeling tools, incorporating higher-resolution data, and improving model calibration to enhance the accuracy and reliability of depletion estimates.
- Adopting an iterative approach: Understanding ISW depletions is an ongoing process which requires continuously evaluating and updating models as new data becomes available and knowledge of the groundwater system improves.

By acknowledging these limitations and actively working to overcome them, groundwater managers can enhance their ability to effectively monitor surface water depletion. This, in turn, will lead to more informed and sustainable management of groundwater resources, ensuring the long-term health of both surface water and groundwater systems.

PUBLIC DRAFT

5.6.4 Statewide Stream Gaging

Stream gages are critical tools for monitoring California's water resources and provide one of several key datasets essential in evaluating the state's interconnected surface water and groundwater systems. These devices record flow levels in rivers, streams, and other waterways, enabling water managers, researchers, and policymakers to assess water availability and regulatory compliance, track seasonal changes, and respond to potential droughts and floods. Stream gage data also support groundwater management efforts by offering insights into stream-aquifer interactions, a key factor in sustainable water use. Additionally, stream gage data serves as key inputs for hydrological models, aiding model calibration and improving the accuracy of water resource predictions and management strategies.

DWR oversees a network of stream gages across the state, receiving data from approximately 210 operational gages. There are approximately 260 additional operational gages managed by USGS and other agencies across the state. However, the need for modernized monitoring infrastructure prompted the passage of Senate Bill 19 (SB19) in 2019. This legislation directed DWR and the State Water Resources Control Board to develop a comprehensive stream gaging plan to address information gaps by deploying a prioritized network of stream gages across the state in collaboration with relevant agencies and stakeholders)

In 2023, the legislature provided DWR with approximately $20 million one-time funding to begin implementing improvements to the stream gage network. In response, DWR launched the California Stream Gage Improvement Program (CalSIP). This limited-term technical assistance program supports public agencies in modernizing stream gage infrastructure statewide. CalSIP aims to implement stream gage infrastructure improvements, and operations and maintenance, for stream gaging data collection that provides reliable real-time stream flow data to the public. Potential projects under CalSIP include the installation of new stream gages, integration of existing gage data into public databases, reactivation of historical stream gages, upgrades to existing stream gages, the purchase and installation of stream gaging equipment, and the operations and maintenance of improvements installed through the program (though June 2027).

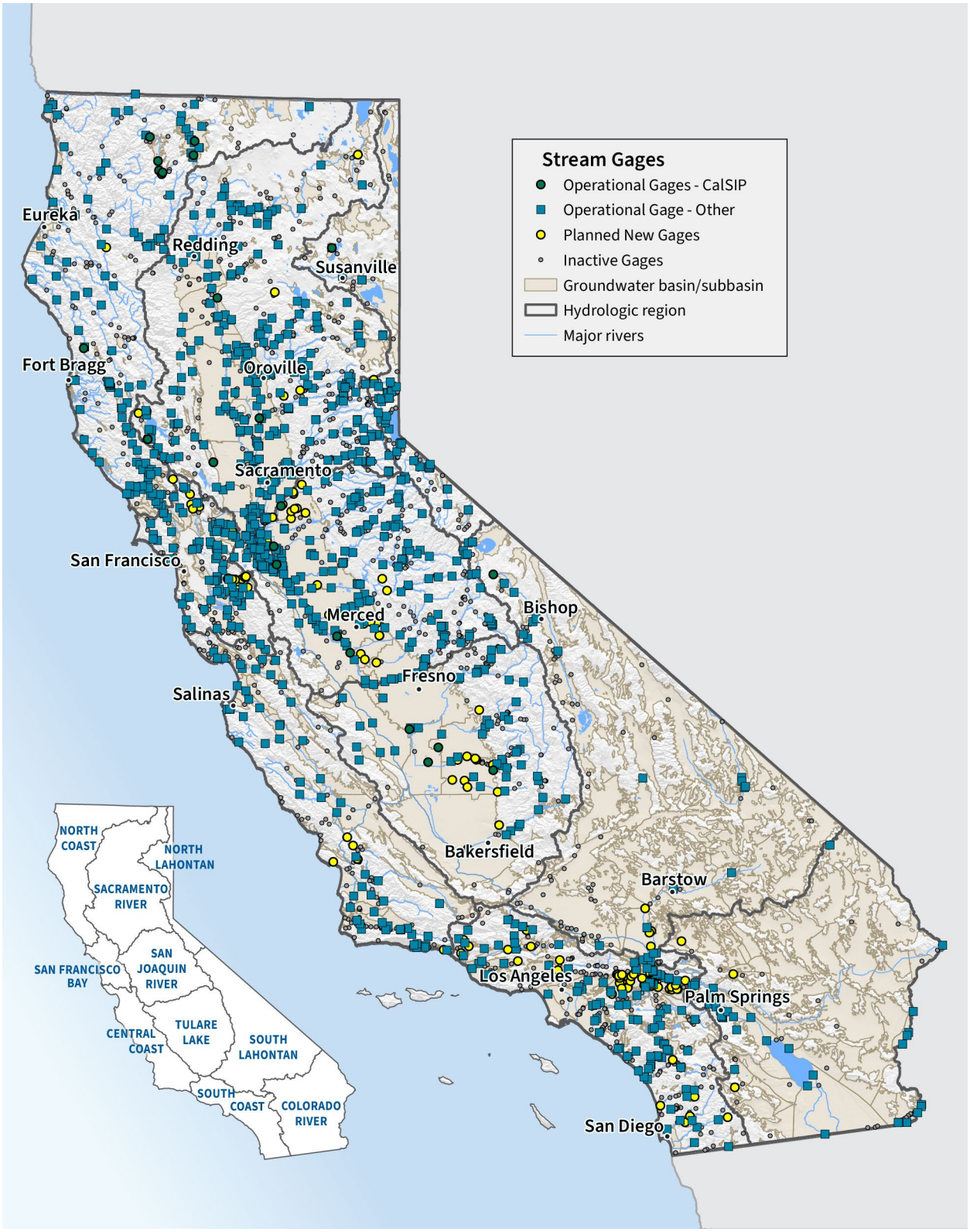
Since its inception, CalSIP has facilitated the installation or modernization of approximately 30 stream gages, referred to as *operational gages*, with plans to fund local agencies to install or upgrade approximately 150 more sites across the state. The program, which has now closed its application period for funding

PUBLIC DRAFT

assistance, has provided approximately $7 million in funding and support to local agencies. These investments improve the state's stream gage network, improving the quality and availability of critical water data. Figure 5-21 illustrates the locations of operational and inactive gages statewide, highlighting the impact of CalSIP on improving California's surface water monitoring capabilities.

PUBLIC DRAFT

Figure 5-21 Statewide Stream Gaging Network



5.7 Seawater Intrusion Monitoring

Seawater intrusion refers to the shoreward and inland migration of the seawater front, also referred to as the saline front, which is the natural interface between fresh groundwater and seawater within an aquifer. This inland migration of seawater can be driven by both natural processes and anthropogenic activities that impact the hydraulic gradient of coastal aquifers. As fresh groundwater storage within these coastal aquifers decreases, landward migration of seawater can occur, with the potential to compromise the quality and reliability of fresh groundwater supplies in the affected coastal communities.

With sea level expected to rise as much as 3.5 feet by the end of the century as a result of climate change (California Ocean Protection Council 2020), the seawater front could migrate to lower elevations in coastal groundwater basins and reach further inland than current conditions, even if groundwater levels remain stable and do not decline (Befus et al. 2020). This potential seawater intrusion increases the likelihood of adverse impacts on the beneficial uses of groundwater as the seawater intrusion front approaches groundwater supply wells and sensitive environmental areas along the coast.

To track the seawater intrusion front and its changes over time, groundwater monitoring is a critical management action in coastal basins that are used for groundwater production. This monitoring should include routine measurements of both groundwater levels and groundwater quality to prevent adverse impacts on beneficial uses. Key indicators of seawater intrusion, such as total dissolved solids (TDS) and chloride, should be regularly monitored in coastal basins. By monitoring and estimating the extent of the seawater intrusion front over time, water managers can better predict where and when impacts to freshwater aquifers are likely to occur.

5.7.1 Monitoring Methods

Groundwater monitoring and analyses should be sufficient for mapping and tracking the three-dimensional extent of the seawater intrusion front and the movement of existing seawater intrusion front or degraded water quality over time. Monitoring and analyses should be routinely conducted to assess whether beneficial uses and users are at risk of being adversely affected by degraded water quality associated with seawater intrusion.

Water quality constituents that are commonly used to monitor seawater intrusion include TDS and chloride, as their concentrations differ significantly between

PUBLIC DRAFT

freshwater and seawater, making seawater intrusion clearly detectable in groundwater samples. For context, freshwater has a TDS concentration of 1,000 milligrams per liter (mg/L) or less. Brackish water is characterized by a TDS concentration ranging from 1,000 to10,000 mg/L, while saline water is characterized by 10,000 to 35,000 mg/L TDS, and seawater has a TDS concentration of approximately 35,000 mg/L (see Table 5-7). Chloride is the largest component of TDS in seawater and has a concentration of about 19,000 mg/L (Barlow 2003).

Table 5-7 Total Dissolved Solids Concentrations Based on Water Type

Constituent	Freshwater	Brackish	Saline	Seawater
Total Dissolved Solids (TDS)	up to 1,000 mg/L	1,000–10,000 mg/L	10,000–35,000 mg/L	35,000 mg/L

The large disparity in concentrations of TDS and chloride between freshwater and seawater makes groundwater quality analysis an effective method for determining the occurrence, extent, and timing of seawater intrusion. Other constituents that may be beneficial to analyze are iodide and bromide, which could provide information about the source(s) of salinity (California Department of Water Resources 2016a*)*.

Other methods of monitoring seawater intrusion include measuring electrical conductivity, which correlates with salinity, using direct sampling and geophysical methods as well as borehole and airborne electromagnetic surveys. These survey methods usually need technical processing and interpretation and should be evaluated in conjunction with other geologic or hydrogeologic data to accurately characterize seawater intrusion (U.S. Geological Survey 2024).

Monitoring groundwater elevations or the hydraulic head in a monitoring well network can provide information about the hydraulic gradient and the direction of seawater intrusion front movement. The depth to the seawater intrusion front can be estimated using the Ghyben-Herzberg equation, where the depth to the interface between freshwater and seawater is 40 times deeper than the height of the groundwater table or potentiometric surface above sea level (Figure 5-22).

PUBLIC DRAFT

Figure 5-22 Conceptual Diagram Showing the Estimated Depth of the Seawater Intrusion Front using the Ghyben-Herzberg Equation

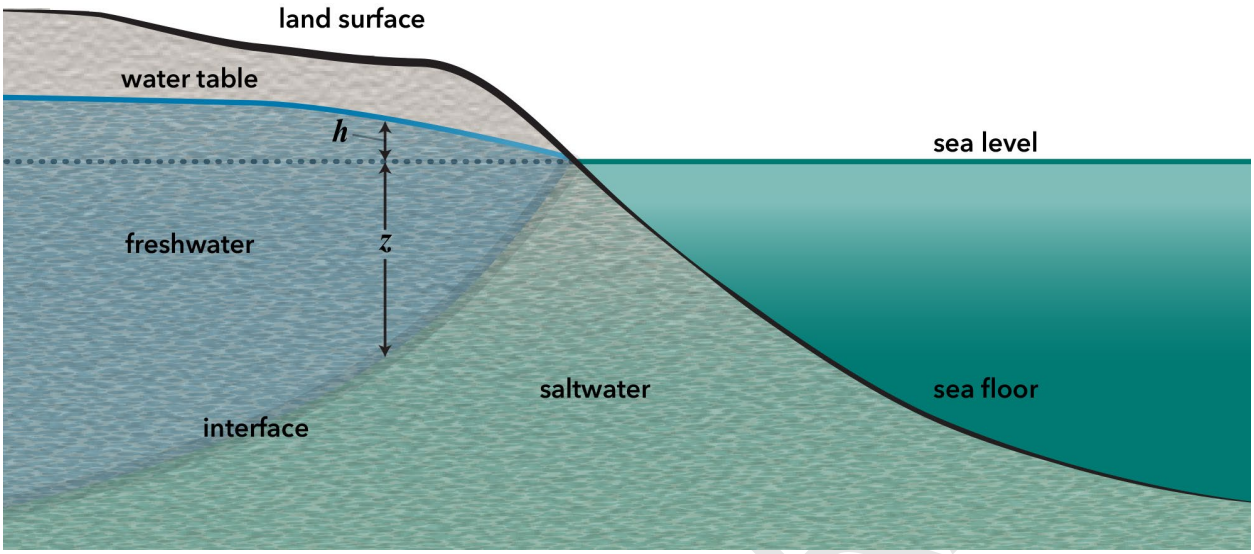


Figure 5-22 Note: The height of the fresh groundwater table above sea level is represented by h and the depth to the interface is represented by z.

Monitoring changes in freshwater groundwater levels relative to the distance and depth of water supply wells offers insights into two key areas: the potential and timing for seawater intrusion advancing inland, and whether this migration could degrade water quality enough to compromise beneficial uses. However, as groundwater is removed from aquifer storage, it may be replaced by seawater. Therefore, solely measuring groundwater levels without chemical analysis is insufficient for accurately assessing seawater intrusion.

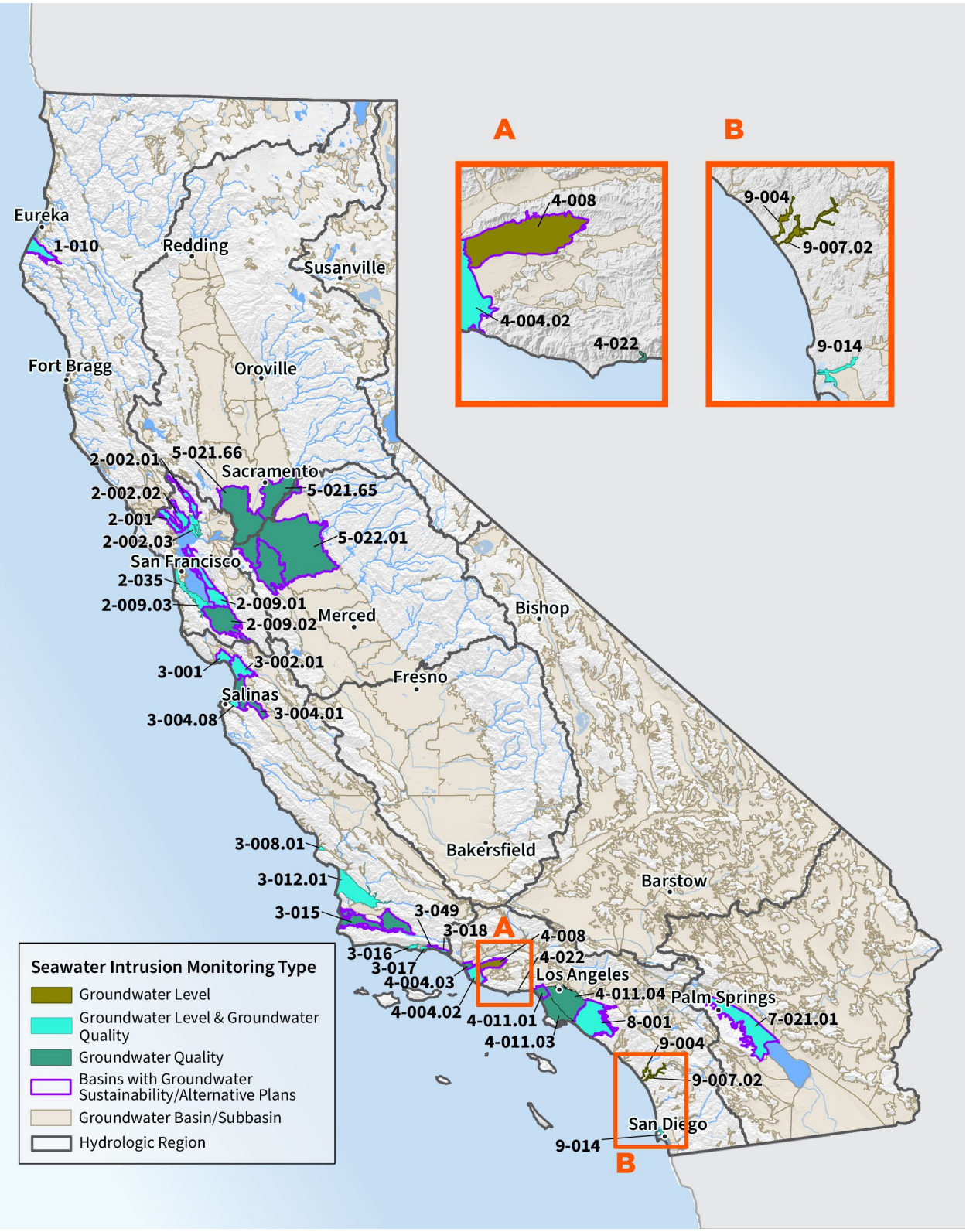
By routinely monitoring groundwater quality over time, water managers can track whether groundwater quality is stable, degrading, or improving. By combining this water quality data with groundwater level monitoring data, inferences can be made regarding the timing and cause of seawater intrusion. However, for this type of analysis to be beneficial, a comprehensive groundwater monitoring network must be in place.

Recent DWR compilation of available data for seawater intrusion monitoring shows several data gaps exist, where no data is available from coastal groundwater basins (Figure 5-23). This lack of data in some basins can be a result of multiple factors, including low population density, lack of public water systems that are required to be monitored, and lack of groundwater reliance resulting from aquifer impairment.

These types of data are essential for community water managers who rely on coastal groundwater basins for their water supply as they help inform conjunctive management decisions and forecast potential adverse impacts to beneficial uses. Therefore, routine monitoring of groundwater conditions through a seawater intrusion well network is crucial for preventing the detrimental effects of water quality degradation caused by seawater intrusion.

PUBLIC DRAFT

Figure 5-23 Groundwater Basins with Seawater Intrusion Monitoring



5.7.2 Data Collection

The DWR's best management practices (BMP) for monitoring seawater intrusion, which are based on standards for monitoring water quality, recommend analyzing groundwater samples from each principal aquifer that is currently affected, or may be affected in the future, by seawater intrusion for chloride, at a minimum, at least semiannually (California Department of Water Resources 2016a).

SGMA requires high- and medium-priority basins that are susceptible to seawater intrusion to be monitored for chloride or by using a method that can be converted to chloride measurements. Furthermore, the spatial density of the monitoring network must be adequate to map an isocontour of chloride as a representation of the seawater intrusion front. Existing water quality data from other monitoring or regulatory programs can be utilized, but collection of water quality samples may be required if the available data are not adequate to map the movement of the chloride isocontour.

The BMP mentioned above recommends a measurement frequency in wells near the seawater intrusion front that is adequate to characterize the fluctuations in hydraulic head attributable to changes in climate, water supplies, land use, and groundwater pumping, regardless of drought years or wet years. The DWR BMP for *Monitoring Networks and Identification of Data Gaps* recommends a monitoring frequency of at least quarterly and up to daily for monitoring wells in aquifers that have high hydraulic conductivity and large groundwater withdrawals (California Department of Water Resources 2016b).

Monitoring for seawater intrusion has historically been conducted locally by water agencies based on applicability, need, groundwater reliance, and financial feasibility. SGMA requires high- and medium-priority basins to be monitored to ensure that protective minimum thresholds are not exceeded if seawater intrusion is an applicable sustainability indicator for the basin. However, seawater intrusion monitoring is also conducted in some basins that are not subject to SGMA requirements.

To identify the areas in California where seawater intrusion monitoring is occurring, DWR reviewed information compiled during the statewide basin prioritization effort as well as data from GSPs, historical studies (including DWR Bulletins), and publication from other agencies, such as annual reports and planning documents. The detail and frequency of monitoring data vary widely across coastal groundwater basins, with no data available for many basins,

PUBLIC DRAFT

particularly in basins where groundwater is not relied upon for beneficial use. In this research effort, basins with groundwater quality data collected since 2011 are presented in Table 5-8 and Figure 5-23. Seawater intrusion monitoring is conducted by local water agencies in 36 groundwater basins since 2011. Of those basins, 92% (33 of 36 basins) analyze water quality.

Table 5-8 Groundwater Basins with Seawater Intrusion Monitoring Data Since 2011

Basin Number	Basin Name	Basin Priority	Seawater Intrusion Monitoring Type
1-010	Eel River Valley	Medium	Groundwater Level & Groundwater Quality
2-001	Petaluma Valley	Medium	Groundwater Level & Groundwater Quality
2-002.01	Napa-Sonoma Valley — Napa Valley	High	Groundwater Level & Groundwater Quality
2-002.02	Napa-Sonoma Valley — Sonoma Valley	High	Groundwater Level & Groundwater Quality
2-002.03	Napa-Sonoma Valley — Napa-Sonoma Lowlands	Very Low	Groundwater Level & Groundwater Quality
2-009.01	Santa Clara Valley — Niles Cone	Medium	Groundwater Level & Groundwater Quality
2-009.02	Santa Clara Valley — Santa Clara	High	Groundwater Quality
2-009.03	Santa Clara Valley — San Mateo Plain	Very Low	Groundwater Level & Groundwater Quality
2-009.04	Santa Clara Valley — East Bay Plain	Medium	Groundwater Level & Groundwater Quality
2-035	Westside	Very Low	Groundwater Level & Groundwater Quality
3-001	Santa Cruz Mid-County	High	Groundwater Level & Groundwater Quality
3-002.01	Corralitos — Pajaro Valley	High	Groundwater Level & Groundwater Quality
3-004.01	Salinas Valley — 180/400 Foot Aquifer	High	Groundwater Quality
3-004.08	Salinas Valley — Seaside	Very Low	Groundwater Level & Groundwater Quality
3-004.10	Salinas Valley — Monterey	Medium	Groundwater Quality
3-008.01	Los Osos Valley — Los Osos Area	Very Low	Groundwater Quality

PUBLIC DRAFT

Basin Number	Basin Name	Basin Priority	Seawater Intrusion Monitoring Type
3-012.01	Santa Maria River Valley — Santa Maria	Very Low	Groundwater Level & Groundwater Quality
3-015	Santa Ynez River Valley	Medium	Groundwater Quality
3-016	Goleta	Very Low	Groundwater Level & Groundwater Quality
3-017	Santa Barbara	Very Low	Groundwater Level & Groundwater Quality
3-018	Carpinteria	High	Groundwater Level & Groundwater Quality
3-049	Montecito	Medium	Groundwater Level & Groundwater Quality
4-004.02	Santa Clara River Valley — Oxnard	High	Groundwater Level & Groundwater Quality
4-004.03	Santa Clara River Valley — Mound	High	Groundwater Quality
4-008	Las Posas Valley	High	Groundwater Level
4-011.01	Coastal Plain of Los Angeles — Santa Monica	Medium	Groundwater Quality
4-011.03	Coastal Plain of Los Angeles — Central	Very Low	Groundwater Quality
4-011.04	Coastal Plain of Los Angeles — West Coast	Very Low	Groundwater Quality
4-022	Malibu Valley	Very Low	Groundwater Quality
5-021.65	Sacramento Valley — South American	High	Groundwater Quality
5-021.66	Sacramento Valley — Solano	Medium	Groundwater Quality
5-022.01	San Joaquin Valley — Eastern San Joaquin	High	Groundwater Quality
5-022.15	San Joaquin Valley — Tracy	High	Groundwater Quality
5-022.19	San Joaquin Valley — East Contra Costa	Medium	Groundwater Quality
7-021.01	Coachella Valley — Indio	Medium	Groundwater Level & Groundwater Quality
8-001	Coastal Plain of Orange County	Medium	Groundwater Level & Groundwater Quality
9-004	Santa Margarita Valley	Very Low	Groundwater Level
9-007.02	San Luis Rey Valley — Lower San Luis Rey Valley	Very Low	Groundwater Level
9-014	Mission Valley	Very Low	Groundwater Level & Groundwater Quality

PUBLIC DRAFT

5.7.3 Data Analysis

GSP Regulations require high- and medium-priority basins that are susceptible to seawater intrusion to monitor chloride concentrations, or perform measurements convertible to chloride concentrations, so that the current and projected rate, extent, and movement of seawater intrusion for each applicable principal aquifer can be calculated and mapped as a chloride isocontour. Contrary to minimum thresholds for other sustainability indicators, the seawater intrusion minimum threshold is not set at individual monitoring sites. Instead, the minimum threshold is set along a chloride isocontour line, which is a representation of the seawater intrusion front. In order to map the three-dimensional extent of the seawater intrusion front, a spatially adequate number of groundwater samples must be analyzed, at least quarterly, for chloride or a surrogate analyte that can be quantitatively correlated with chloride concentration, then mapped as a chloride isocontour (California Department of Water Resources 2016b*)*. The chloride isocontour maps can be analyzed over time to determine the ongoing extent, movement direction, and velocity of the seawater intrusion front. The movement of the seawater intrusion front over time should be analyzed and compared with the locations of nearby groundwater production wells and the aquifer that supplies groundwater to those wells to determine if beneficial uses and their users might be impacted by seawater intrusion.

Another type of water quality analysis considers the ionic composition of groundwater. The cation and anion concentrations can be plotted on Piper and Stiff diagrams to assist in determining the influence of seawater interaction with the coastal aquifer and to infer the source(s) of salinity (Hajji et al. 2022). Other types of data analysis that can supplement the management of seawater intrusion include analyzing groundwater levels and analytical modeling. As previously discussed, the depth of the seawater intrusion front can be calculated using the height of the fresh groundwater table or potentiometric surface that is above sea level, so analysis of groundwater level fluctuations and groundwater quality analyses can provide information regarding the depth and movement direction of the seawater intrusion front.

For more information regarding monitoring and modeling seawater intrusion, see the DWR's BMP documents (California Department of Water Resources. 2016c and 2016d*)*.

In the DWR compilation of seawater intrusion monitoring activities and data for CalGW Update 2025, the most common parameters analyzed by local water

PUBLIC DRAFT

managers consisted of chloride, total dissolved solids, and specific conductance. Data for these parameters are tabulated in the Seawater Intrusion Section of Chapter 6, "Groundwater Conditions."

PUBLIC DRAFT

6 . Groundwater Conditions

Chapter Summary

Chapter 6, "Groundwater Conditions," of *California's Groundwater: Bulletin 118 — Update 2025* (CalGW Update 2025), provides a detailed analysis of California's groundwater conditions, leveraging extensive data on groundwater levels, water quality, groundwater storage, land subsidence, and seawater intrusion, and contains the available information on interconnected surface water.

This chapter examines groundwater levels, presenting data on depth-to-groundwater and groundwater elevations. These measurements illustrate both seasonal and long-term trends across the state and within individual hydrologic regions. These metrics help reveal critical insights into groundwater depletion, change in storage, and recharge. This chapter continues by exploring changes in groundwater storage, particularly in the Central Valley, using data models and comparing several estimates.

Groundwater quality is discussed with a focus on constituents of concern such as 1,2,3-trichloropropane, nitrate, arsenic, uranium, total dissolved solids, hexavalent chromium, and PFOA (perfluorooctanoic acid) and PFOS (perfluorooctane sulfonate) which are part of a large group of lab-made chemicals known as perfluoroalkyl and polyfluoroalkyl substances (PFAS). These data are essential for understanding and managing the suitability of groundwater for various uses, particularly in areas that are already contaminated and areas vulnerable to contamination.

The chapter further examines regional land subsidence, using satellite and GPS-based data to document regions where excessive groundwater extraction has led to significant ground-level changes. Groundwater-surface water interactions are also briefly reviewed in this chapter to underscore their role in basin management, while seawater intrusion, a critical issue in some coastal areas, is discussed in terms of its impacts and regional monitoring efforts.

Together, these analyses provide a comprehensive view of California's groundwater conditions, highlighting the importance of data-driven management strategies for achieving sustainable groundwater use.

PUBLIC DRAFT

Chapter 6, "Groundwater Conditions," aligns with the themes of CalGW Update 2025, including Theme 4, "Enhancing Groundwater Data, Tools, and Analysis for Decision Support," by leveraging extensive data on groundwater levels, quality, storage, and subsidence, supporting informed and effective management decisions. It also reinforces Theme 2, "Accelerating Momentum for Sustainability," as its in-depth analyses on issues like change in storage and subsidence help identify areas where targeted management can ensure long-term water availability.

6.1 Introduction

Groundwater conditions across California's diverse basins and non-basin areas are influenced by complex natural and human-made causes. Variations in hydrology impact groundwater availability and demand. Surface water and groundwater management practices, including conjunctive use and managed aquifer recharge, further shape local conditions. Land use choices can also significantly affect groundwater resources. Groundwater quality plays an important role in determining groundwater use and influences water management practices. Evaluating conditions using groundwater data provides important information and insight about the state of groundwater at a local or regional scale.

This chapter presents the results of a series of analyses using available data to evaluate groundwater conditions, including groundwater levels, groundwater quality, land subsidence, groundwater storage, groundwater-surface water interaction, and seawater intrusion as of spring 2024. More up-to-date groundwater conditions are published twice per year by DWR in the California's Groundwater: Semi-Annual Updates. This chapter presents current groundwater conditions, long-term trends, regional variations, and the impacts of droughts, floods, and management strategies on groundwater conditions. While this chapter provides sufficient detail to allow comparisons across Hydrologic Regions (HRs), it is not intended for analyzing or assessing specific local conditions.

Information about groundwater monitoring methods and networks can be found in Chapter 5, "Groundwater Monitoring." A summary of conditions in each hydrologic region can be found in Chapter 7, "Groundwater at a Glance: Hydrologic Region Summaries." Information regarding the methods, assumptions, and data used in compiling this section are provided in Appendix C, "Methods and Assumptions." Links to the various tools, interactive maps, and datasets discussed in this chapter are included in Appendix D, "Citations, Reference Materials, and Links." Basin-

PUBLIC DRAFT

specific data used for this report are available in Appendix G, "Hydrologic Region, Basin, and County Data."

6.2 Groundwater Levels

Groundwater levels (or groundwater elevations) are one of the most basic indicators of groundwater conditions. This section presents findings on recent and current groundwater conditions based on an analysis of groundwater elevation data from 2019 to 2024. Groundwater conditions were negatively impacted by a brief but severe drought from 2020 to 2022 that resulted in reductions in surface water availability and increases in groundwater extractions. Nevertheless, significant improvements occurred because of wet conditions in Water Year (WY) 2023 followed by average conditions in WY 2024. During WY 2023 and WY 2024, increased surface water availability helped reduce the severe demand on groundwater observed during the prior drought years. Together with reduced groundwater pumping and increased groundwater recharge, groundwater levels increased in many parts of the State. Recovery, however, remains uneven. Many areas show significant improvements of groundwater levels, particularly in the Sacramento River Hydrologic Region, but the San Joaquin River and Tulare Lake hydrologic regions continue to face challenges, with over half of wells still below pre-drought levels. This underscores the dual impact of climate variability and groundwater management, highlighting that despite short-term gains, many groundwater basins have yet to recover to their pre-drought levels from 2019, signaling the need for sustained efforts in groundwater management.

6.2.1 Depth to Groundwater

The depth to groundwater can be measured directly and is the distance from a known reference point at or near the ground surface to the water level in the well. Figure 6-1 displays spring 2024 depth to groundwater as measured in wells throughout the state and reported to DWR. All available groundwater level data were reviewed and represent groundwater levels from a range of well use types, well depths, and screened intervals, including wells with unknown construction details. For more information about the well monitoring, see Chapter 5, "Groundwater Monitoring."

Spring 2024 depth to groundwater data, shown in Figure 6-1, reflect conditions before the typical irrigation season begins, representing a time of year when the depth to groundwater is typically at its shallowest. The data from January 1 through May 31 for each well were reviewed; for wells with multiple

PUBLIC DRAFT

measurements, the measurement closest to March 15 was used to represent spring depth to groundwater.

Figure 6-2 shows spring 2024 depth to groundwater contour map for the Central Valley groundwater basins, displaying lines of equal depth to groundwater. These contour lines were generated using data from wells that intersect unconfined to semi-confined aquifers and only in areas with sufficient data. Both Figures 6-1 and 6-2 indicate that the depth to groundwater is greater in the southern Central Valley. Additionally, the depth to groundwater is shallower near major water bodies, such as the Sacramento and San Joaquin rivers, and increases as land surface elevation increases, particularly near the Sierra foothills.

In the northern Central Valley (Sacramento River Hydrologic Region), depth to groundwater ranges from less than five feet to around 160 feet below ground surface (bgs), with the shallowest depths located west of the Sacramento River and the greatest depths found east of the City of Sacramento. Depth to groundwater often become shallower next to surface water because surface water bodies, such as rivers, lakes, and streams, can naturally recharge nearby aquifers. This illustrates a direct connection between surface water and groundwater, particularly in areas with permeable soils and unconfined aquifers.

In the southern Central Valley (San Joaquin River and Tulare Lake hydrologic regions), groundwater levels are more variable. The depth to groundwater in the western half of the San Joaquin River Hydrologic Region is shallowest along the valley floor adjacent to the San Joaquin River and tributaries. Depth to groundwater increases toward the eastern side of the valley, near the foothills of the Sierra Nevada. In the Tulare Lake Hydrologic Region, depth to groundwater continues to increase southward, reaching depths of 300 to 600 feet bgs north of the City of Bakersfield. Groundwater levels in the Tulare Lake Hydrologic Region vary widely due to complex geology, intensive agricultural pumping, and uneven surface water availability for recharge. Additionally, land subsidence from over-extraction has altered aquifer structures, further contributing to the variability in groundwater levels across the region.

PUBLIC DRAFT

Figure 6-1 Depth to Groundwater by Hydrologic Region (Spring 2024)

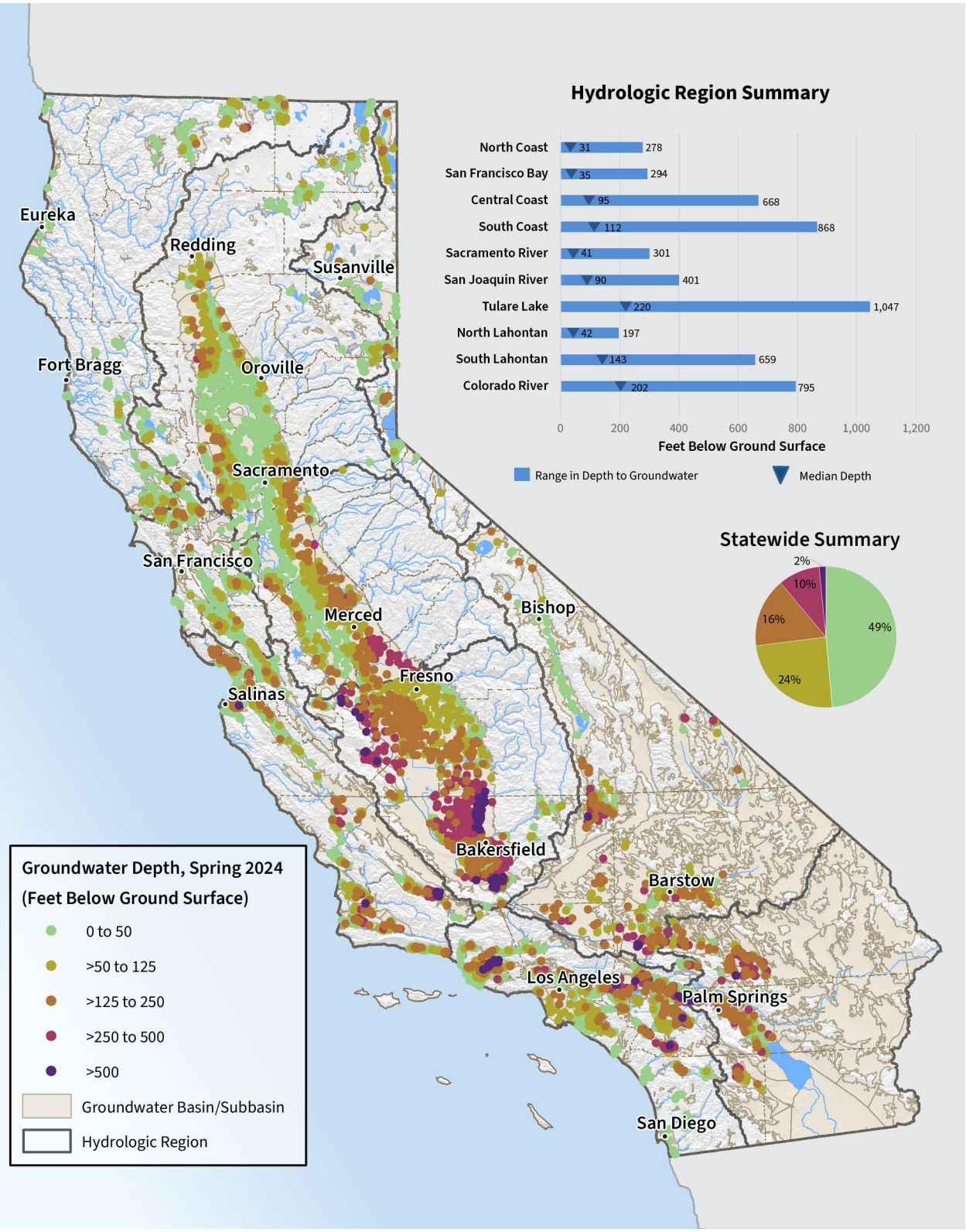
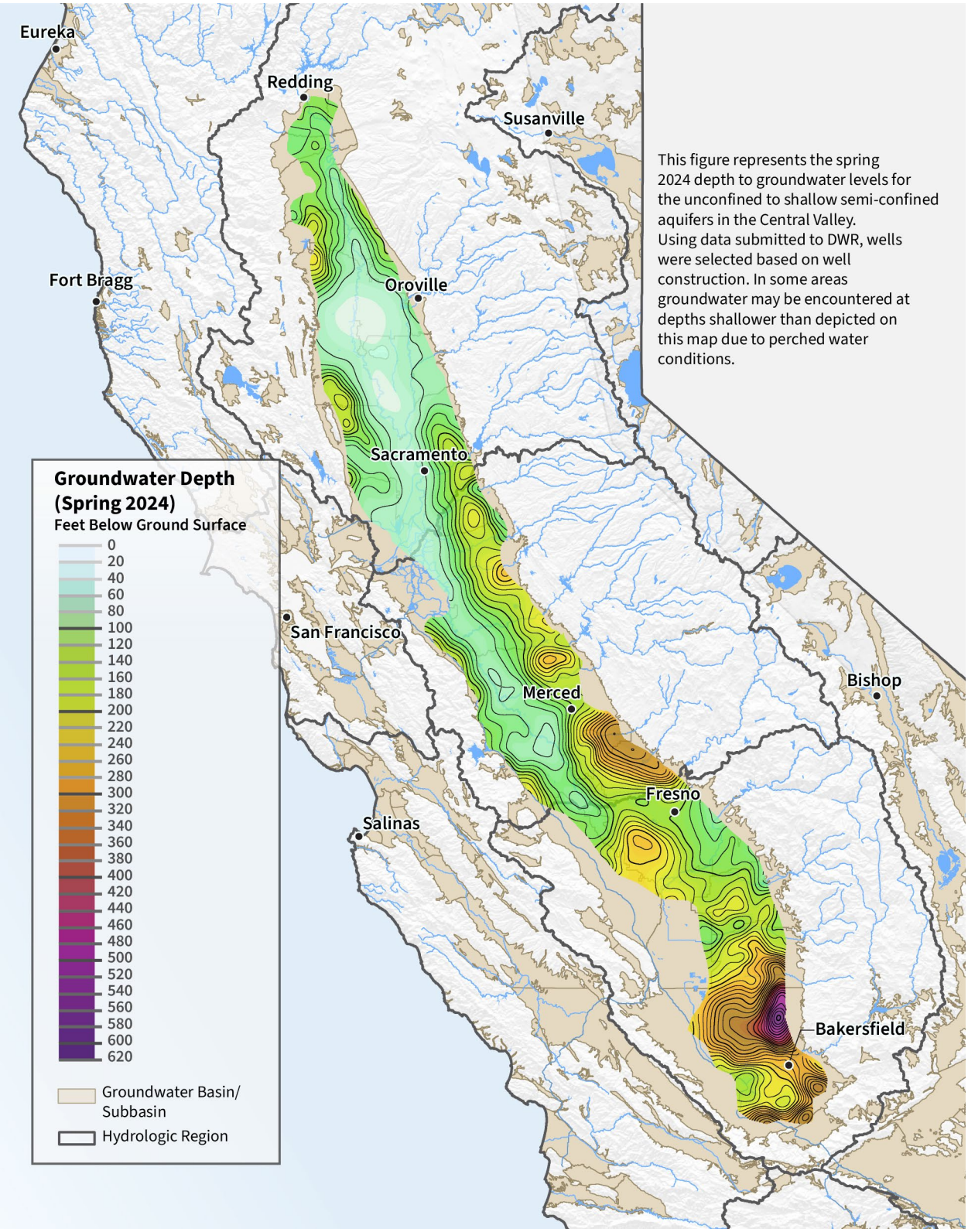


Figure 6-2 Depth to Groundwater Contour Map for the Central Valley (Spring 2024)



6.2.2 Groundwater Surface Elevation

Groundwater surface elevation is calculated by subtracting the measured depth to groundwater from the elevation of the ground surface or reference point at the well. The groundwater surface elevation represents the groundwater level relative to the mean sea level, also referred to as the *National Vertical Datum 1988* (NAVD88). Groundwater elevations are important both for understanding groundwater flow direction and for determining the hydraulic head in an aquifer. The hydraulic head is determined by two main factors: pressure and elevation, which together drive groundwater movement from areas of higher hydraulic head to areas of lower hydraulic head, a concept also referred to as the *hydraulic gradient*. In an unconfined aquifer, the hydraulic head is typically called the water table.

Contour maps of groundwater surface elevation can reveal regional groundwater flow directions, discharge or recharge areas (such as streams and lakes), high and low water-use zones, possible contaminant plume movement, land subsidence, and seawater intrusion. Figure 6-3 shows the spring 2024 groundwater elevation contours for the unconfined to shallow semi-confined aquifers in the Central Valley, representing the water table. Arrows indicate the general direction of horizontal groundwater flow; however, vertical movement is not depicted. In the Sacramento Valley portion of the Sacramento Hydrologic Region, groundwater flow generally follows the natural topography. In the northern portion of the valley, near the cities of Redding and Red Bluff, groundwater elevations exceed 500 feet (National Vertical Datum 1988). Groundwater generally flows from these higher elevations along the valley edges toward the Sacramento River and other drainage systems, then continues southward toward the Sacramento-San Joaquin Delta.

In spring 2024, groundwater cones of depression were observed extending from the southern part of the Sacramento River Hydrologic Region into the northern part of the San Joaquin River Hydrologic Region. These depressions, located roughly between the cities of Sacramento and Stockton, reached elevations as low as -40 feet (National Vertical Datum 1988). Large cones of depression were also observed in the southern portions of the San Joaquin River Hydrologic Region, southwest of the City of Fresno and northwest of the City of Bakersfield. These features, indicative of overdraft, behave like closed groundwater systems (Pauloo and Fogg 2021).

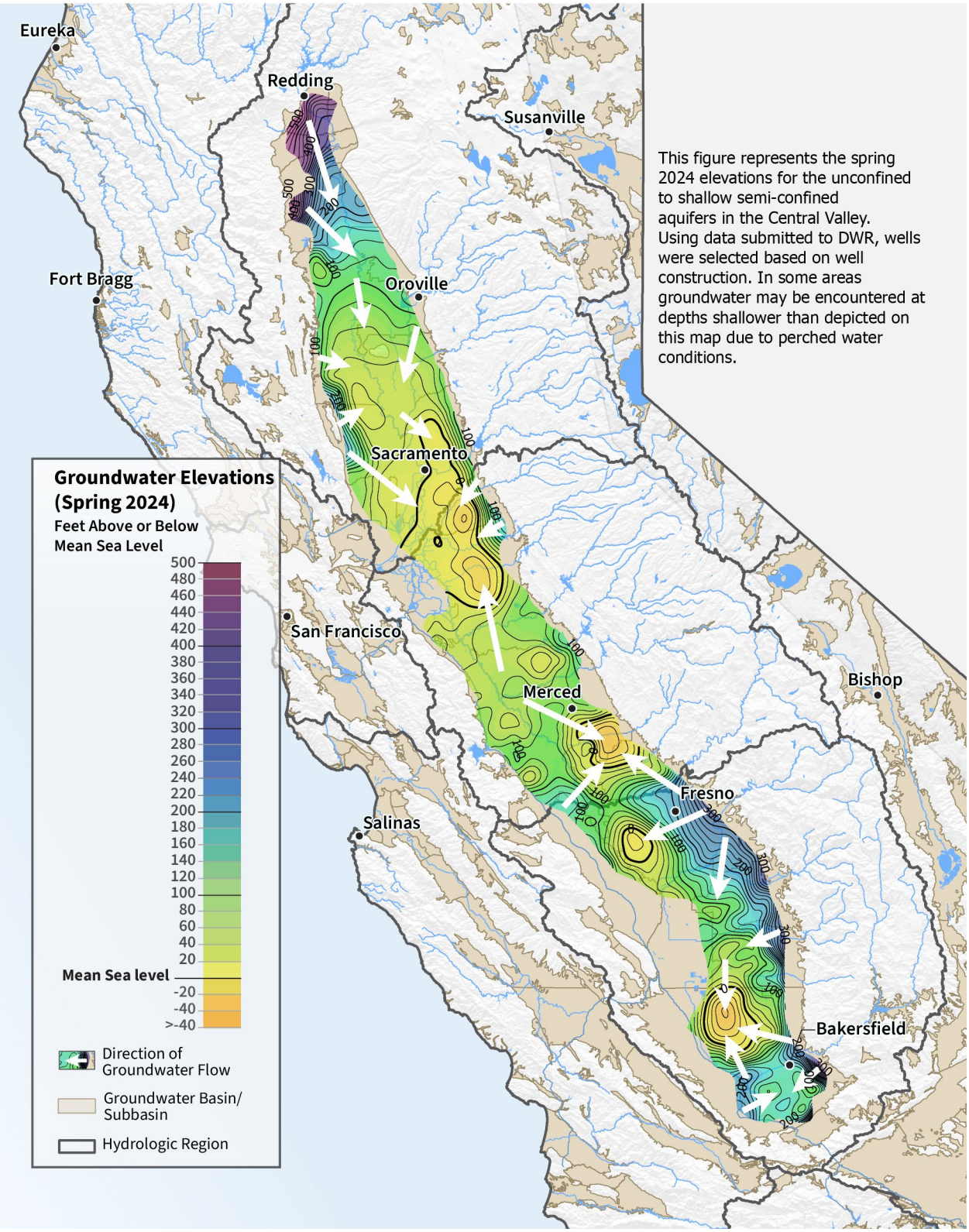
Groundwater flow within the Tulare Lake Hydrologic Region is more complex. In the areas east of the cities of Fresno and Tulare, groundwater elevations along the

PUBLIC DRAFT

eastern edge of the region exceed 300 feet (National Vertical Datum 1988). This higher elevation zone indicates that groundwater flows westward toward lower groundwater elevations following the slope of the foothills and diverges along major waterways. Once on the valley floor, the groundwater gradient and flow are directed toward large cones of depression in the southern portions of San Joaquin River Hydrologic Region southeast of Merced, southwest of Fresno, and northwest of Bakersfield.

PUBLIC DRAFT

Figure 6-3 Groundwater Surface Elevation Contour Map for the Central Valley (Spring 2024)



6.2.3 Groundwater Level Percentiles

Comparing current groundwater level measurements to a well's historical data provides valuable context for current conditions at that site. This comparison involves statistical analysis and the application of groundwater percentiles to recent measurements. A groundwater level percentile is calculated by comparing a single measurement to all past readings taken during the same month at that well, ranking it within the percentile distribution. Measurements falling within the 25th to 75th percentile range are considered normal. For this analysis, a ranking was assigned only if there were measurements from the same month for at least 10 different years. For a detailed description of this analysis, see Appendix C, "Methods and Assumptions."

Groundwater level percentiles for fall 2022 (August, September, October) are summarized in Table 6-1 and shown in Figure 6-4. During the 2020–2022 drought, there was a high demand for groundwater due to reduced surface water availability caused by lower precipitation. Based on fall 2022 groundwater levels percentiles, 60% of wells statewide were below normal, 30% were at the normal, and 10% were above the normal. Additionally, 50% of the wells were near historic lows (Table 6-1).

Groundwater level percentiles for spring 2024 (March, April, May) are summarized in Table 6-1 and shown in Figure 6-5. This period followed a wet WY 2023, which led to flooding in the southern Central Valley, and an average precipitation year in WY 2024. As a result of the wet WY 2023, groundwater demand was low, allowing for reduced extraction and increased recharge.

Statewide, based on spring 2024 groundwater level percentiles, 23% of wells were below the normal, 35% were at the normal, and 42% were above the normal (Table 6-1). More than 50% of wells in both the San Joaquin River and Tulare Lake hydrologic regions were below the normal. The South Coast and San Francisco Bay hydrologic regions had the highest percentage of wells above the normal.

The comparison between fall 2022 and spring 2024 groundwater data highlights significant improvements in groundwater levels following the wet conditions of 2023 and lower groundwater extraction rates in 2024. In fall 2022, during the peak of California's most recent drought, 60% of wells were below the normal, with close to half of the wells approaching historic lows. By spring 2024, after a wet year combined with reduced groundwater demand, only 23% of wells were below the normal, while 42% were above the normal, indicating substantial

PUBLIC DRAFT

groundwater recharge. Despite this overall improvement in groundwater levels, the San Joaquin River and Tulare Lake hydrologic regions still show more than 50% of wells below the normal. Additionally, areas along the northern and western Sacramento Valley have a concentration of wells below the normal, pointing to localized areas that have not yet recovered. This comparison underscores the importance of both climate variability and groundwater management practices in restoring groundwater levels across the state.

Table 6-1 Summary of Groundwater Level Percentiles[1] (Fall 2022 and Spring 2024)

Statewide Percentile Class	Total Well Count	Lowest on Record[2]	Less than 10%	10–25%	25–75% (Normal)	75–90%	Greater than 90%	Highest on Record[3]
Fall 2022: August, September, October (High Groundwater Demand)	5,765	20%	23%	17%	30%	6%	3%	<1%
Spring 2024: March, April, May (Low Groundwater Demand)	4,866	4%	8%	11%	35%	17%	14%	11%

Table 6-1 Notes:

1. *Groundwater level percentile class is determined by comparing a current measurement to past groundwater level readings taken in the same month at that well, showing its statistical ranking among all recorded levels. For example, if 90% of past readings are deeper, the current measurement is in the 90th percentile. If only 10% are deeper, it falls in the 10th percentile. A measurement is considered normal if it falls within the 25th to 75th percentile range.*
2. *Lowest on Record percentile class is counted separately from the Less than 10% class.*
3. *Highest on Record percentile class is counted separately from the Greater than 90% class.*

PUBLIC DRAFT

Figure 6-4 Groundwater Level Conditions as of Fall 2022 (August, September, October)

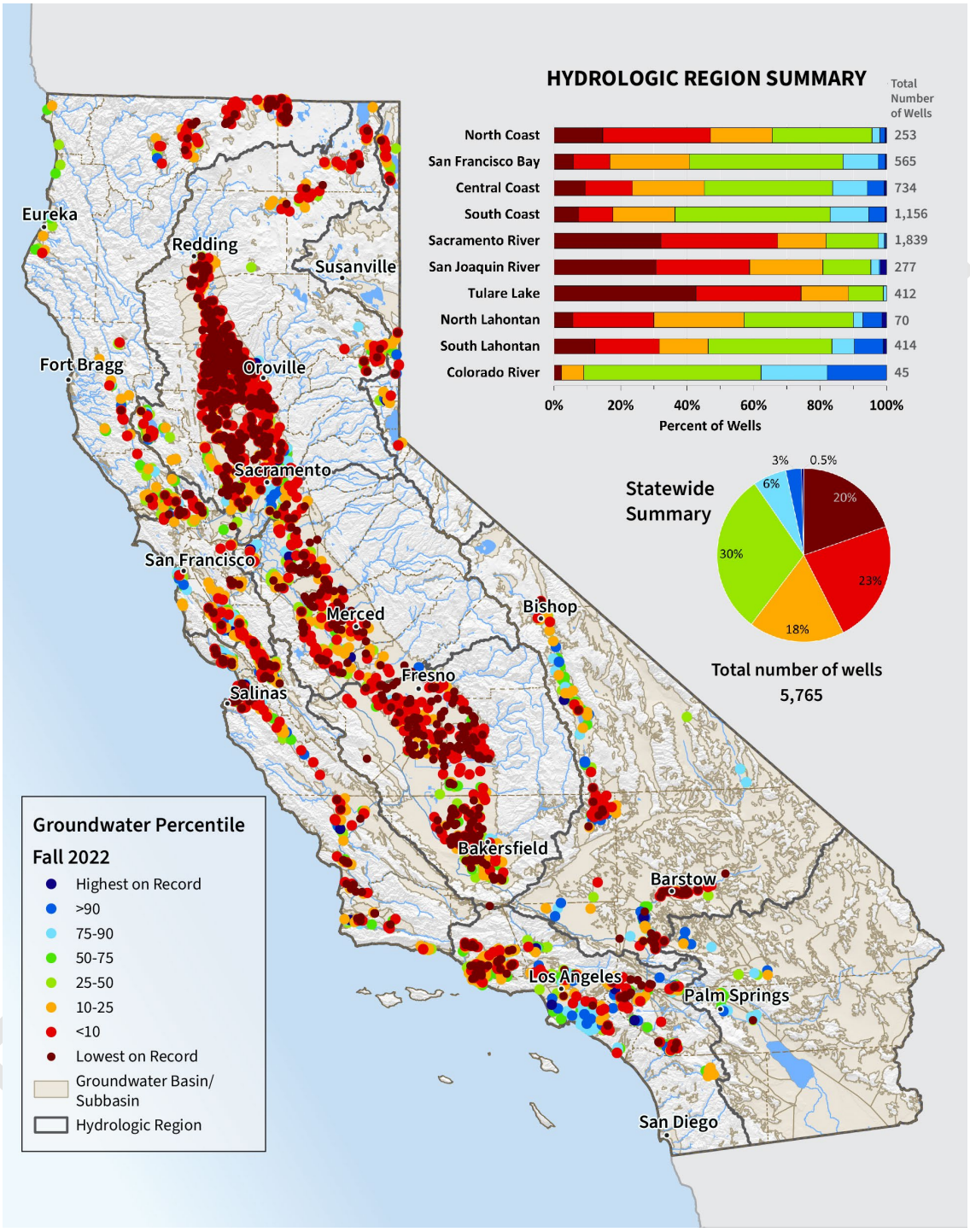


Figure 6-4 Note: Groundwater level percentile class is determined by comparing a current measurement to past groundwater level readings taken in the same month at that well, showing its statistical ranking among all recorded levels.

Figure 6-5 Groundwater Level Conditions as of Spring 2024 (March, April, May)

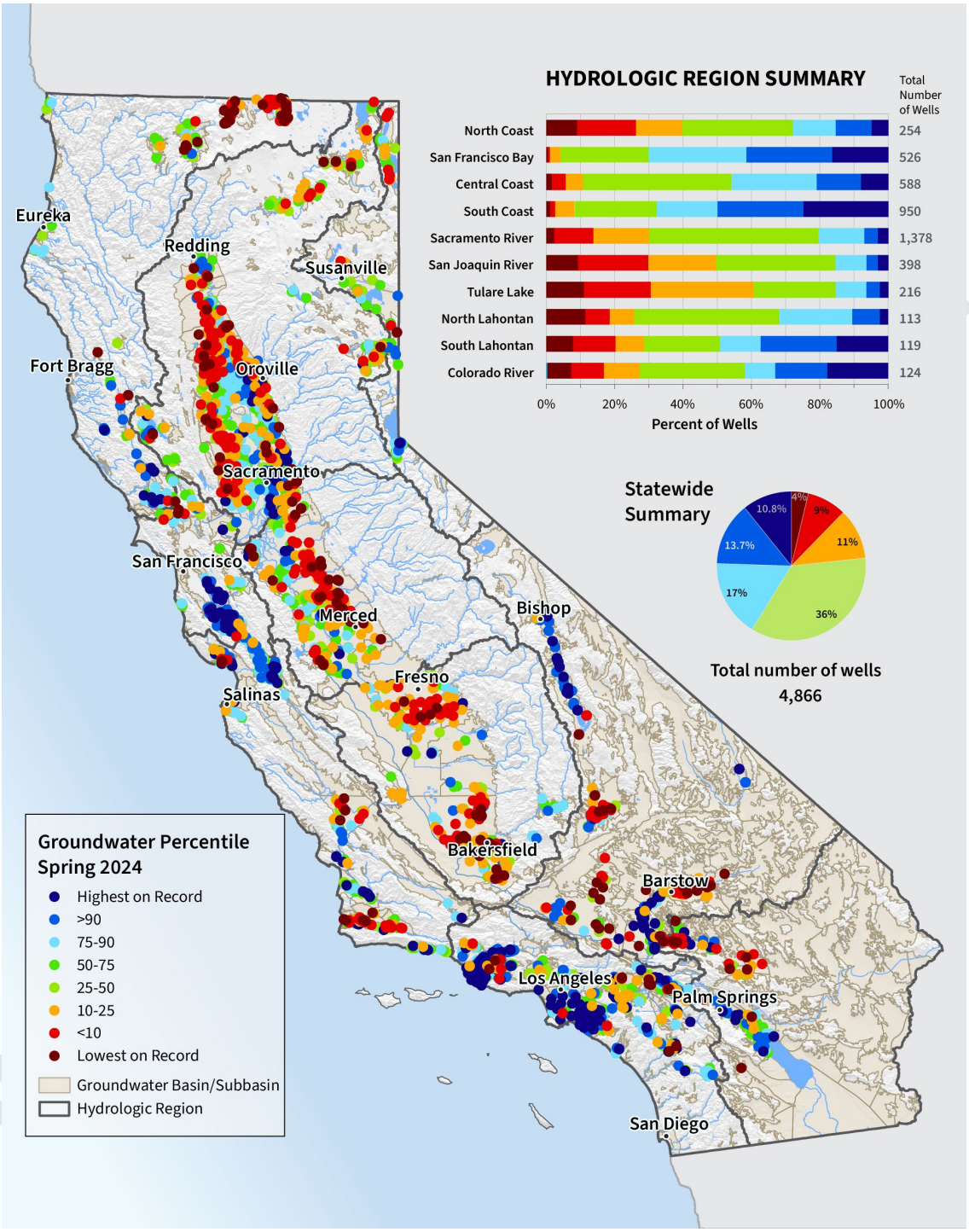


Figure 6-5 Note: Groundwater level percentile class is determined by comparing a current measurement to past groundwater level readings taken in the same month at that well, showing its statistical ranking among all recorded levels.

6.2.4 Groundwater Level Changes

Groundwater level (GWL) change maps show the net difference in groundwater elevation using measurements taken from the same well at different times. The change is calculated by subtracting a previous groundwater level elevation from a more recent one, with positive values indicating a rise in levels and negative values indicating a decline. When changes from multiple wells are analyzed, they reveal regional trends in aquifer recovery or depletion over a set period. These changes, especially declines during drought, can highlight vulnerabilities affecting groundwater wells, the environment, areas at risk of land subsidence, water quality degradation, and beneficial users.

The one-year groundwater level change map (Figure 6-6) compares spring 2023 to spring 2024, comparing a wet year to an average precipitation year. The five-year change map (Figure 6-7) compares spring 2019 to spring 2024, a period that includes the 2020 to 2022 drought. The 10-year change map (Figure 6-8) compares spring 2014 to spring 2024, a period that included the 2012 to 2016 and 2020 to 2022 droughts. Table 6-2 summarizes the number and percentage of wells with groundwater level changes for these time periods.

PUBLIC DRAFT

Table 6-2 Summary of Groundwater Level Changes (2023–2024, 2019–2024, and 2014–2024)

Period	Total Well Count	Decrease > 25 ft	Decrease 5 to 25 ft	No Significant Change (Less than +/- 5 ft)	Increase 5 to 25 ft	Increase >25 ft
1-Year GWL Change Spring 2023 to Spring 2024	6,316	1%	4%	60%	25%	9%
5-Year GWL Change Spring 2019 to Spring 2024	4,829	4%	22%	52%	15%	7%
10-year GWL Change Spring 2014 to Spring 2024	4,505	7%	13%	39%	29%	12%

PUBLIC DRAFT

Figure 6-6 One-Year Changes in Groundwater Levels (Spring 2023-Spring 2024)

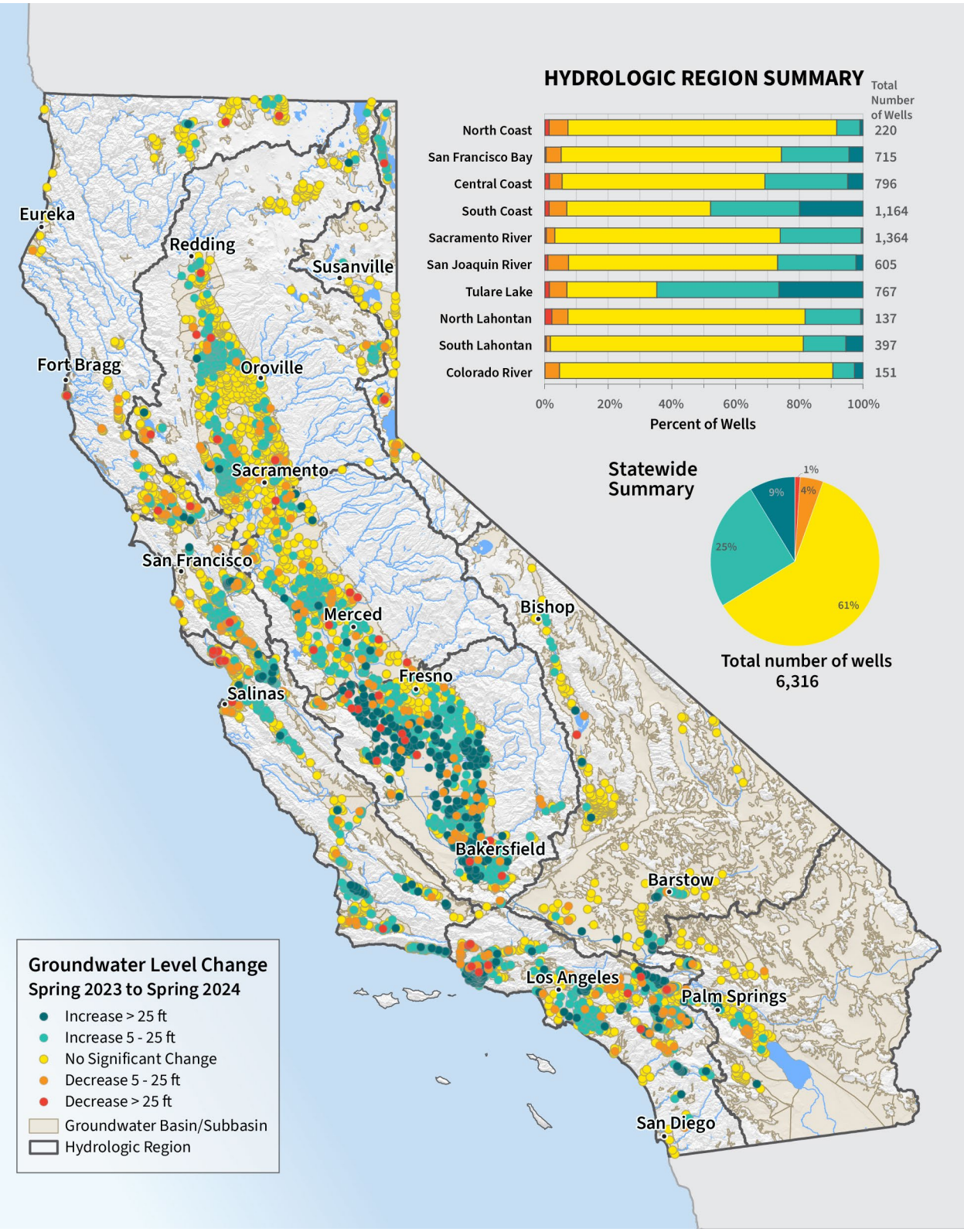


Figure 6-7 Five-Year Changes in Groundwater Levels (Spring 2019-Spring 2024)

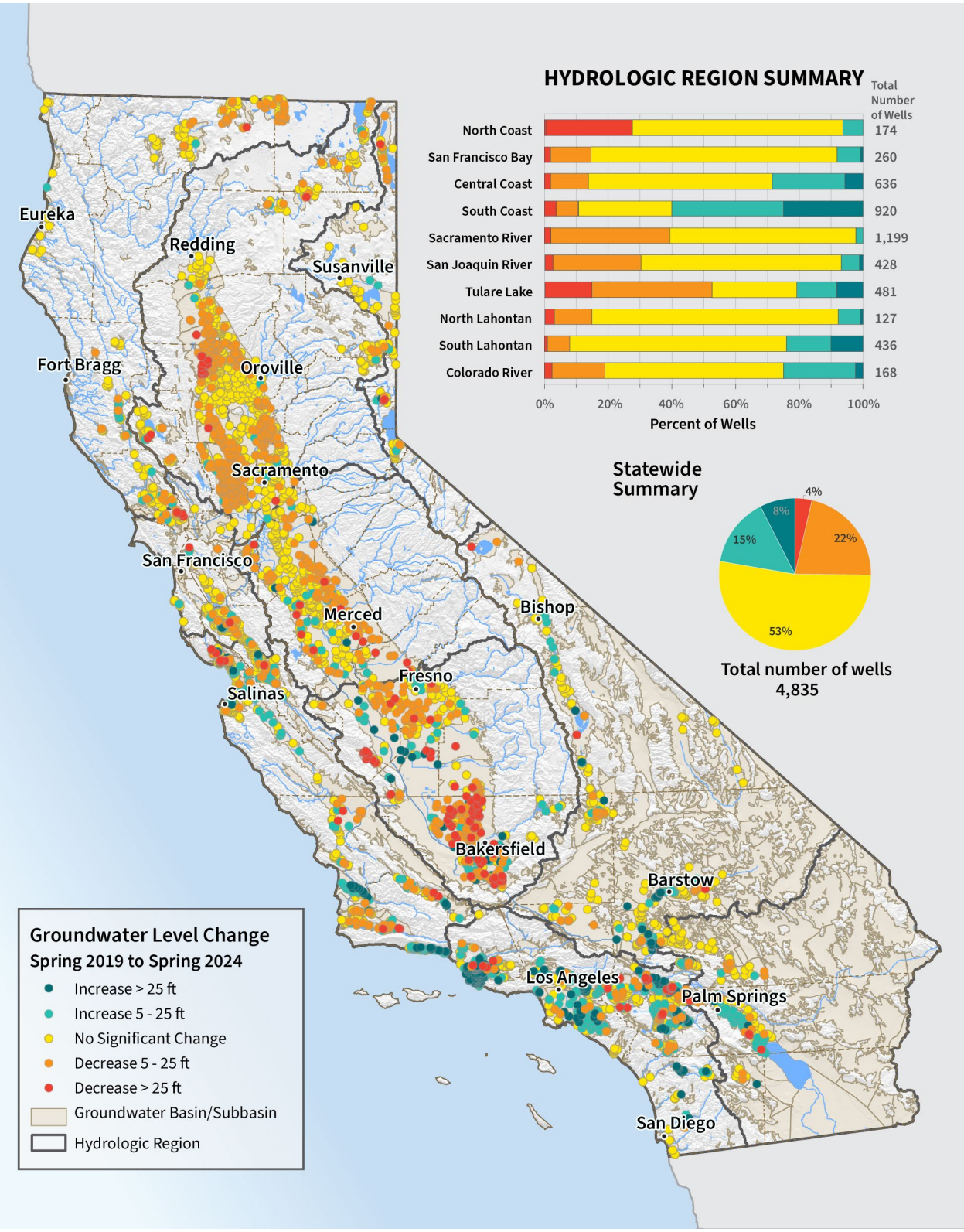


Figure 6-8 **Ten-Year Changes in Groundwater Levels (Spring 2014-Spring 2024)**

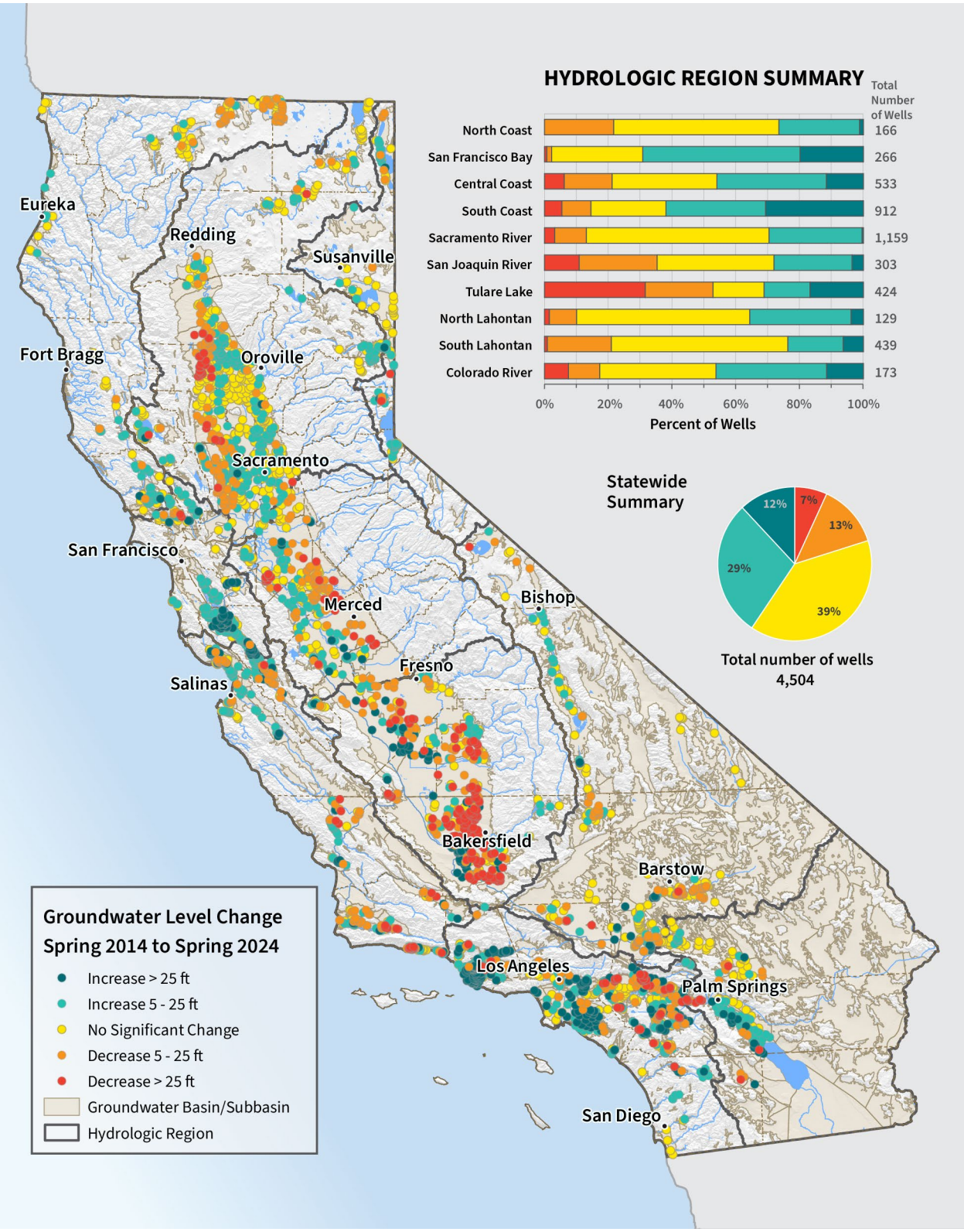


Figure 6-6 and Table 6-2 show improving groundwater conditions based on a one-year groundwater level comparison. In the one-year change between spring 2023 and spring 2024, 34% of measured wells showed groundwater level increases of more than five feet, while only 6% showed declines greater than five feet. Additionally, 60% of wells showed no significant change (less than +/- 5 feet). The highest percentage of wells with rising groundwater levels from spring 2023 to spring 2024 was found in the Tulare Lake, South Coast, and San Francisco Bay hydrologic regions.

Figure 6-7 and Table 6-2 show the five-year groundwater level comparison and indicate that a significant number of the measured wells have not returned to the pre-drought groundwater levels of 2019. Statewide, between 2019 and 2024, 26% of wells showed a five-year decline, 22% of wells had an increase in groundwater levels, and about 52% of wells showed no significant change in groundwater levels. The Tulare Lake Hydrologic Region experienced the most significant declines, with about 53% of wells reporting lower groundwater levels. Statewide, the Central Coast and South Coast hydrologic regions experienced the greatest increases in groundwater levels.

Figure 6-8 and Table 6-2 show the 10-year groundwater level comparison, taken during the middle of the 2012 to 2016 drought, to be that 41% of groundwater levels are five feet or more higher while only 20% are more than five feet lower. Spring 2024 groundwater levels in 39% of wells are similar to 2014 levels, which is an improvement over the previous 10-year comparisons (presented in DWR California's Groundwater: Semi-Annual Updates) and is the first time the spring 10-year change comparison has shown more increases than decreases in water levels. The 10-year comparison of water levels within the Tulare Lake and San Joaquin River hydrologic regions show decreases of more than 5 feet. The majority of measured wells in the San Francisco Bay and Central Coast hydrologic regions had groundwater levels increases of 5 feet or more.

While the one-year groundwater level change analysis shows groundwater recovery in 2024 following above-average precipitation in much of the state in 2023, the five-year analysis highlights the fact that groundwater basins across much of the state have not fully recovered to the pre-drought levels of 2019.

6.2.5 Groundwater Level Trends

Long-term trends in groundwater levels provide a broader perspective on the sustainable management of groundwater in response to climate influences and the

PUBLIC DRAFT

needs of beneficial users over many years. Statistical trend analysis systematically evaluates groundwater level trends over time across multiple monitoring wells, applying weighting to consecutive measurements to better quantify both the trajectory and magnitude of trends. Trend analysis is more than a direct comparison of measurements from two different time periods, as it applies weighting to consecutive measurements to better quantify the trajectory of trends over time. This analysis method allows for graphing and mapping of the results and displaying spatial patterns in groundwater level changes. As such, trend analysis is a simple but powerful method for interpreting the status of groundwater conditions at local to regional scales and complements the more labor-intensive visual interpretation of individual hydrographs. Groundwater levels at selected wells were analyzed using the Mann-Kendall non-parametric test to determine whether a statistically significant trend (declining trend, no trend, or increasing trends in groundwater levels) was present during the specified period. If a statistically significant trend was observed, the Theil-Sen method was used to calculate the estimated slope of the trend line to quantify the decline or increase. Appendix C, "Methods and Assumption," has more details.

A 20-year analysis period was selected using data from wells with at least 10 years of data within the 2004–2024 period. This period includes the dryer periods of 2007–2009, 2012–2016, and 2020–2022; and wetter periods of 2005–2006, 2011, 2017, and 2023–2024.The results of the analysis are categorized by the slope and slope direction and presented in Figure 6-9 and Table 6-3.

Several clusters of wells across the state experienced significant groundwater level declines during the 2004–2024 period. Approximately 51% of wells statewide exhibited a declining groundwater level trend. This represents an improvement from the 65% these wells reported in the 2020 CalGW, which is based on an analysis of the groundwater level data from 1998 to 2018 (California Department of Water Resources 2020). In the Central Valley, declining groundwater level trends were more prevalent in the south and less prevalent and less severe in the north. Significant declines occurred in the southeastern basins of the San Joaquin River Hydrologic Region, in the majority of the basins in the Tulare Lake Hydrologic Region, and along the western edge of the basins in the Sacramento River Hydrologic Region. In contrast, there is an increase in groundwater levels in the basins in the southeastern portion of the Sacramento River Hydrologic Region, in an area roughly overlying Sacramento County.

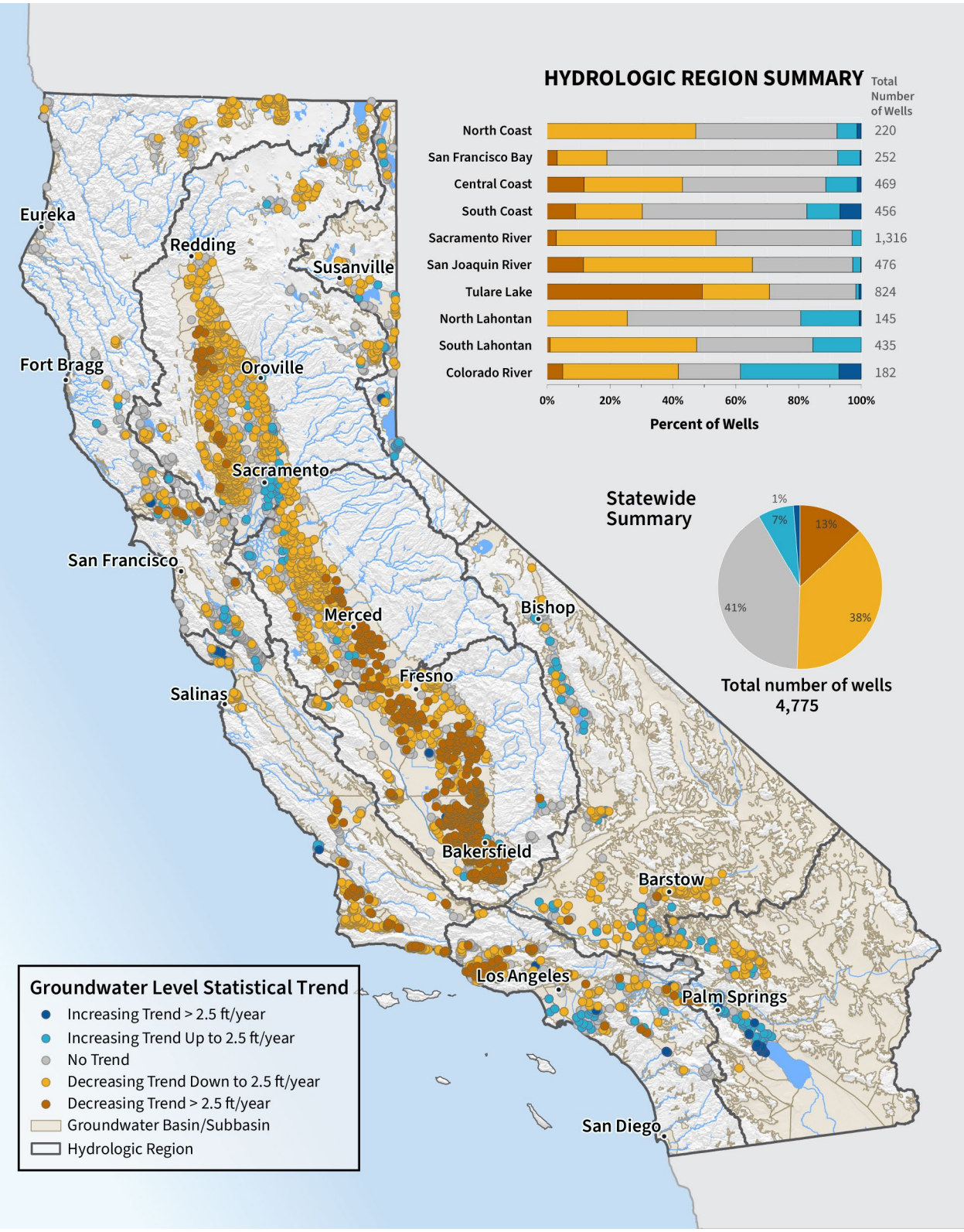
PUBLIC DRAFT

Table 6-3 Summary of Groundwater Level Trends (2004–2024)

Period	Total Well Count	Decrease > 2.5 ft	Decrease 0.01 – 2.5 ft	No Significant Trend	Increase 0.01 – 2.5 ft	Increase > 2.5 ft
20-Year Trend: 2004 to 2024	4,775	13%	38%	41%	7%	1%

PUBLIC DRAFT

Figure 6-9 Groundwater Level Trend Analysis Results (2004-2024)



6.3 Change in Groundwater Storage

The change in groundwater storage refers to the difference in the volume of groundwater within an aquifer between two time periods. These estimates provide important insights into how natural processes and management practices affect groundwater resources by summarizing the balance between inputs such as natural and managed recharge, and outputs such as groundwater pumping.

A wide range of techniques and tools can be used to estimate the change in groundwater storage. DWR and other public agencies have developed numerical models to produce these estimates for the Central Valley and other areas of the state. Additionally, GSAs provide the change in groundwater storage data for high- and medium-priority basins within and outside the Central Valley as part of annual reporting for the SGMA.

This section compares change in groundwater storage estimates for the Central Valley using various methods. Estimates for different periods are provided for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions depending on the method used. Variations in estimates can be attributed to differences in the analysis method, analysis timeframe (e.g., spring to spring or fall to fall estimates), and geographic coverage.

Methods or data sources used to estimate change in groundwater storage in this section include:

- *DWR Groundwater Level Method.* Using custom GIS tools, groundwater level data from two monitoring periods are analyzed to create a water level difference contour, showing changes in groundwater levels across the aquifer. Specific yield, which relates water level changes to storage, is used with the water level difference contour to calculate the change in groundwater storage between the two time periods. Specific yield values for this analysis were obtained from DWR's C2VSim-FG and USGS's CVHM2, with results presented as DWR-GWL (c2vsim param) and DWR-GWL (cvhm2 param), respectively. This method can be used in areas where there is sufficient groundwater level data and knowledge of the aquifer's hydrogeologic characteristics. While this approach represents how DWR implements the groundwater level method, other techniques may also be used to estimate storage changes using groundwater levels. More details on the DWR Groundwater Level Method are provided in Appendix C, "Methods and Assumptions."

PUBLIC DRAFT

- DWR's California Central Valley Groundwater-Surface Water Simulation Model – Fine Grid (C2VSim-FG). C2VSim-FG is a numerical model that simulates water movement through the linked land surface, groundwater, and surface water flow systems in California's Central Valley, and can be used to estimate changes in groundwater storage.
- NASA Gravity Recovery and Climate Experiment (GRACE) Program. The GRACE (2002–2017) and GRACE Follow-On (2018-current) programs use twin satellites to measure Earth's gravitational field with remarkable precision. By detecting tiny variations in gravity caused by changes in mass on Earth, GRACE helps scientists monitor shifts in water storage, ice mass, and sea level. This satellite-based remote sensing technique can provide estimates of change in groundwater storage at a regional scale.
- SGMA Annual Reports are another source of information on changes in groundwater storage for basins subject to the SGMA reporting. In the Central Valley, GSAs managing critically overdrafted basins began submitting annual reports in 2020, starting with data from WY 2019. The remaining Central Valley basins began submitting annual reports in 2022, starting with data from WY 2021. The analysis presented here included an examination of 173 annual reports, covering WYs 2019–2023, for basins within the Central Valley. The estimates provided in these annual reports were prepared using a variety of methods, including groundwater level analysis developed by local agencies, numerical models such as C2VSim-FG or other models, and combinations of these or other approaches. These methods also varied in the annual timeframes they covered. The reports provided the annual change in groundwater storage that occurred between spring periods, fall periods, and other timeframes. Figure 6-10 illustrates the mix of methods and timeframes used in annual reports for basins within the Central Valley.

PUBLIC DRAFT

Figure 6-10 Mix of Change in Groundwater Storage Estimation Methods and Timeframes used in Annual Reports for Basins within the Central Valley

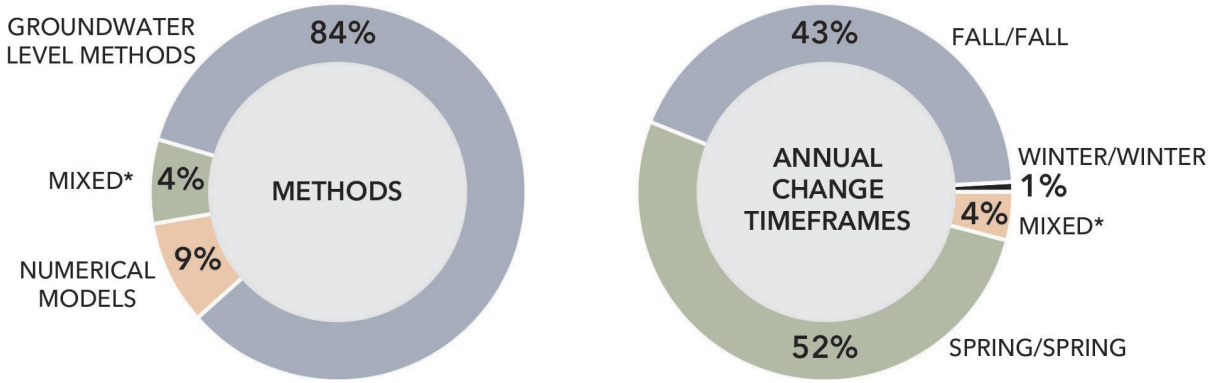


Figure 6-10 Notes: "Mixed" refers to a combination of methods or periods shown, or a method or period not listed. "Groundwater level methods" refer to methods developed by local agencies and not the DWR Groundwater Level Method.

The geographic area and resolution of spatial data are crucial factors in developing estimates for change in groundwater storage. The methods used to estimate the change in storage presented in this section are based on different geographic areas, as depicted in Figure 6-11 and described below.

Estimates developed using the DWR Groundwater Level Method reflect annual changes in the unconfined aquifer storage within groundwater basins in the Central Valley portions of the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions. The areas covered in the analysis are described as "Reporting Areas" (Figure 6-11) and are based on the distribution of available groundwater level measurement data. All areas where the density of groundwater level measurements is greater than one measurement per 50 square miles were included in the analysis. The average density of data points within the Central Valley Reporting Area is about one measurement per 36 square miles.

The DWR C2VSim-FG model, designed to simulate the groundwater and surface water flow conditions within the Central Valley, consists of approximately 30,000 nodes and 33,000 elements. The change in groundwater storage estimates from this model cover all the groundwater basins within the Central Valley (Figure 6-11).

The NASA GRACE-Follow On (GRACE-FO) data is processed and presented on a global grid, where the Earth's surface is divided into uniform-sized grid cells, often referred to as "pixels" with a spatial resolution of about 300–500 km (186–311

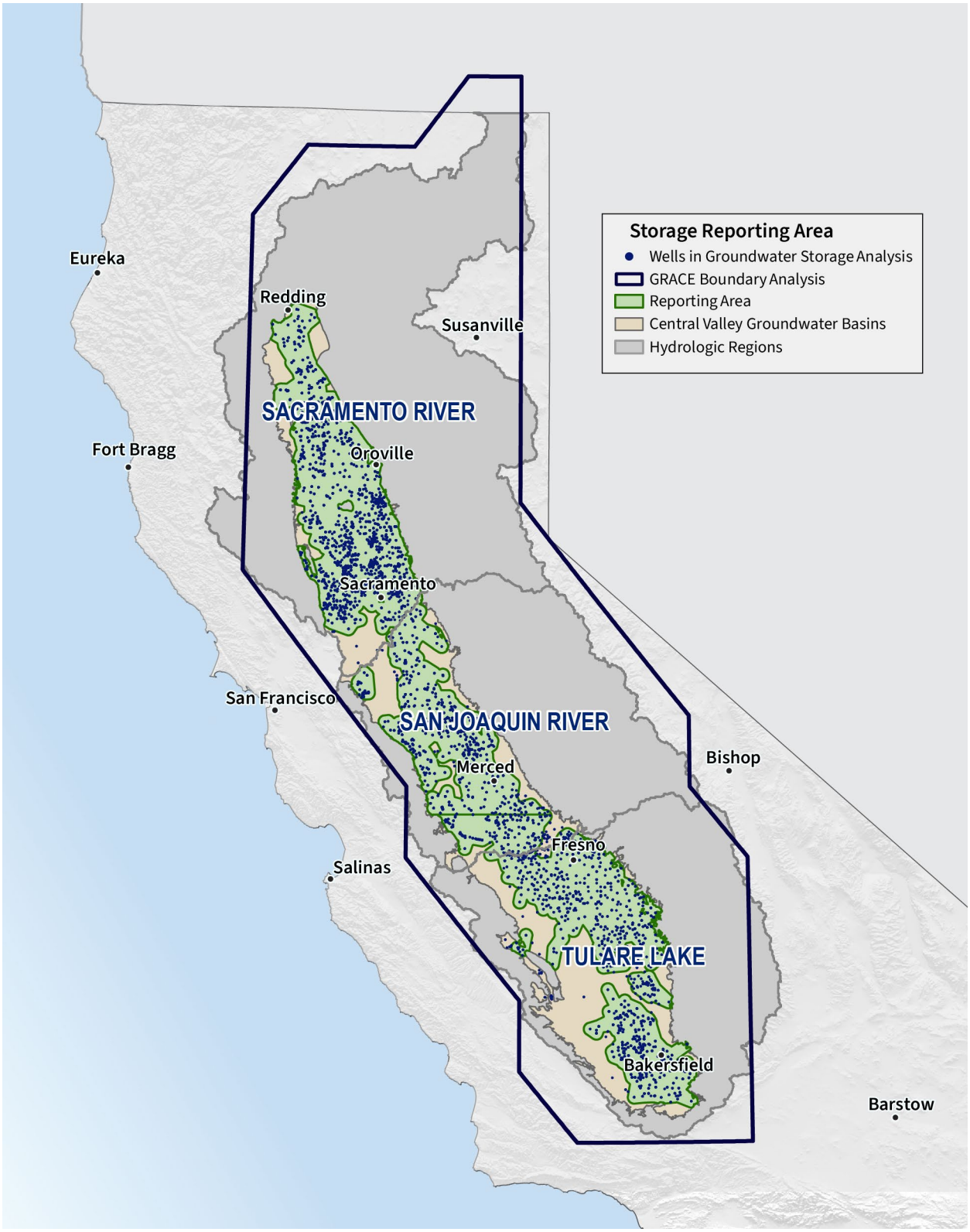
PUBLIC DRAFT

miles). The estimates shown in this section are based on the GRACE and GRACE-FO data. The analysis boundary area is generally defined by the major California river basins. While this analysis does not provide a specific estimate for the Central Valley basins, its boundary marginally extends beyond the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, as depicted in Figure 6-11.

Annual report data for basins subject to the SGMA reporting has been analyzed for all basins within Central Valley starting from WY 2021, and for critically overdrafted basins and the North and South Yuba subbasins for WY 2019 and WY 2020. The spatial resolution of data used in this analysis varies by basin, depending on the method used by the GSA.

PUBLIC DRAFT

Figure 6-11 Reporting Areas for Various Methods Used to Estimate Change in Groundwater Storage



6.3.1 Change in Groundwater Storage – 2006 to 2024

Long-term estimates for change in groundwater storage are available for the three methods described above. All methods show a net decrease in groundwater storage over the respective geographic areas and time frames they cover: approximately 21 million acre-feet (maf) between 2006 and 2024 using the DWR Groundwater Level Method, 26 maf between 2006 and 2021 using the DWR C2VSim-FG model, and 54 maf between 2006 and 2023 using the NASA GRACE data (Table 6-4). Variance in the estimated change in groundwater storage is attributed to the differences in the estimation methods and the area covered by these estimates. Although these estimates differ, the trend of decreasing groundwater storage is consistent and significant with all methods. During the 19-year period from 2006 to 2024, there were 10 drought years, which led to increased demand for groundwater and subsequent declines in groundwater storage, while non-drought years saw only limited increases in groundwater levels (Figure 6-12 and Table 6-4).

PUBLIC DRAFT

Figure 6-12 Estimated Cumulative Change in Groundwater Storage using DWR Groundwater Level Method, DWR C2VSim-FG Model, and NASA GRACE Program Data (in Thousand Acre-Feet)

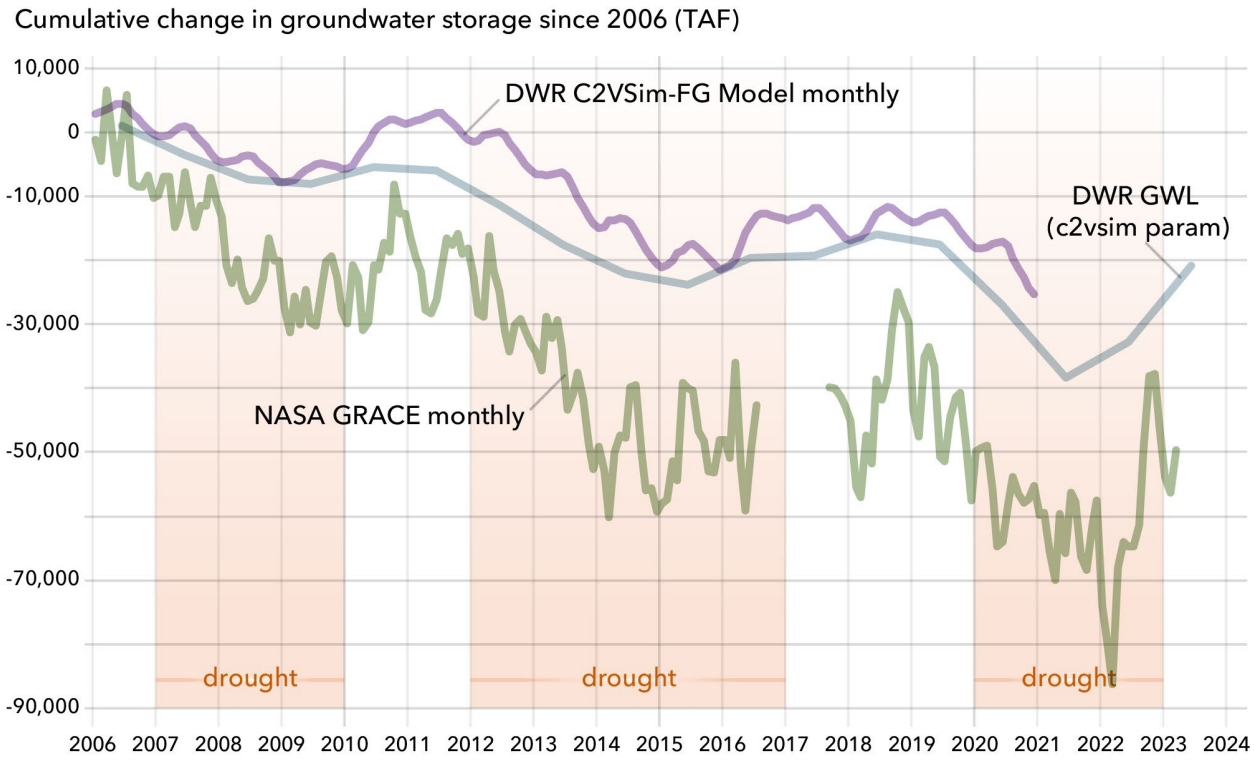


Figure 6-12 Notes: NASA GRACE and DWR C2VSim-FG Model methods show cumulative data for a monthly timestep analysis. DWR GWL (c2vsim param) method shows cumulative data for an annual timestep, based on a spring-to-spring analysis. The analysis uses C2VSim-FG Version 1.5, and estimates are provided for geographic areas defined in Section 6.3.

PUBLIC

Table 6-4 Estimated Cumulative Change in Groundwater Storage using DWR Groundwater Level Method, DWR C2VSim-FG Model, and NASA GRACE Program Data (in Thousand Acre-Feet)[1]

Year[2]	DWR GWL (c2vsim param)[3]	DWR C2VSim-FG Model[4]	NASA GRACE[5]
2006	3,263	3,303	-1,103
2007	1,116	-272	-9,835
2008	-3,502	-4,227	-13,105
2009	-7,399	-7,773	-27,563
2010	-8,067	-5,692	-29,880
2011	-5,395	1,218	-15,962
2012	-5,989	-1,269	-22,407
2013	-11,413	-5,978	-34,361
2014	-17,520	-14,426	-49,121
2015	-21,959	-20,740	-58,031
2016	-23,769	-21,631	-48,103
2017	-19,547	-13,685	-
2018	-19,206	-17,154	-
2019	-15,883	-14,740	-43,392
2020	-17,550	-18,473	-49,765
2021	-26,909	-26,011	-59,780
2022	-38,330	-	-73,983
2023	-32,722	-	-53,902
2024	-20,869	-	-

Table 6-4 Notes:

1. *NASA GRACE and DWR C2VSim-FG methods show cumulative data for October of each year, based on a monthly timestep analysis. DWR GWL (c2vsim param) method shows cumulative data for an annual timestep, based on a spring-to-spring analysis.*
2. *Estimates provided for geographic areas covered by the analyses, as defined in Section 6.3.*
3. *Source of 2006–2018 data is the California Water Plan — Groundwater Update 2013. Values represent averages of minimum and maximum values. See Methods and Assumptions for details.*
4. *The analysis uses C2VSim-FG Version 1.5.*
5. *NASA GRACE data unavailable for WYs 2017, 2018 and 2024.*

PUBLIC DRAFT

6.3.2 Change in Groundwater Storage – Water Years 2019–2024

Annual reports, submitted in compliance with the SGMA, provide estimates of the change in groundwater storage. Currently available reports cover the period from WY 2019 to WY 2023, while a dataset representing the years when all basins were required to submit reports under SGMA is available for WY 2021 to WY 2023. A comparison of the annual report data with estimates from two of the other methods presented above is provided in this section.

California's Central Valley groundwater storage has experienced significant fluctuations in recent years, reflecting the impacts of drought and subsequent partial recovery. From WY 2019 to WY 2024, groundwater storage initially increased, followed by substantial declines during the drought years of 2020–2022, with some recovery observed in WY 2023 and WY 2024.

Tables 6-5 through 6-10 and Figures 6-13 through 6-18 summarize the estimated change in groundwater storage for each hydrologic region, where data are available, using the various methods previously described.

Sacramento River Hydrologic Region

Table 6-5 Estimated Annual Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet)

Year	SGMA Annual Reports	DWR GWL (c2vsim-FG param)	DWR GWL (cvhm2 param)	DWR C2VSim-FG Model
2019	81	1,156	2,619	480
2020	-83	-1,392	-3,090	-947
2021	-1,730	-1,029	-2,253	-1,721
2022	-936	-1,418	-3,045	-
2023	1,082	1,340	3,047	-
2024	-	573	1,270	-

Table 6-5 Notes: SGMA annual report estimates for WY 2019–2020 reflect partial data, covering groundwater storage data for North Yuba and South Yuba subbasins only. SGMA annual reports and DWR C2VSim-FG Model methods show water year estimates; DWR GWL methods show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

PUBLIC DRAFT

Figure 6-13 Estimated Annual Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet)**

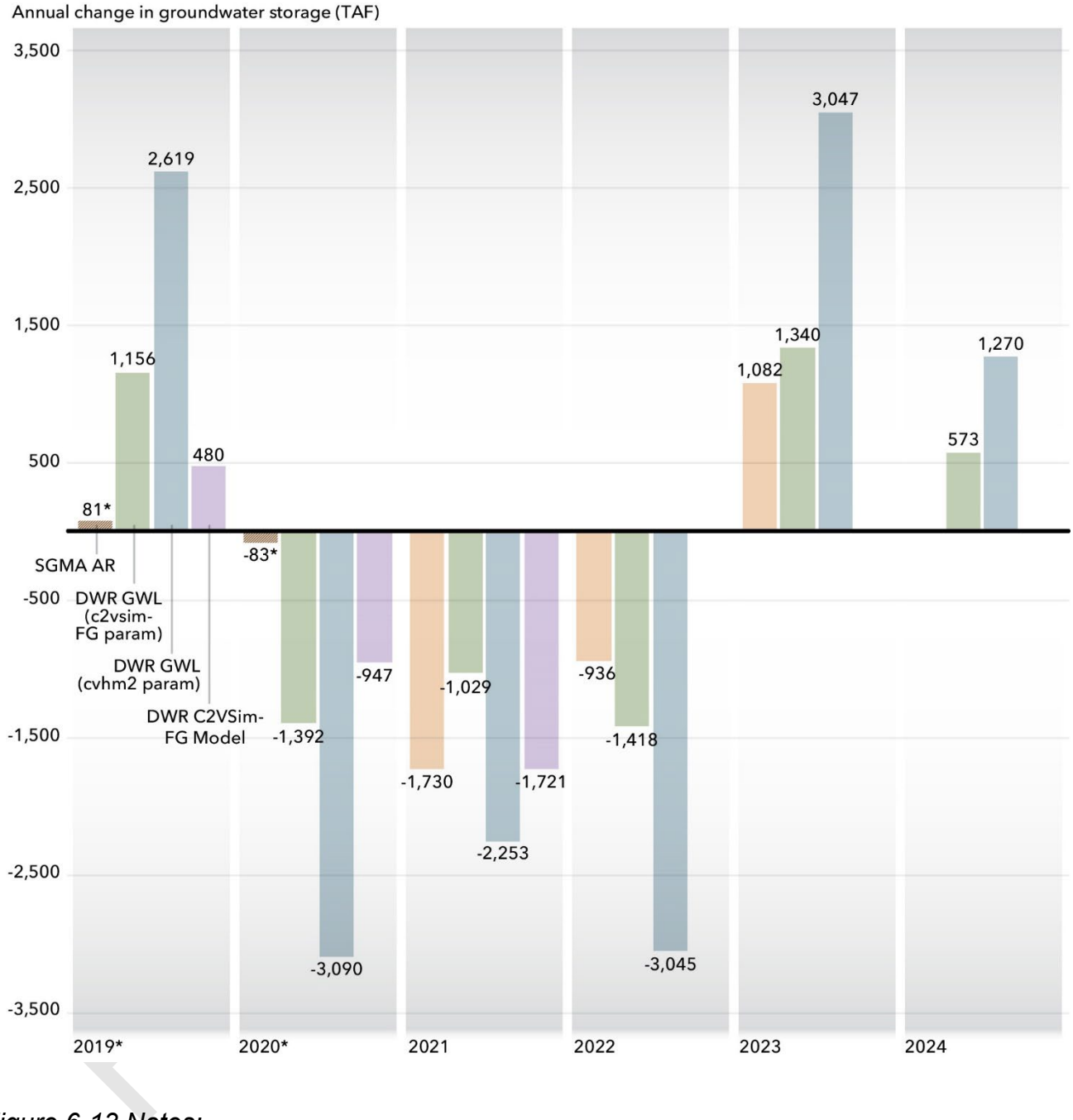


Figure 6-13 Notes:

** SGMA annual report estimates for WY 2019 and WY 2020 reflect partial data, covering groundwater storage data for the North Yuba and South Yuba subbasins only.*

***SGMA annual reports (AR) and DWR C2VSim-FG Model methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.*

Table 6-6 Cumulative Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet)

Year	SGMA Annual Reports	DWR GWL (c2vsim-FG param)	DWR GWL (cvhm2 param)	DWR C2VSim-FG Model
2019	81	1,156	2,619	480
2020	-2	-236	-471	-467
2021	-1,732	-1,265	-2,724	-2,188
2022	-2,668	-2,683	-5,769	-
2023	-1,586	-1,343	-2,722	-
2024	-	-770	-1,452	-

Figure 6-6 Notes: SGMA annual report estimates for WYs 2019–2020 reflect partial data, covering groundwater storage data for North Yuba and South Yuba subbasins only. SGMA annual reports and C2VSim-FG methods show water year estimates; DWR GWL methods show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

PUBLIC DRAFT

Figure 6-14 Cumulative Change in Groundwater Storage for the Sacramento River Hydrologic Region using Various Methods (in Thousand Acre-Feet)**

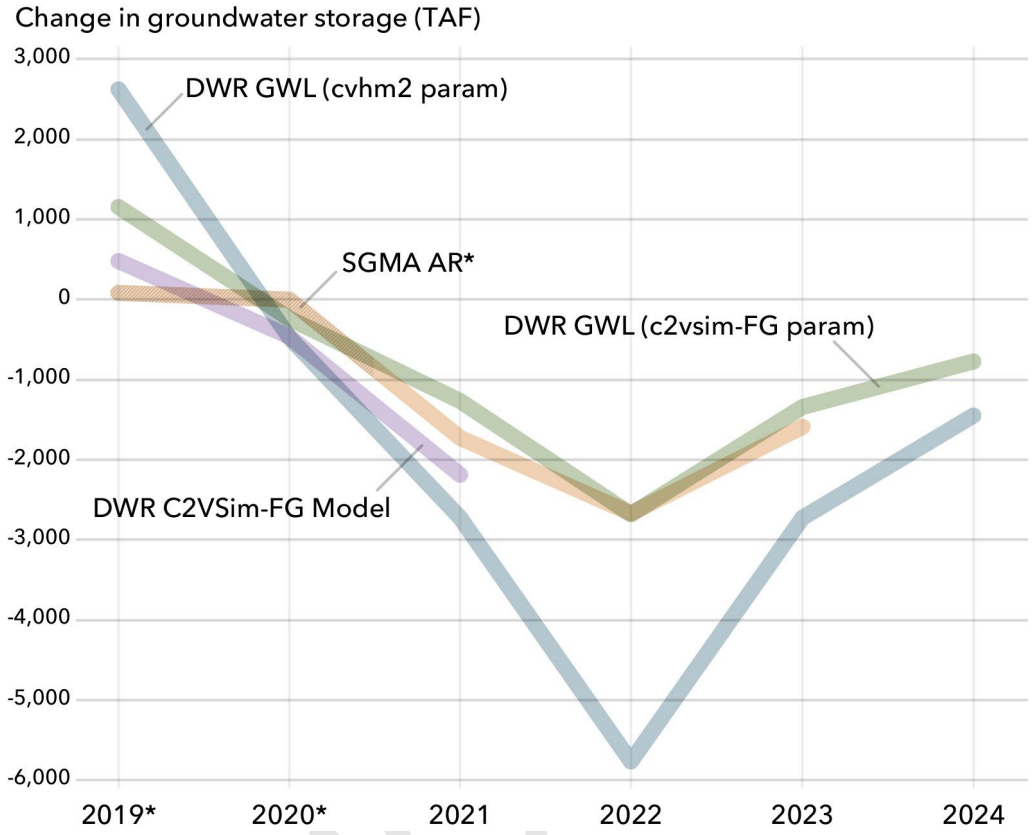


Figure 6-14 Notes:

** SGMA annual report estimates for WY 2019–2020 reflect partial data, covering groundwater storage data for North Yuba and South Yuba subbasins only.*

*** SGMA annual reports (AR) and DWR C2VSim-FG methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.*

PUBLIC

San Joaquin River Hydrologic Region

Table 6-7 Estimated Annual Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet)

Year	SGMA Annual Reports	DWR GWL (c2vsim-FG param)	DWR GWL (cvhm2 param)	DWR C2VSim-FG Model
2019	81	417	378	424
2020	-527	-894	-1,259	-966
2021	-1,513	-532	-934	-1,758
2022	-1,685	-2,312	-4,283	-
2023	1,061	1,669	3,036	-
2024	-	1,345	2,017	-

Table 6-7 Notes: SGMA annual report estimates for WY 2019–2020 reflect partial data, covering groundwater storage data for critically overdrafted basins only. SGMA annual reports and C2VSim-FG methods show water year estimates; DWR GWL methods show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

PUBLIC DRAFT

Figure 6-15 Estimated Annual Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet)

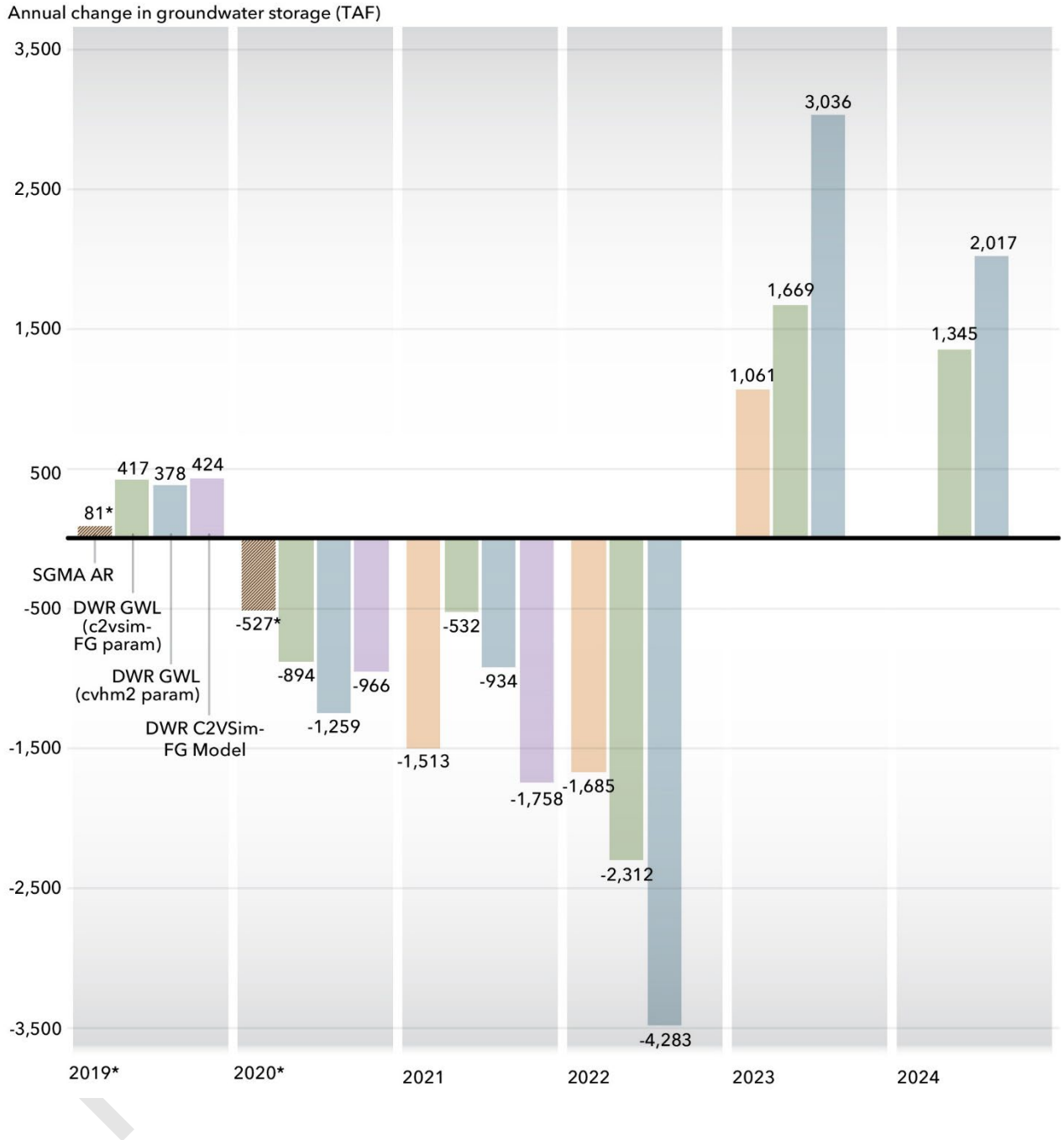


Figure 6-15 Notes: SGMA annual report estimates for WY 2019–2020 reflect partial data, covering groundwater storage data for critically overdrafted basins only. SGMA annual reports (AR) and DWR C2VSim-FG methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

Table 6-8 Cumulative Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet)

Water Year	SGMA Annual Reports	DWR GWL (c2vsim-FG param)	DWR GWL (cvhm2 param)	DWR C2VSim-FG Model
2019	81	417	378	424
2020	-446	-477	-880	-542
2021	-1,959	-1,010	-1,814	-2,301
2022	-3,644	-3,322	-6,098	-
2023	-2,583	-1,653	-3,061	-
2024	-	-308	-1,045	-

Table 6-8 Notes: SGMA annual report estimates for WY 2019–2020 reflect partial data, covering groundwater storage data for critically overdrafted basins only. SGMA annual reports and DWR C2VSim-FG methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

PUBLIC DRAFT

Figure 6-16 Cumulative Change in Groundwater Storage for the San Joaquin River Hydrologic Region using Various Methods (in Thousand Acre-Feet)**

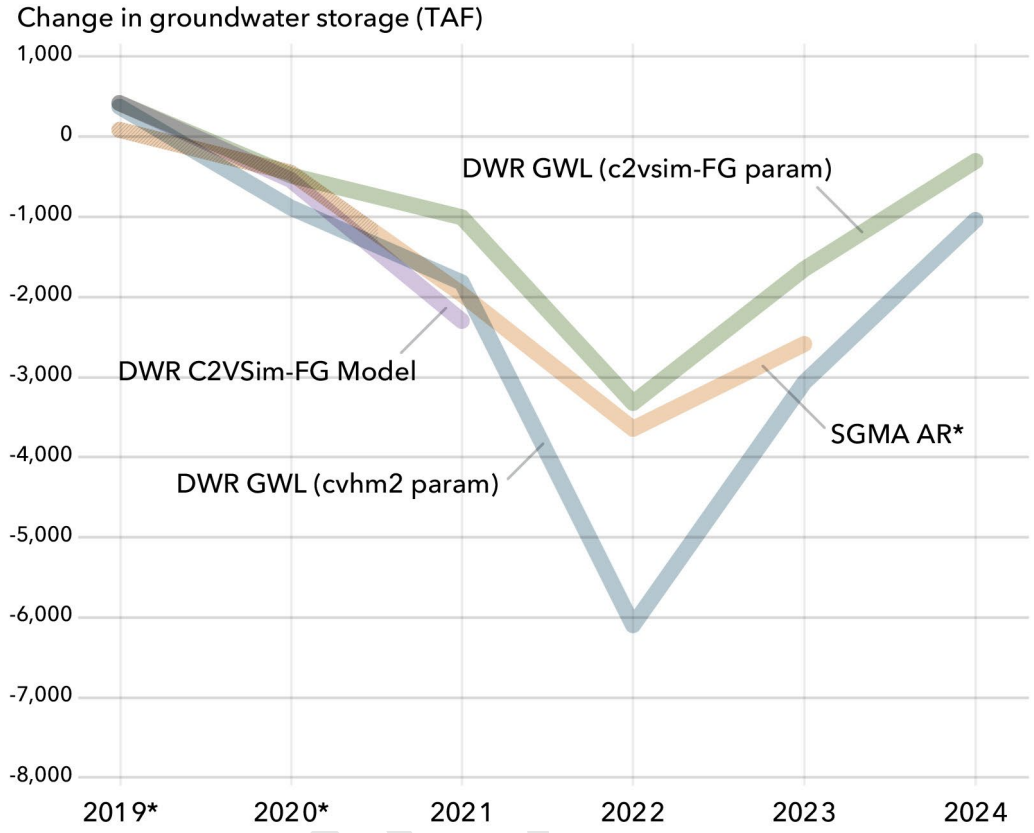


Figure 6-16 Notes:

**SGMA annual report estimates for WY 2019–2020 reflect partial data, covering groundwater storage data for critically overdrafted basins only.*

***SGMA annual reports (AR) and DWR C2VSim-FG methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.*

PUBLIC

Tulare Lake Hydrologic Region

Table 6-9 Estimated Annual Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet)

Year	SGMA Annual Reports	DWR GWL (c2vsim-FG param)	DWR GWL (cvhm2 param)	DWR C2VSim-FG Model
2019	1,349	739	1,337	1,520
2020	-1,893	1,011	2,290	-1,724
2021	-3,859	-4,574	-9,395	-3,921
2022	-3,196	-3,708	-8,076	-
2023	5,242	405	1,720	-
2024	-	6,320	12,180	-

Table 6-9 Notes: SGMA annual reports and C2VSim-FG methods show water year estimates; DWR GWL methods show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

PUBLIC DRAFT

Figure 6-17 Estimated Annual Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet)

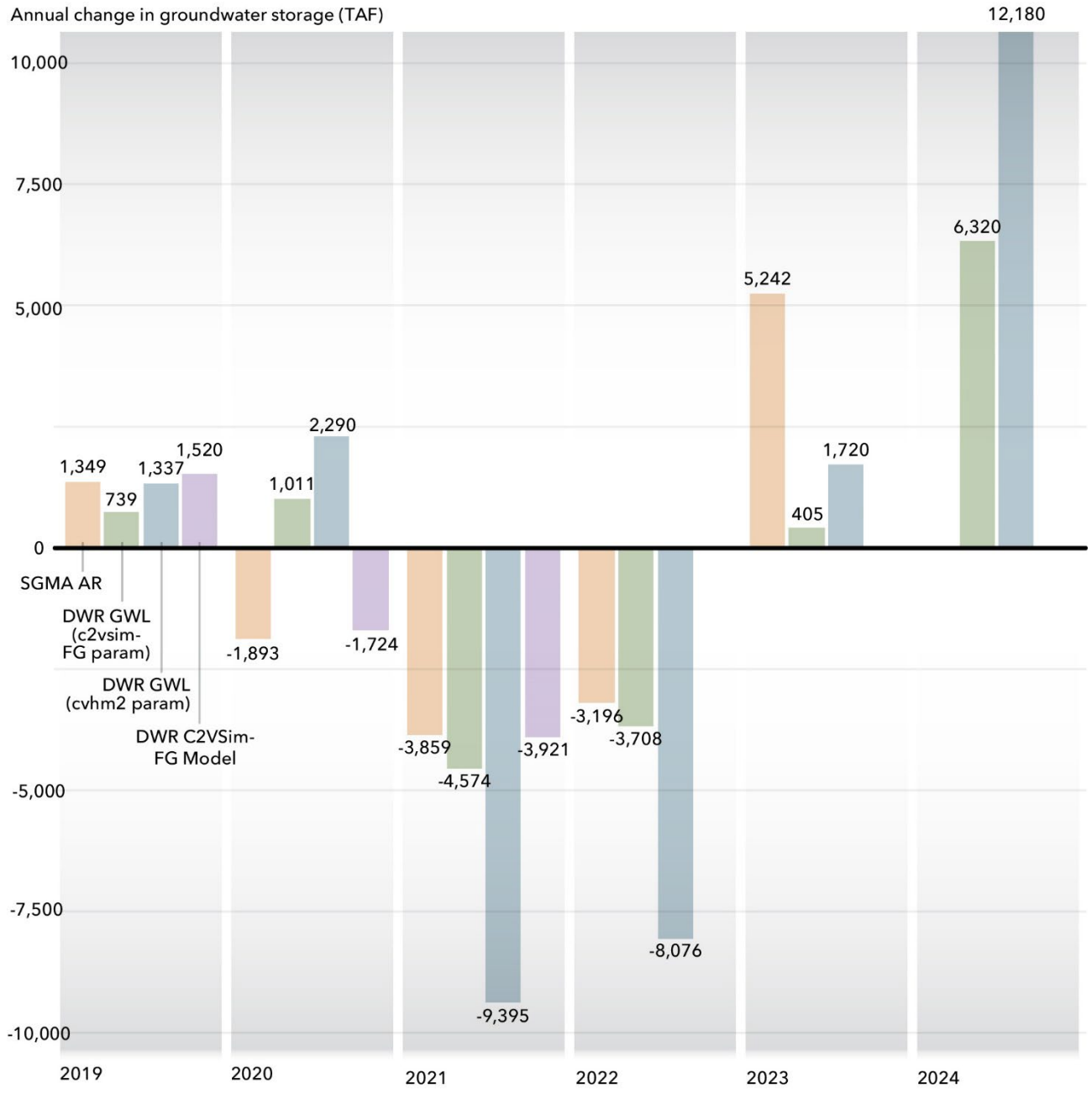


Figure 6-17 Notes: SGMA annual reports (AR) and DWR C2VSim-FG methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

Table 6-10 Cumulative Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet)

Year	SGMA Annual Reports	DWR GWL (c2vsim-FG param)	DWR GWL (cvhm2 param)	DWR C2VSim-FG Model
2019	1,349	739	1,337	1,520
2020	-544	1,750	3,627	-203
2021	-4,403	-2,824	-5,768	-4,125
2022	-7,599	-6,532	-13,844	-
2023	-2,357	-6,127	-12,125	-
2024	-	193	56	-

Table 6-10 Notes: SGMA annual reports and C2VSim-FG methods show water year estimates; DWR GWL methods show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

PUBLIC DRAFT

Figure 6-18 Cumulative Change in Groundwater Storage for the Tulare Lake Hydrologic Region using Various Methods (in Thousand Acre-Feet)

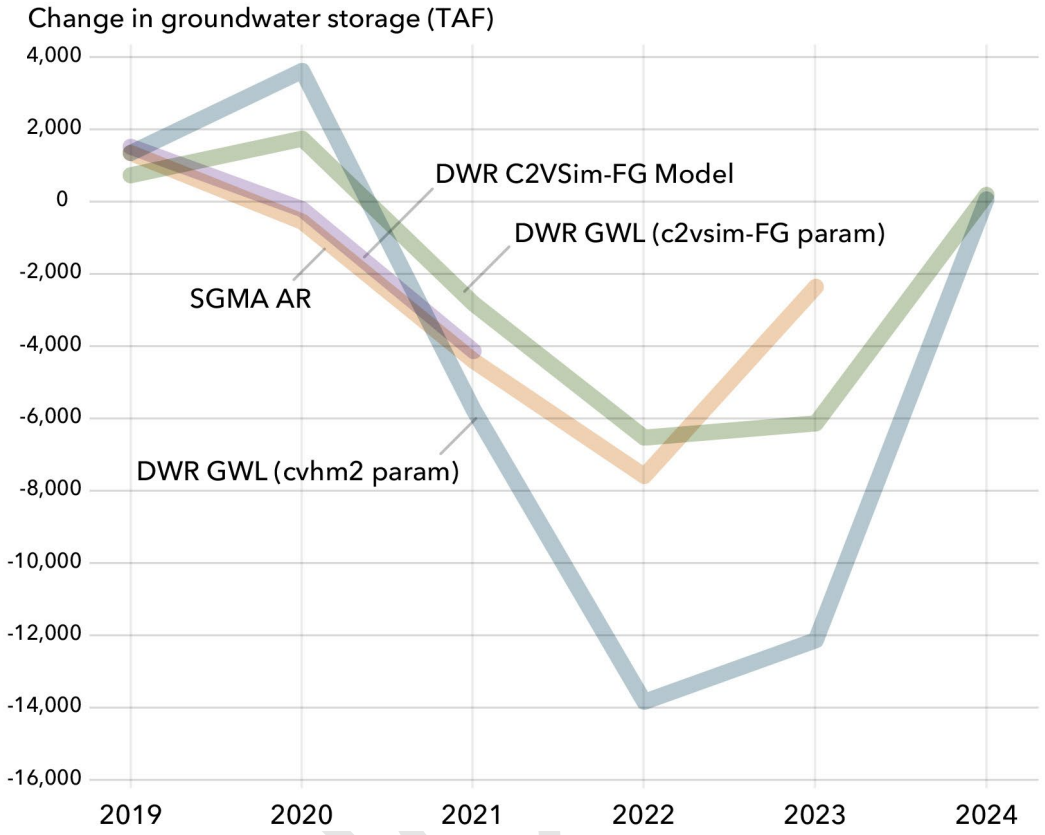


Figure 6-18 Notes: SGMA annual reports (AR) and DWR C2VSim-FG methods show water year estimates; DWR GWL methods (including c2vsim param and cvhm2 param) show spring-spring annual estimates. The analysis uses C2VSim-FG Version 1.5.

6.4 Groundwater Quality

Groundwater quality varies greatly in California's groundwater basins because of a broad range of natural and anthropogenic influences. Groundwater quality conditions can be assessed by collecting groundwater samples and comparing the results to a set of drinking water standards, such as the maximum contaminant level set by the U.S. Environmental Protection Agency (EPA) and the California Office of Environmental Health Hazard Assessment (OEHHA). Groundwater quality trends can be assessed by comparing the data from one well to those of nearby wells, or by comparing the data over time from a single well. This report includes groundwater quality conditions information based on comparison of sample data with maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), and notification levels (NLs), collectively referred to as *reference concentrations*.

PUBLIC

Groundwater quality information is available from several sources, such as online data repositories for regulatory and voluntary programs, technical reports, or online tools. Links to many of these resources are provided in Appendix D, "Citations, Reference Materials, and Links."

6.4.1 Overall Groundwater Quality Conditions

The groundwater quality information available from the State Water Resources Control Board (State Water Board) Groundwater Ambient Monitoring and Assessment (GAMA) Program's groundwater information system is used to summarize groundwater quality conditions in California. As described in Chapter 5, "Groundwater Monitoring," the GAMA database includes raw groundwater quality sampling results (i.e., samples taken prior to treatment) from the entire state in both basin and non-basin areas. For this analysis, the State Water Board queried data from GAMA geographic information system. All data from wells with water quality data from October 1, 2013, through September 30, 2023, were compiled into a dataset named "Statewide Groundwater Quality Data" (WQ Conditions dataset).

Water quality monitoring wells in the GAMA system include dedicated monitoring wells as well as domestic, irrigation, municipal, and other supply wells that take water quality measurements. To conduct the water quality analysis based on baseline groundwater conditions, wells labeled as active contaminant investigations, active cleanup sites, or monitoring wells for permitted discharge sites such as gas station cleanups, hazardous site cleanups, and similar projects, were omitted from the dataset and analysis.

The WQ Conditions dataset contains groundwater quality sampling results from 33,922 water quality monitoring wells (see Chapter 5, "Groundwater Monitoring," Figure 5-10). Although the source dataset provides the most comprehensive statewide coverage available, the locations tend to be biased toward urban and basin areas. This analysis reports on the quality of raw groundwater and does not indicate or predict the quality of water delivered as the water may be treated prior to delivery and use. For the groundwater quality sampling results, see the WQ Conditions dataset posted on the California Natural Resources Agency (CNRA) Open Data website.

The results of the WQ dataset query provide a summary of overall groundwater quality conditions in California. Water quality monitoring wells were organized into three categories of low, medium, and high concentration of a particular COC. The

PUBLIC DRAFT

highest measurement of a given constituent over the ten-year period determines the category assigned to a well using the following rules:

- Low (measurement was greater than 0 and less than or equal to half of the reference concentration).
- Medium (measurement was greater than half the reference concentration and less than or equal to the reference concentration).
- High (measurement was greater than the reference concentration).

6.4.2 Concentrations for Constituents of Concern

Eight constituents of concern were selected for analysis to highlight statewide groundwater quality trends. These constituents were selected based on known toxicity (1,2,3-TCP, NO_3N, As, U, Cr6), known effects to beneficial water use (TDS), and emerging contaminants of concern (PFOA, PFOS). They are: 1,2,3-trichloropropane (1,2,3-TCP), nitrate as nitrogen (NO_3N), arsenic (As), uranium (U), hexavalent chromium (Cr(VI) or Cr6), total dissolved solids (TDS), Perfluorooctanoic Acid (PFOA), and Perfluorooctane Sulfonate (PFOS).

- 1,2,3-TCP is a synthetic organic compound that was primarily used as a cleaning and degreasing agent. It was historically blended into pesticides. 1,2,3-TCP exposure has been demonstrated to cause cancer in laboratory animals. In 2009, OEHHA established a California-specific MCL of 0.005 micrograms per liter (State Water Resources Control Board 2009).
- Nitrate as nitrogen is an inorganic, water-soluble compound that is often associated with potentially fatal human health effects, such as methemoglobinemia (a cause of blue baby syndrome) (World Health Organization 2016). In 2009, OEHHA established a California-specific MCL of 10 milligrams per liter.
- Arsenic, an inorganic semi-metalloid that is present in the environment naturally and as a result of certain human activities, is a known human carcinogen (State Water Resources Control Board 2017a). OEHHA established a California-specific MCL of 10 micrograms per liter.
- Uranium is a radionuclide that occurs naturally in many geologic formations. In California, it is often associated with granitic rocks of the Sierra Nevada and the Peninsular Ranges and their detritus. The most common uranium isotope, U-238, is only weakly radioactive; it is not considered to be a hazardous radioactive substance but can function as a weak chemical poison in high concentrations (World Health Organization 2012; State Water Resources Control Board 2017b). Uranium may also be associated with other

PUBLIC DRAFT

radionuclides, such as gross alpha and gross beta radiation. OEHHA established a California-specific MCL of 20 picocuries per liter of air.

- Hexavalent chromium (Cr6) is a form of chromium that can occur naturally from geology or from human activity. It can be formed through a reaction with manganese in the presence of oxygen and is a concern where oxygenated water can enter the groundwater system in large quantities. There are several types of chromium, but Cr6 is the most biologically active and harmful to human health and therefore regulated. In 2024, the State Water Resource Control Board adopted an MCL of 10 micrograms per liter (State Water Resources Control Board 2024a).
- TDS is the measure of all dissolved organic and inorganic substances in water, primarily minerals and salts. TDS is often used as a proxy for measuring water salinity and detecting seawater intrusion. Low TDS concentrations can give water a flat taste, which most people dislike. Even though high TDS concentrations are not usually harmful to human health, they may limit the beneficial uses of groundwater by giving it a sour, bitter, or metallic taste, or by staining household fixtures and corroding pipes. Based on these aesthetic effects, OEHHA established a California-specific secondary MCL (SMCL) of 1,000 milligrams per liter for TDS for short periods of time. While the USEPA and California Water Code Title 22 recommend an SMCL of 500 milligrams per liter, the higher SMCL applies only for California and is used for this analysis.
- Perfluorooctanoic Acid (PFOA) is part of a class of chemicals called per- and polyfluoroalkyl substances (PFAS) used for water-repellent and non-stick properties. PFOA has been used to manufacture non-stick cookware and firefighting foams. PFAS chemicals, including PFOA, are chemically stable and take a long time to break down, earning the name "forever chemicals." Because these chemicals persist in the environment, they have been identified as an emerging contaminant of concern for monitoring. In August 2019, the State Water Board issued a notification level (NL) of 5.1 nanograms per liter (State Water Resources Control Board 2019a). In 2024, the US EPA set the MCL for PFOA to 4 nanograms per liter (United States Environmental Protection Agency 2024). The analysis for PFOA for this document uses the NL of 5.1 nanograms per liter.
- Perfluorooctane Sulfonate (PFOS) is part of a class of chemicals called per- and polyfluoroalkyl substances (PFAS) used for water-repellent and non-stick properties. PFOS has been used in firefighting foams, fireproof garments, water-repellent fabrics, and paper packaging. In August 2019, the State

PUBLIC DRAFT

Water Board issued a notification level (NL) of 6.5 nanograms per liter (State Water Resources Control Board 2019b). In 2024, the US EPA set the MCL for PFOS to 4 nanograms per liter (United States Environmental Protection Agency 2024). The analysis for PFOA for this document uses the NL of 6.5 nanograms per liter.

For additional information on other emerging contaminants and their impact on water quality, especially drinking water for frontline communities, see the 2024 Drinking Water Needs Assessment (California State Water Resources Control Board 2024b).

Table 6-11 lists the number of water quality monitoring wells tested for each constituent listed above within each hydrologic region. Table 6-12 provides the percentage of water quality monitoring wells with the same list of constituents detected at a maximum value greater than the MCL, SMCL, or NL, out of the total number of wells sampled within each hydrologic region and statewide. A separate analysis reviewed all constituents sampled, regardless of whether they exceeded reference concentrations. Table 6-13 shows the three most frequently measured constituents for each hydrologic region, by basin and non-basin areas. The most frequently measured constituents do not match the eight selected COCs

Testing results of the eight selected COCs are provided in Tables 6-14 through 6-21. Results are presented for each region, basin, and non-basin area, as well as a statewide summary. The percentage of wells that exceeded the reference concentration (MCL, SMCL, or NL) was calculated by dividing the number of water quality monitoring wells that exceeded the reference concentration by the total number of wells sampled in the hydrologic region, basin, and non-basin area. The statewide percentage of wells exceeding the reference concentration is calculated using the same method with the statewide totals shown.

PUBLIC DRAFT

Table 6-11 Number of Water Quality Monitoring Wells Tested by Constituent in Each Hydrologic Region and Statewide (Water Years 2014–2023)

Hydrologic Region	1,2,3-TCP	NO_3N	As	U	Cr6	TDS	PFOA	PFOS
North Coast	581	1,163	720	70	707	576	92	92
San Francisco Bay	746	1,130	837	217	744	735	245	245
Central Coast	4,343	7,538	2,508	912	2,019	10,200	365	365
South Coast	2,621	3,159	2,760	2,197	2,469	2,773	1,269	1,269
Sacramento River	1,899	3,462	2,203	859	1,778	2,039	545	545
San Joaquin River	1,934	5,151	2,017	1,101	1,765	1,840	346	346
Tulare Lake	2,187	5,012	2,260	1,147	1,867	2,389	458	458
North Lahontan	154	323	188	59	140	179	21	21
South Lahontan	950	1,389	1,172	784	1,055	1,022	191	191
Colorado River	525	793	618	473	507	616	70	70
Statewide Total	15,940	29,120	15,283	7,819	13,051	22,369	3,602	3,602

Table 6-11 Notes: 1,2,3-TCP = 1,2,3-trichloropropane, As = arsenic, Cr6 = hexavalent chromium, NO3N = nitrate as nitrogen, PFOA = perfluorooctanoic acid, PFOS = perfluorooctane sulfonate, TDS = total dissolved solids, U = uranium.

PUBLIC DRAFT

Table 6-12 Percentage of Water Quality Monitoring Wells Exceeding Reference Concentration in Each Hydrologic Region and Statewide (Water Years 2014–2023)

Hydrologic Region	1,2,3-TCP (MCL)	NO_3N (MCL)	As (MCL)	U (MCL)	Cr6 (MCL)	TDS (SMCL)	PFOA (NL)	PFOS (NL)
North Coast	1%	1%	9%	0%	2%	1%	3%	3%
San Francisco Bay	1%	3%	9%	0%	4%	4%	7%	22%
Central Coast	3%	27%	10%	1%	9%	23%	10%	11%
South Coast	6%	14%	3%	4%	2%	10%	34%	35%
Sacramento River	1%	3%	9%	1%	10%	1%	10%	13%
San Joaquin River	10%	16%	15%	11%	3%	6%	5%	6%
Tulare Lake	22%	21%	14%	12%	1%	5%	8%	11%
North Lahontan	2%	1%	13%	14%	1%	0%	10%	0%
South Lahontan	1%	4%	25%	12%	11%	6%	4%	4%
Colorado River	1%	3%	10%	4%	27%	7%	0%	0%
Statewide	**6%**	**16%**	**11%**	**6%**	**6%**	**14%**	**17%**	**19%**

Table 6-12 Notes: 1,2,3-TCP = 1,2,3-trichloropropane, As = arsenic, Cr6 = hexavalent chromium, NO3N = nitrate as nitrogen, PFOA = perfluorooctanoic acid, PFOS = perfluorooctane sulfonate, TDS = total dissolved solids, U = uranium, % = percent.

PUBLIC DRAFT

Table 6-13 Three Most Frequently Measured Constituent in Each Hydrologic Region by Basin and Non-basin Area (Water Years 2014–2023)

Hydrologic Region	Region Area	First Constituent	Second Constituent	Third Constituent
North Coast	Basin	NO_3N	As	Mn
North Coast	Non-Basin	NO_3N	NO_2	Mn
San Francisco Bay	Basin	NO_3N	1,2,3-TCP	Mn
San Francisco Bay	Non-Basin	NO_3N	Fe	Mn
Central Coast	Basin	NO_3N	SC	TDS
Central Coast	Non-Basin	NO_3N	SC	TDS
South Coast	Basin	NO_3N	ClO_4	PCE
South Coast	Non-Basin	NO_3N	Mn	Fe
Sacramento River	Basin	NO_3N	As	Mn
Sacramento River	Non-Basin	NO_3N	NO_2	Mn
San Joaquin River	Basin	NO_3N	As	1,2,3-TCP
San Joaquin River	Non-Basin	NO_3N	Mn	NO_2
Tulare Lake	Basin	NO_3N	1,2,3-TCP	As
Tulare Lake	Non-Basin	NO_3N	Fe	Mn
North Lahontan	Basin	NO_3N	As	PCE
North Lahontan	Non-Basin	NO_3N	NO_2	Mn
South Lahontan	Basin	NO_3N	As	F
South Lahontan	Non-Basin	NO_3N	U	Alpha
Colorado River	Basin	NO_3N	F	As
Colorado River	Non-Basin	NO_3N	Fe	Mn
Statewide	**Total**	**NO_3N**	**As**	**Mn**

Table 6-13 Notes: 1,2,3-TCP = 1,2,3-trichloropropane, Alpha = gross alpha radionuclides, As = arsenic, ClO4 = perchlorate, F = fluorine, Fe = iron, Mn = manganese, NO2 = nitrite, NO3N = nitrate as nitrogen, PCE = Tetrachloroethene, SC = Specific Conductivity, TDS = total dissolved solids, U = uranium. Columns are ordered as the 1st, 2nd, and 3rd most frequently measured constituent.

PUBLIC DRAFT

1,2,3-Trichloropropane

From WY 2014 to WY 2023, a total of 15,940 water quality monitoring wells across the state were tested for 1,2,3-TCP. Of these,14,850 wells (93%) had concentrations at or below the MCL of 0.005 micrograms per liter, assigning them a low category, while 1,021 wells (6%) exceeded the MCL, assigning them a high category.

Water quality monitoring wells with high concentrations of 1,2,3-TCP were identified in all hydrologic regions. The highest percentage of high-category wells were in the Tulare Lake, San Joaquin River, and South Coast hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas. Figure 6-19 illustrates the statewide distribution of high, medium, and low concentration categories of 1,2,3-TCP. Table 6-14 presents the same data in a tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-19 Geographic Distribution of 1,2,3-TCP Concentrations Detected in Groundwater (Water Years 2014–2023)

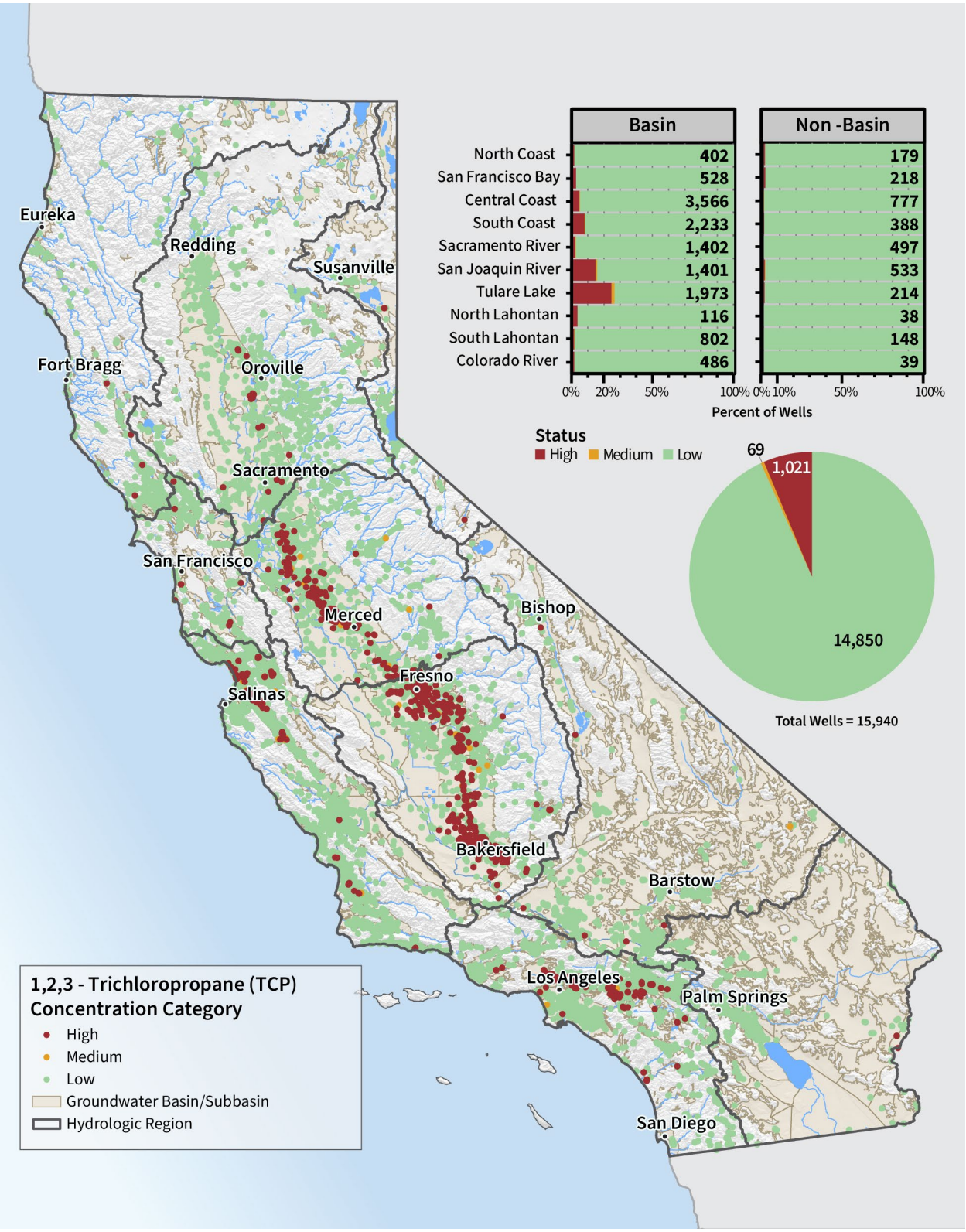


Table 6-14 Statistics of 1,2,3-TCP Concentrations in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	399	0	3	0.7
North Coast	Non-basin	178	0	1	0.6
San Francisco Bay	Basin	519	0	9	1.7
San Francisco Bay	Non-basin	216	0	2	0.9
Central Coast	Basin	3,411	15	140	3.9
Central Coast	Non-basin	776	1	0	0
South Coast	Basin	2,069	4	160	7.2
South Coast	Non-basin	387	0	1	0.3
Sacramento River	Basin	1,382	1	19	1.4
Sacramento River	Non-basin	497	0	0	0
San Joaquin River	Basin	1,192	12	197	14.1
San Joaquin River	Non-basin	528	2	3	0.6
Tulare Lake	Basin	1,468	32	473	24
Tulare Lake	Non-basin	213	0	1	0.5
North Lahontan	Basin	113	0	3	2.6
North Lahontan	Non-basin	38	0	0	0
South Lahontan	Basin	794	2	6	0.7
South Lahontan	Non-basin	148	0	0	0
Colorado River	Basin	483	0	3	0.6
Colorado River	Non-basin	39	0	0	0
Statewide Total	-	**14,850**	**69**	**1,021**	**6.4**

Table 6-14 Notes: 1,2,3-TPC = 1,2,3-Trichloropropane. Maximum contaminant level (MCL) = 0.005 micrograms per liter. Low is less than half the MCL. Medium is between half the MCL and the MCL. High is more than the MCL.

PUBLIC DRAFT

Nitrate as Nitrogen

From WY 2014 to WY 2023, a total of 29,120 water quality monitoring wells across the state were tested for nitrate as nitrogen. Of these, 19,772 wells (68%) had concentrations at or below the MCL of 10 milligrams per liter, assigning them to a category of Low, while 4,610 wells (16%) exceeded the MCL, assigning them to a category of High.

Water quality monitoring wells with high concentrations of nitrate as nitrogen were identified in all hydrologic regions. The highest percentage of high-category wells were in the Central Coast, Tulare Lake, and South Coast hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas, except for in the Colorado River Hydrologic Region. Figure 6-20 illustrates the statewide distribution of high, medium, and low concentration categories of nitrate as nitrogen. Table 6-15 presents the same data in tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-20 Geographic Distribution of Nitrate as Nitrogen Concentrations Detected in Groundwater (Water Years 2014-2023)

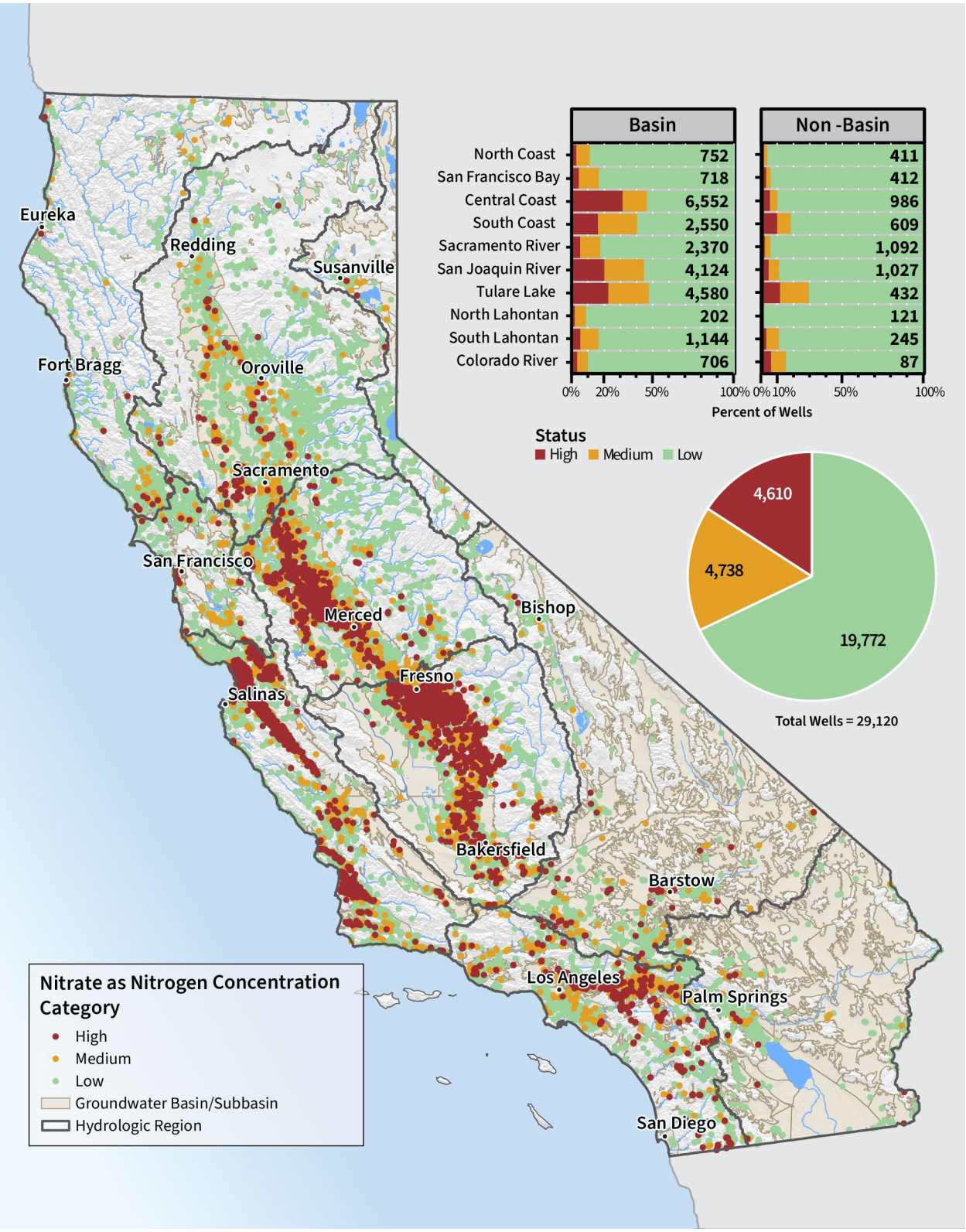


Table 6-15 Statistics of Nitrate as Nitrogen Concentrations (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	675	61	16	2.1
North Coast	Non-basin	402	8	1	0.2
San Francisco Bay	Basin	604	88	26	3.6
San Francisco Bay	Non-basin	395	11	6	1.5
Central Coast	Basin	3,553	986	2,013	30.7
Central Coast	Non-basin	904	44	38	3.9
South Coast	Basin	1,539	617	394	15.5
South Coast	Non-basin	507	51	51	8.4
Sacramento River	Basin	1,970	297	103	4.3
Sacramento River	Non-basin	1,048	36	8	0.7
San Joaquin River	Basin	2,306	1,023	795	19.3
San Joaquin River	Non-basin	928	68	31	3
Tulare Lake	Basin	2,421	1,155	1,004	21.9
Tulare Lake	Non-basin	310	78	44	10.2
North Lahontan	Basin	186	14	2	1
North Lahontan	Non-basin	121	0	0	0
South Lahontan	Basin	964	128	52	4.5
South Lahontan	Non-basin	222	19	4	1.6
Colorado River	Basin	642	46	18	2.5
Colorado River	Non-basin	75	8	4	4.6
Statewide	-	19,772	4,738	4,610	15.8

Table 6-15 Notes: Maximum contaminant level (MCL) = 10 milligrams per liter. Low is less than half the MCL. Medium is between half the MCL and the MCL. High is more than the MCL.

PUBLIC DRAFT

Arsenic

From WY 2014 to WY 2023, a total of 15,283 water quality monitoring wells across the state were tested for arsenic. Of these, 11,963 wells (78%) had concentrations at or below the MCL of 10 micrograms per liter, assigning them a low category, while 1,683 wells (11%) exceeded the MCL, assigning them a high category.

Water quality monitoring wells with high concentrations of arsenic were identified in all hydrologic regions. The highest percentage of high-category monitoring wells were in the South Lahontan, North Lahontan, and San Joaquin River hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas, except for in the Central Coast, South Coast, San Joaquin River, and Tulare Lake hydrologic regions. Figure 6-21 illustrates the statewide distribution of high, medium, and low concentration categories of arsenic. Table 6-16 presents the same data in tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-21 Geographic Distribution of Arsenic Concentrations Detected in Groundwater (Water Years 2014-2023)

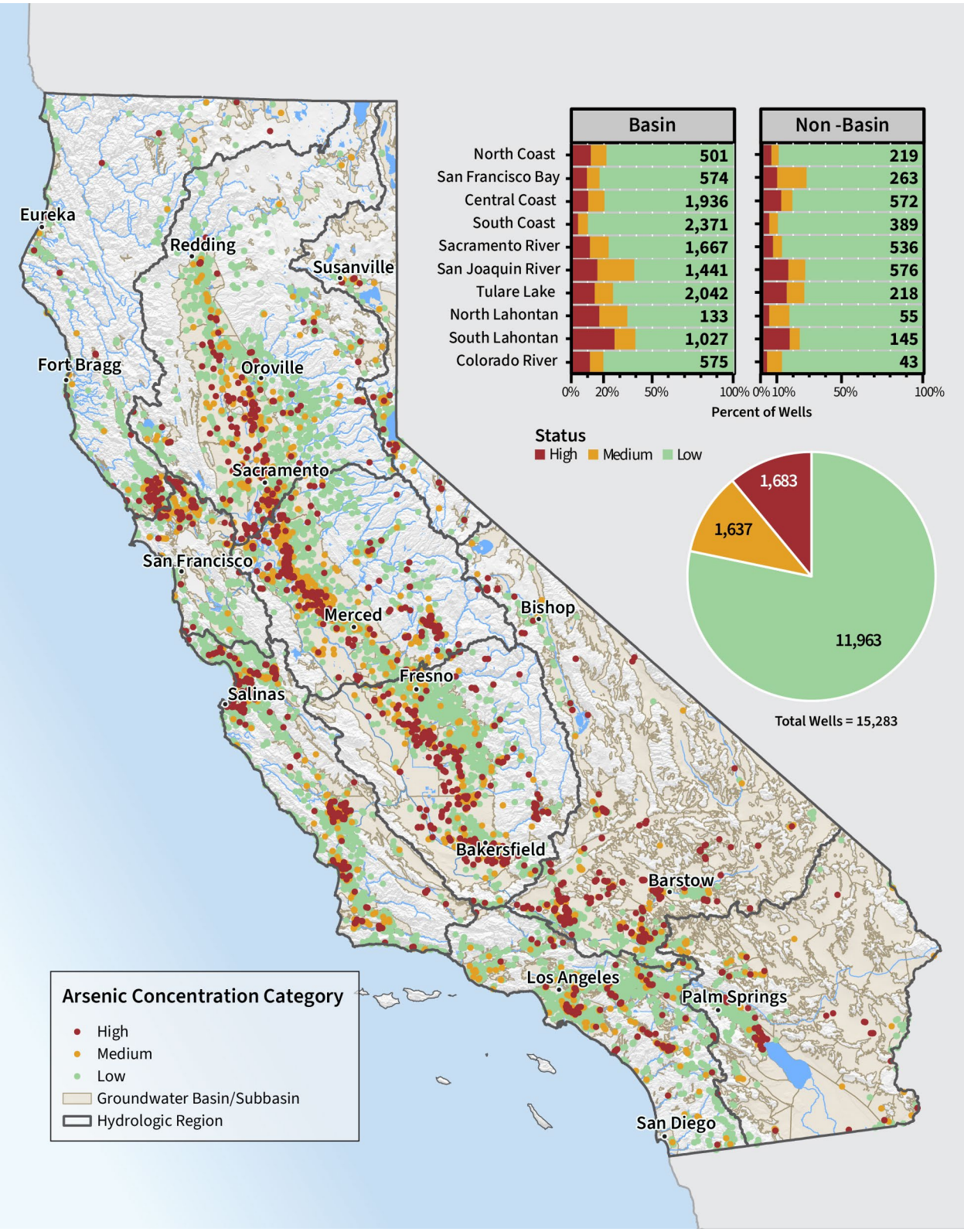


Table 6-16 Statistics of Arsenic Concentrations in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	397	48	56	11.2
North Coast	Non-basin	198	10	11	5
San Francisco Bay	Basin	479	45	50	8.7
San Francisco Bay	Non-basin	192	48	23	8.7
Central Coast	Basin	1,557	197	182	9.4
Central Coast	Non-basin	468	40	64	11.2
South Coast	Basin	2,153	139	79	3.3
South Coast	Non-basin	354	21	14	3.6
Sacramento River	Basin	1,299	192	176	10.6
Sacramento River	Non-basin	474	30	32	6
San Joaquin River	Basin	891	329	221	15.3
San Joaquin River	Non-basin	425	60	91	15.8
Tulare Lake	Basin	1,533	233	276	13.5
Tulare Lake	Non-basin	162	24	32	14.7
North Lahontan	Basin	88	23	22	16.5
North Lahontan	Non-basin	46	7	2	3.6
South Lahontan	Basin	630	131	266	25.9
South Lahontan	Non-basin	112	9	24	16.6
Colorado River	Basin	467	47	61	10.6
Colorado River	Non-basin	38	4	1	2.3
Statewide	-	11,963	1,637	1,683	11

Table 6-16 Notes: Maximum contaminant level (MCL) = 10 micrograms per liter. Low is less than half the MCL. Medium is between half the MCL and the MCL. High is more than the MCL.

PUBLIC DRAFT

Uranium

From WY 2014 to WY 2023, a total of 7,819 water quality monitoring wells across the state were tested for uranium. Of these, 6,740 wells (86%) had concentrations at or below the MCL of 20 picocuries per liter of air, assigning them a low category, while 487 wells (6 percent) exceeded the MCL, assigning them a high category.

Water quality monitoring wells with high concentrations of uranium were identified in all hydrologic regions except the North Coast and San Francisco Bay. The highest percentage of high-category wells were in the North Lahontan, San Joaquin River, and South Lahontan hydrologic regions. Non-basin areas had higher percentages of high-category wells than basin areas except for in the North Lahontan Hydrologic Region. The percentage of high-category wells was particularly high in the South Lahontan Hydrologic Region. Figure 6-22 illustrates the statewide distribution of high, medium, and low concentration categories of uranium. Table 6-17 presents the same data in tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-22 Geographic Distribution of Uranium Concentrations Detected in Groundwater (Water Years 2014-2023)

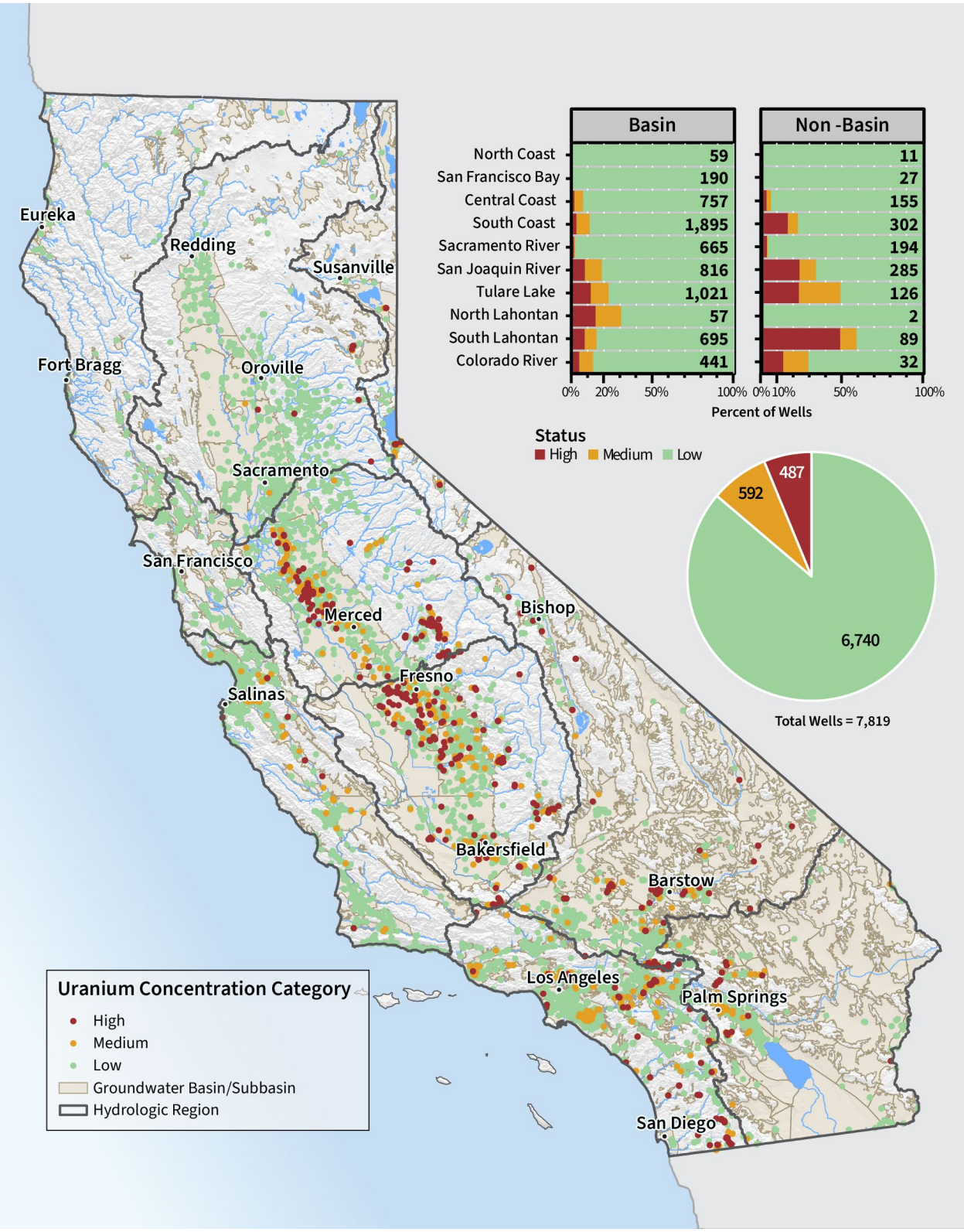


Table 6-17 Statistics of Uranium Concentrations in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	59	0	0	0
North Coast	Non-basin	11	0	0	0
San Francisco Bay	Basin	190	0	0	0
San Francisco Bay	Non-basin	27	0	0	0
Central Coast	Basin	710	41	6	0.8
Central Coast	Non-basin	148	4	3	1.9
South Coast	Basin	1,703	155	37	2
South Coast	Non-basin	237	19	46	15.2
Sacramento River	Basin	658	3	4	0.6
Sacramento River	Non-basin	189	1	4	2.1
San Joaquin River	Basin	672	83	61	7.5
San Joaquin River	Non-basin	191	30	64	22.5
Tulare Lake	Basin	797	113	111	10.9
Tulare Lake	Non-basin	65	33	28	22.2
North Lahontan	Basin	40	9	8	14
North Lahontan	Non-basin	2	0	0	0
South Lahontan	Basin	595	49	51	7.3
South Lahontan	Non-basin	37	9	43	48.3
Colorado River	Basin	386	38	17	3.9
Colorado River	Non-basin	23	5	4	12.5
Statewide	-	6,740	592	487	6.2

Table 6-17 Notes: Maximum contaminant level (MCL) = 20 picocuries per liter of air. Low is less than half the MCL. Medium is between half the MCL and the MCL. High is more than the MCL.

PUBLIC DRAFT

Hexavalent Chromium

From WY 2014 to WY 2013, a total of 13,051 water quality monitoring wells across the state were tested for Cr6. Of these, 11,015 wells (84%) had concentrations at or below the MCL of 10 micrograms per liter, assigning them a low category, while 801 wells (6 percent) exceeded the MCL, assigning them a high category.

Water quality monitoring wells with high concentrations of Cr6 were identified in all hydrologic regions. The highest percentage of high-category wells were in the Colorado River, Sacramento River, and South Lahontan hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas. Figure 6-23 illustrates the statewide distribution of high, medium, and low concentration categories of Cr6. Table 6-18 presents the same data in a tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-23 Geographic Distribution of Hexavalent Chromium Concentrations Detected in Groundwater (Water Years 2014–2023)

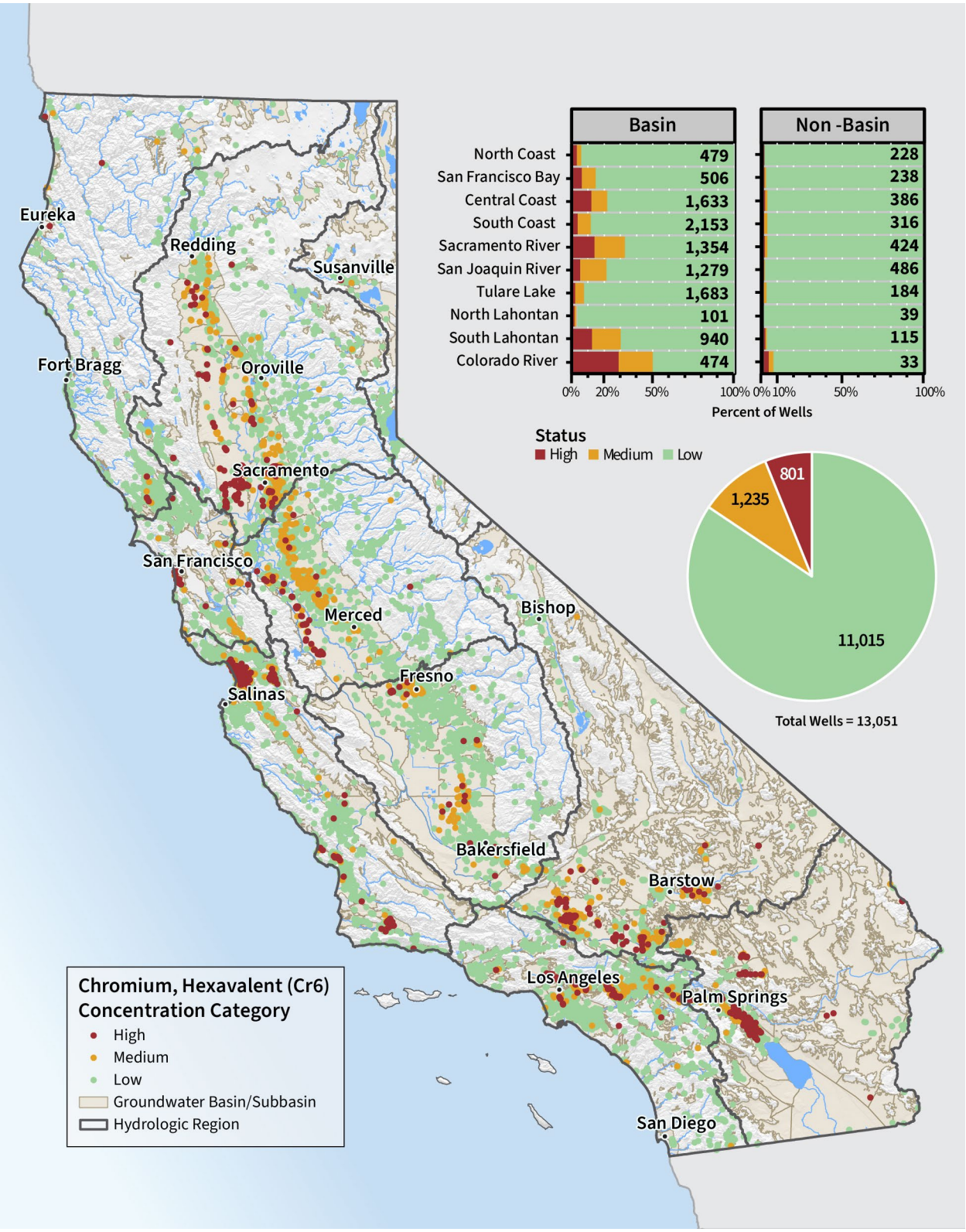


Table 6-18 Statistics of Hexavalent Chromium Detected in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	455	13	11	2.3
North Coast	Non-basin	227	0	1	0.4
San Francisco Bay	Basin	435	43	28	5.5
San Francisco Bay	Non-basin	235	2	1	0.4
Central Coast	Basin	1,288	159	186	11.4
Central Coast	Non-basin	378	5	3	0.8
South Coast	Basin	1,919	174	60	2.8
South Coast	Non-basin	309	6	1	0.3
Sacramento River	Basin	920	253	181	13.4
Sacramento River	Non-basin	415	7	2	0.5
San Joaquin River	Basin	1,015	207	57	4.5
San Joaquin River	Non-basin	483	2	1	0.2
Tulare Lake	Basin	1,570	92	21	1.2
Tulare Lake	Non-basin	181	3	0	0
North Lahontan	Basin	99	1	1	1
North Lahontan	Non-basin	39	0	0	0
South Lahontan	Basin	663	166	111	11.8
South Lahontan	Non-basin	113	1	1	0.9
Colorado River	Basin	240	100	134	28.3
Colorado River	Non-basin	31	1	1	3
Statewide	-	11,015	1,235	801	6.1

Table 6-18 Notes: Maximum contaminant level (MCL) = 10 micrograms per liter. Low is less than half the MCL. Medium is between half the MCL and the MCL. High is more than the MCL.

PUBLIC DRAFT

Total Dissolved Solids

From WY 2014 to WY 2023, a total of 22,369 water quality monitoring wells across the state were tested for TDS. Of these, 12,897 wells (58%) had concentrations at or below the SMCL of 1,000 milligrams per liter, assigning them a low category, while 3,041 wells (14%) exceeded the SMCL, assigning them a high category. This SMCL is the upper limit for California.

Water quality monitoring wells with high concentrations of TDS were identified in all hydrologic regions. The highest percentage of high-category wells were in the Central Coast, South Coast, and Colorado River hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas. Figure 6-24 illustrates the statewide distribution of high, medium, and low concentration categories of TDS. Table 6-19 presents the same data in a tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-24 Geographic Distribution of Total Dissolved Solids Concentrations Detected in Groundwater (Water Years 2014–2023)

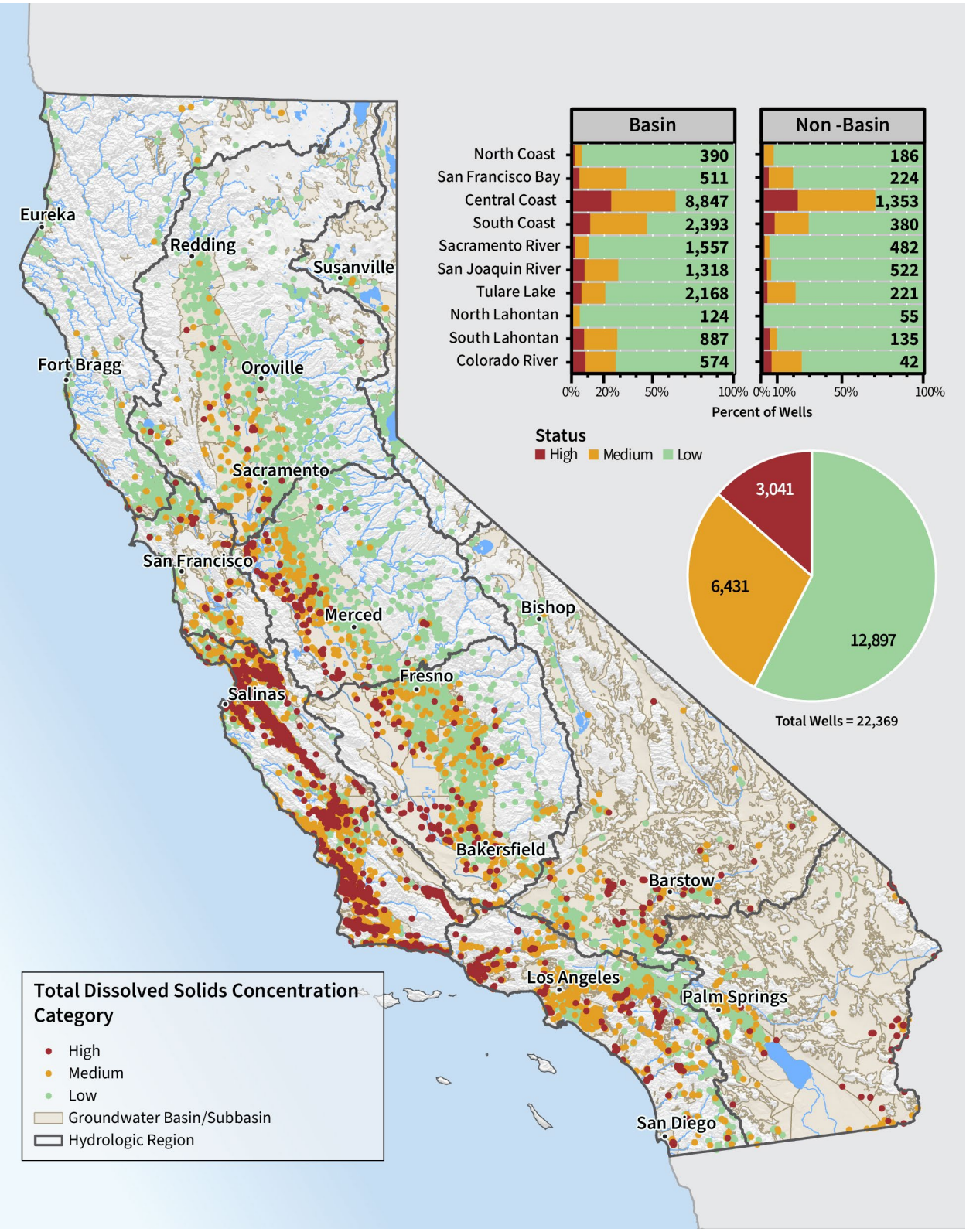


Table 6-19 Statistics of Total Dissolved Solids in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	369	17	4	1
North Coast	Non-basin	175	11	0	0
San Francisco Bay	Basin	342	149	20	3.9
San Francisco Bay	Non-basin	183	34	7	3.1
Central Coast	Basin	3,220	3,540	2,087	23.6
Central Coast	Non-basin	405	660	288	21.3
South Coast	Basin	1,300	838	255	10.7
South Coast	Non-basin	273	81	26	6.8
Sacramento River	Basin	1,406	131	20	1.3
Sacramento River	Non-basin	465	15	2	0.4
San Joaquin River	Basin	950	275	93	7.1
San Joaquin River	Non-basin	498	14	10	1.9
Tulare Lake	Basin	1,736	320	112	5.2
Tulare Lake	Non-basin	177	39	5	2.3
North Lahontan	Basin	119	5	0	0
North Lahontan	Non-basin	55	0	0	0
South Lahontan	Basin	645	181	61	6.9
South Lahontan	Non-basin	124	6	5	3.7
Colorado River	Basin	423	107	44	7.7
Colorado River	Non-basin	32	8	2	4.8
Statewide	-	12,897	6,431	3,041	13.6

Table 6-19 Notes: Secondary maximum contaminant level (SMCL) = 1,000 milligrams per liter. Low is less than half the SMCL. Medium is between half the SMCL and the SMCL. High is more than the SMCL.

PUBLIC DRAFT

Perfluorooctanoic Acid (PFOA)

From WY 2014 to WY 2023, a total of 3,602 water quality monitoring wells across the state were tested for PFOA. Of these, 2,780 wells (77%) had concentrations at or below the NL of 5.1 nanograms per liter, assigning them a low category, while 605 wells (17%) exceeded the NL, assigning them a high category.

Water quality monitoring wells with high concentrations of PFOA were identified in all hydrologic regions except the Colorado River Hydrologic Region. The highest percentage of high-category wells were in the South Coast, Sacramento River, and Central Coast hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas except for the San Joaquin River and South Lahontan hydrologic regions, and no data was available for the non-basin areas of the Colorado River Hydrologic Region. Figure 6-25 illustrates the statewide distribution of high, medium, and low concentration categories of PFOA. Table 6-20 presents the same data in a tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-25 Geographic Distribution of Perfluorooctanoic Acid (PFOA) Concentrations Detected in Groundwater (Water Years 2014-2023)

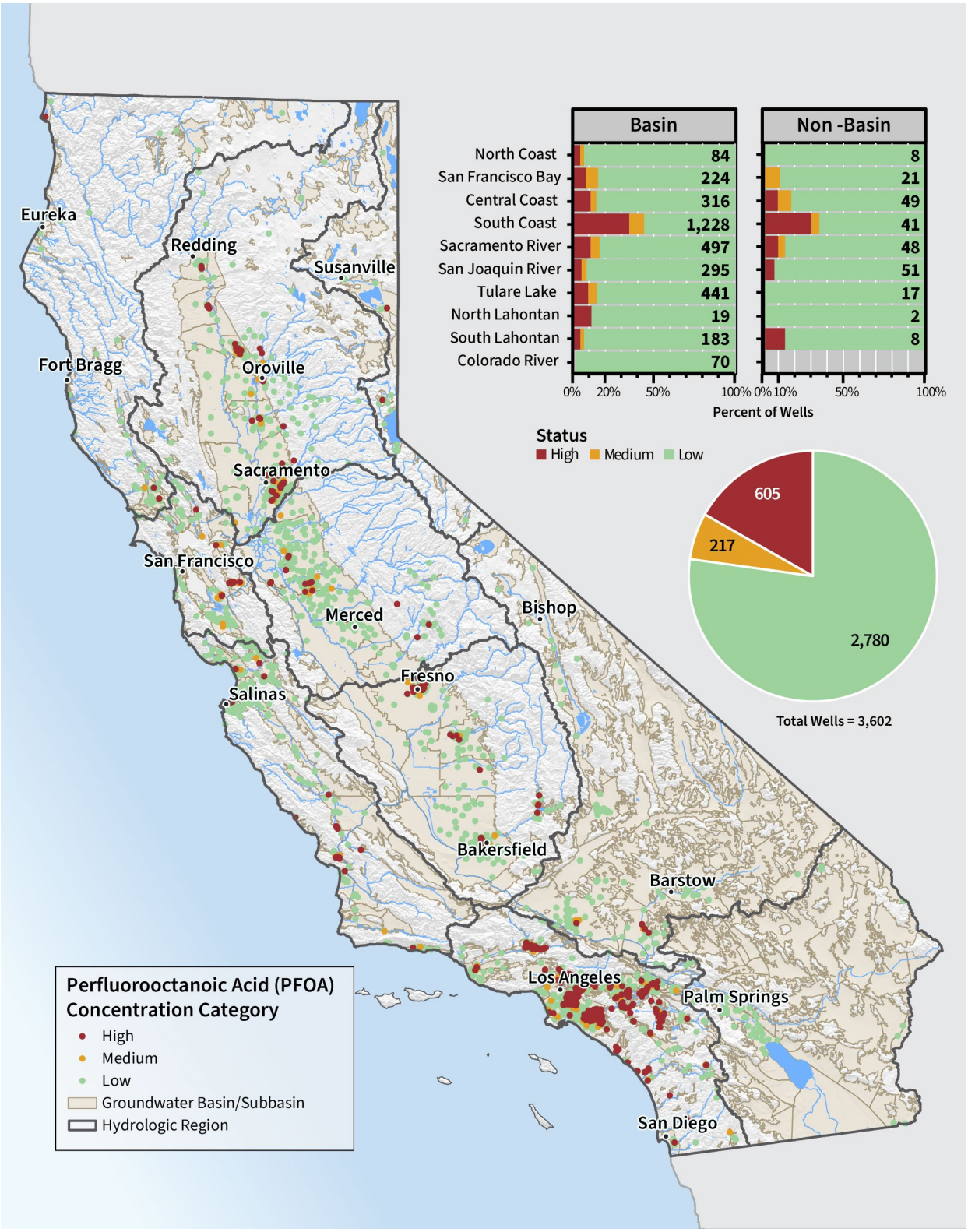


Table 6-20 Statistics of Perfluorooctanoic Acid in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	79	2	3	3.6
North Coast	Non-basin	8	0	0	0
San Francisco Bay	Basin	191	17	16	7.1
San Francisco Bay	Non-basin	19	2	0	0
Central Coast	Basin	273	11	32	10.1
Central Coast	Non-basin	41	4	4	8.2
South Coast	Basin	696	112	420	34.2
South Coast	Non-basin	27	2	12	29.3
Sacramento River	Basin	419	28	50	10.1
Sacramento River	Non-basin	42	2	4	8.3
San Joaquin River	Basin	273	9	13	4.4
San Joaquin River	Non-basin	48	0	3	5.9
Tulare Lake	Basin	379	24	38	8.6
Tulare Lake	Non-basin	17	0	0	0
North Lahontan	Basin	17	0	2	10.5
North Lahontan	Non-basin	2	0	0	0
South Lahontan	Basin	172	4	7	3.8
South Lahontan	Non-basin	7	0	1	12.5
Colorado River	Basin	70	0	0	0
Colorado River	Non-basin	NA	NA	NA	NA
Statewide	-	2,780	217	605	16.8

Table 6-20 Notes: Notification level (NL) = 5.1 nanograms per liter. Low is less than half the NL. Medium is between half the NL and the NL. High is more than the NL.

PUBLIC DRAFT

Perfluorooctane Sulfonate (PFOS)

From WY 2014 to WY 2023, a total of 3,602 water quality monitoring wells statewide were tested for PFOS. Of these, 2,706 wells (75%) had concentrations at or below the NL of 6.5 nanograms per liter, assigning them a low category, while 683 wells (19%) exceeded the NL, assigning them a high category.

Water quality monitoring wells with high concentrations of PFOS were identified in all hydrologic regions except the Colorado River. The highest percentage of high-category monitoring wells are in the South Coast, San Francisco Bay, and Central Coast hydrologic regions. Basin areas had higher percentages of high-category wells than non-basin areas except for the South Lahontan Hydrologic Region, and no data was available for the non-basin areas of the Colorado River Hydrologic Region. Figure 6-26 illustrates the statewide distribution of high, medium, and low concentration categories of PFOS. Table 6-21 presents the same data in a tabular format by hydrologic region.

PUBLIC DRAFT

Figure 6-26 Geographic Distribution of Perfluorooctane Sulfonate Concentrations Detected in Groundwater (Water Years 2014–2023)

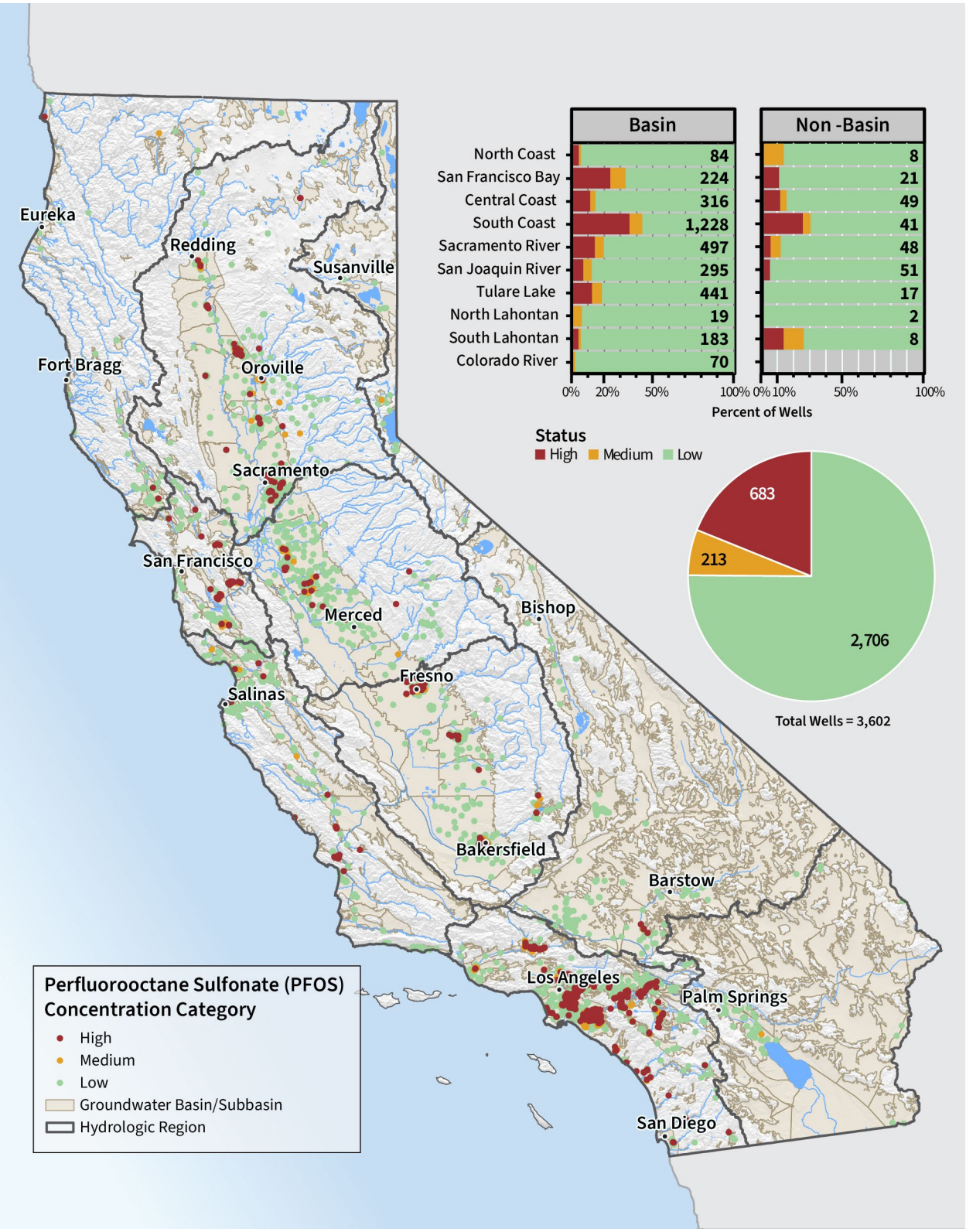


Table 6-21 Statistics of Perfluorooctane Sulfonate in Groundwater (Water Years 2014–2023)

Hydrologic Region	Region Area	Low Concentration Category (Number of Wells)	Medium Concentration Category (Number of Wells)	High Concentration Category (Number of Wells)	Percent High of Total Wells
North Coast	Basin	80	1	3	3.6
North Coast	Non-basin	7	1	0	0
San Francisco Bay	Basin	151	21	52	23.2
San Francisco Bay	Non-basin	19	0	2	9.5
Central Coast	Basin	273	9	34	10.8
Central Coast	Non-basin	42	2	5	10.2
South Coast	Basin	702	97	429	34.9
South Coast	Non-basin	29	2	10	24.4
Sacramento River	Basin	402	28	67	13.5
Sacramento River	Non-basin	43	3	2	4.2
San Joaquin River	Basin	261	15	19	6.4
San Joaquin River	Non-basin	49	0	2	3.9
Tulare Lake	Basin	362	28	51	11.6
Tulare Lake	Non-basin	17	0	0	0
North Lahontan	Basin	18	1	0	0
North Lahontan	Non-basin	2	0	0	0
South Lahontan	Basin	174	3	6	3.3
South Lahontan	Non-basin	6	1	1	12.5
Colorado River	Basin	69	1	0	0
Colorado River	Non-basin	NA	NA	NA	NA
Statewide	-	2,706	213	683	19

Table 6-21 Notes: Notification level (NL) = 6.5 nanograms per liter. Low is less than half the NL. Medium is between half the NL and the NL. High is more than the NL.

PUBLIC DRAFT

6.4.3 Groundwater Quality Reported Under SGMA

Three constituents commonly measured by GSPs and Alternatives (see Table 5-6) are nitrate (Figure 6-20), arsenic (Figure 6-21), and total dissolved solids (Figure 6-24). Statewide, nitrate had the greatest percentage of wells (15.8) that exceeded the MCL, followed by TDS (13.6%) and arsenic (11%). The fraction of wells exceeding MCLs for these constituents was typically higher in the basin areas (subject to SGMA) compared to the non-basin areas, as shown by the bar charts in Figures 6-20, 6-21, and 6-24. Chlorine was commonly measured in the Central Coast and South Coast hydrologic regions, which may be used to monitor undesirable results from seawater intrusion (see the Seawater Intrusion Section in this chapter). GSPs in the Tulare Lake Hydrologic Region commonly measured 1,2,3-TCP, and the Tulare Lake Hydrologic Region had the greatest percentage of exceedances (24.5 %) of any hydrologic region (Figure 6-19).

More than 45 different constituents were reported in GSPs and Alternative Plans. Additional information, including a list of the reported constituents, is provided in Appendix C, "Methods and Assumptions." These constituents reflect local conditions within an individual basin and may not represent typical conditions over a given hydrologic region. The results of constituents reported by GSAs and Alternatives can be found in the Annual Reports of the respective groundwater basins on the SGMA Portal.

6.5 Land Subsidence

Subsidence in many parts of California has been documented throughout the last century. In the Central Valley, subsidence of more than 28 feet was documented southwest of Mendota over a fifty-year period (Poland et al. 1975). During drought periods occurring between 2000 and 2022, increased groundwater extraction again resulted in accelerated subsidence rates of more than 1.0 foot per year in parts of the San Joaquin Valley (and more than 0.5 foot per year in select parts of the Sacramento Valley) (California Department of Water Resources 2021; California Department of Water Resources 2022). Subsidence in California has caused billions of dollars of impacts on water conveyance, flood control, transportation infrastructure, and groundwater wells (Borchers and Carpenter 2014). Irreversible compaction of aquifer systems (inelastic subsidence) has led to permanent loss of groundwater storage in certain areas (Ireland et al. 1984; Poland and Ireland 1988; Galloway and Burbey 2011; Faunt et al. 2024).

PUBLIC DRAFT

Decades of groundwater extraction have caused widespread groundwater level declines, resulting in a decrease in aquifer-system thickness (compaction) in many areas with compressible sediments.

While the dominant mechanism resulting in land subsidence is due to compaction processes related to groundwater withdrawals, subsidence can also result from oil and gas operations, tectonic and volcanic activity, hydrocompaction of historically dry sediment that becomes saturated, the elastic loading of the Earth's crust due to mass changes, and compaction of organic matter such as peat soil (Borchers and Carpenter 2014; Galloway et al. 1999). The details of mechanics of land subsidence are provided in Chapter 3, "California's Natural and Built Groundwater Infrastructure."

6.5.1 Recent Subsidence Conditions

Since the early 2000s, there have been significant improvements to the State's subsidence monitoring network. This includes the installation of continuous Global Positioning System (CGPS) stations, the installation and refurbishment of extensometers, and, most notably, the State-supported processing and reporting of satellite-based Interferometric Synthetic Aperture Radar (InSAR) data across groundwater basins, with statewide coverage data beginning in June of 2015.

Figure 6-27 shows U.S. Drought Monitor data for California. The U.S Drought Monitor provides maps and tables of areas by drought category over time. Figure 6-28 shows InSAR data of annual subsidence rates for WY 2016 through WY 2023. This time span represents a period of five below-average (dry/drought) years and three above-average (wet) years. WY 2016 was the last year of the 2012–2016 drought, a period of time in which roughly 90 percent of California experienced severe drought conditions. Exceptional drought in the San Joaquin Valley during that period led to increased pumping of groundwater resulting in large areas subsiding at rates exceeding one foot per year (ft/yr) (dark red in Figure 6-28).

While subsidence persisted in the San Joaquin Valley, the regions with historically high subsidence rates fell from more than 1.0 ft/yr to 0.4–0.6 ft/yr; (yellow in Figure 6-28) in WY 2017. Some areas, such as the Westside Subbasin, even experienced uplift (blue in Figure 6-28). The following year (WY 2018) was an abnormally dry year for about 85 percent of California, with about 20 percent of the state experiencing severe drought conditions. During this year, subsidence rates exceeded 0.8 ft/yr in the San Joaquin Valley (red in Figure 6-28). Though not as intense in subsidence magnitude and extent, WY 2018 exhibits similar

PUBLIC DRAFT

subsidence signals of WY 2016. There was a return to wetter conditions in WY 2019, again resulting in diminished subsidence rates and even uplift. While the extent of uplift was not as great as that in WY 2017, the magnitude of land subsidence and extent of subsiding regions were generally lower (falling from 0.4–0.6 ft/yr to 0.2–0.4 ft/yr; green in Figure 6-28).

WY 2020 to WY 2022 represents the most recent drought, which, similar to the 2012–2016 drought, led to increased groundwater extraction. During this period, up to about 95% of California experienced severe drought conditions, and the subsidence patterns were similar to those observed in WY 2016 and WY 2018. Unlike the previous dry/drought years, more prominent subsidence features were observed in Sacramento Valley. During the WY 2020 to WY 2022 drought, the magnitude and extent of subsidence rates increased in each year. WY 2022 saw the return of greater than 1.0 ft/yr subsidence in the San Joaquin Valley. During the wet WY 2023, subsidence rates slowed and displayed similar patterns as previous wet years. Statewide, about 800 square miles of area experienced uplift greater than 0.1 feet, while about 2,400 square miles of area still experienced subsidence of greater than 0.1 feet during WY 2023.

Annualized rate maps of surface displacement can provide insights into the aquifer system response under different hydrological conditions. In years when surface water availability is low, subsidence is greater in magnitude and more widespread primarily due to an increase in groundwater pumping. In wet years, groundwater levels can recover in response to increased recharge and decreased pumping, as seen in Figure 6-6, and subsidence can be reduced or even partly reversed. However, despite the recent increases in groundwater levels, 50% of wells in the San Joaquin River and Tulare Lake hydrologic regions are below normal in Spring 2024 when compared to their historical data based on groundwater level percentiles (Figures 6-4 and 6-5). A comparison of groundwater levels between Spring 2019 and Spring 2024 (Figure 6-7) shows that over 50% of the wells have groundwater level decreases greater than 5.0 feet in the Tulare Lake Hydrologic Region. The subsidence, while diminished recently, reflects that groundwater levels have not recovered enough and are still below critical head values in those regions.

Figure 6-29 shows InSAR data of cumulative subsidence over five years from WYs 2019–2023. Table 6-22 summarizes the InSAR data for the same five-year period. Over that period, statewide data show an area of approximately 4,000 square miles with recorded subsidence greater than 0.5 feet and about 110 square miles with subsidence greater than three feet. A majority of subsidence, particularly

PUBLIC DRAFT

subsidence greater than two feet, occurred in the Tulare Lake Hydrologic Region. This region also experienced the greatest proportion of wells with decreased groundwater levels between Spring 2019 and 2024 (Figure 6-7). The cumulative subsidence map reflects the overall pattern of subsidence observed in the dry/drought years.

Figure 6-27 U.S Drought Monitor Data for California (Percent Area in Drought Monitor Categories)

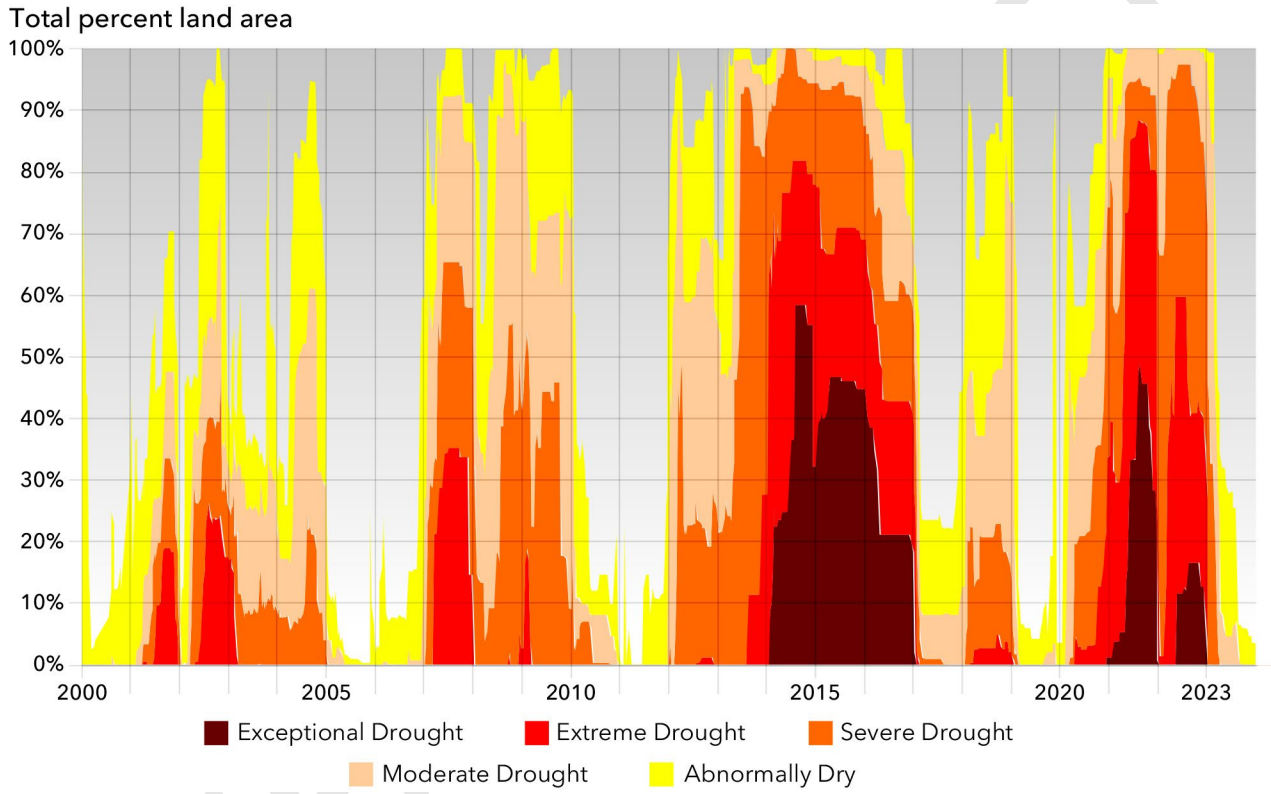


Figure 6-27 Note: Drought categories based on U.S. Drought Monitor classification.

PUBLIC DRAFT

Figure 6-28 Annual InSAR Land Subsidence Data (Water Years 2016-2023)

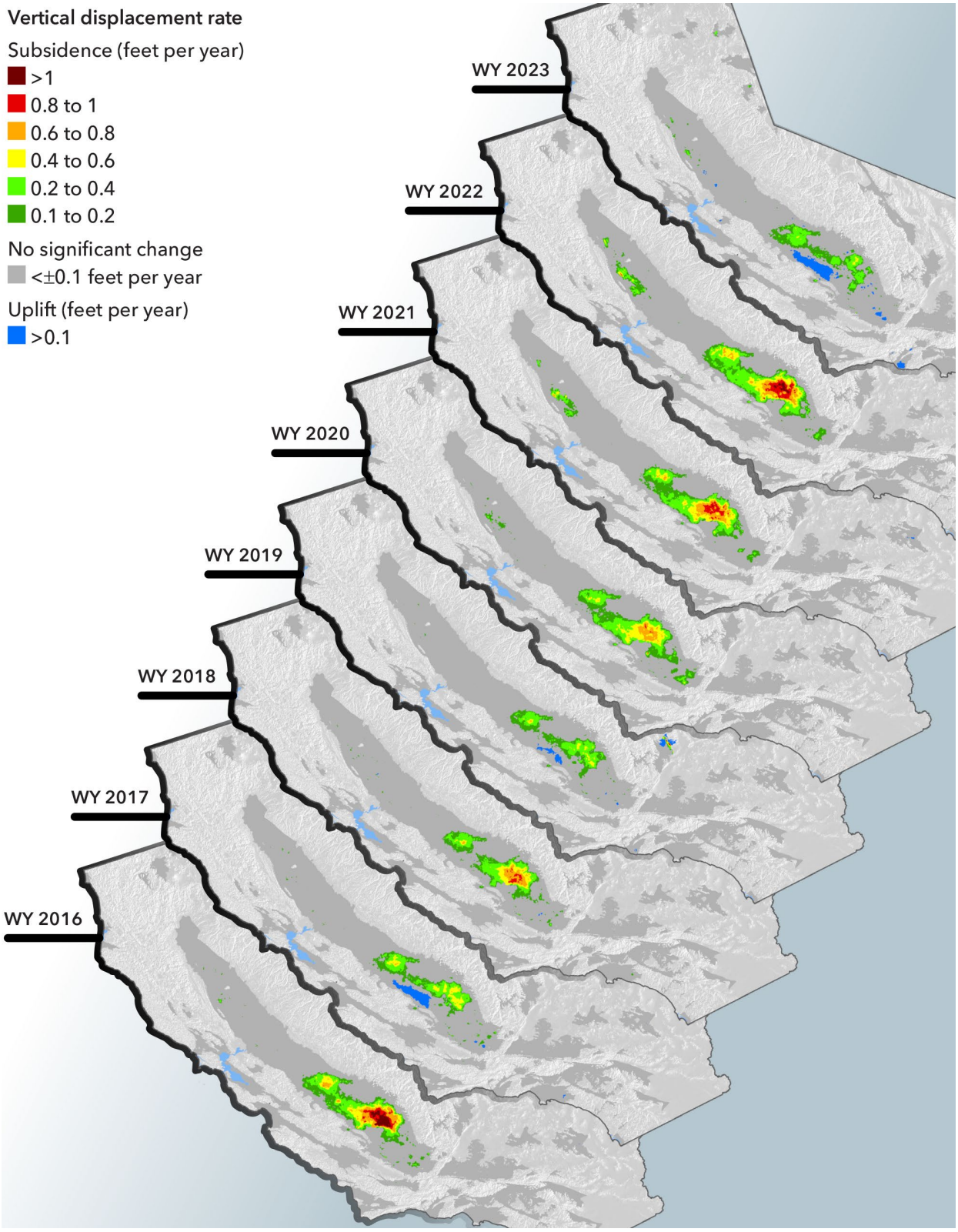


Figure 6-29 Cumulative Land Subsidence over 5 Years (Water Years 2019-2023)

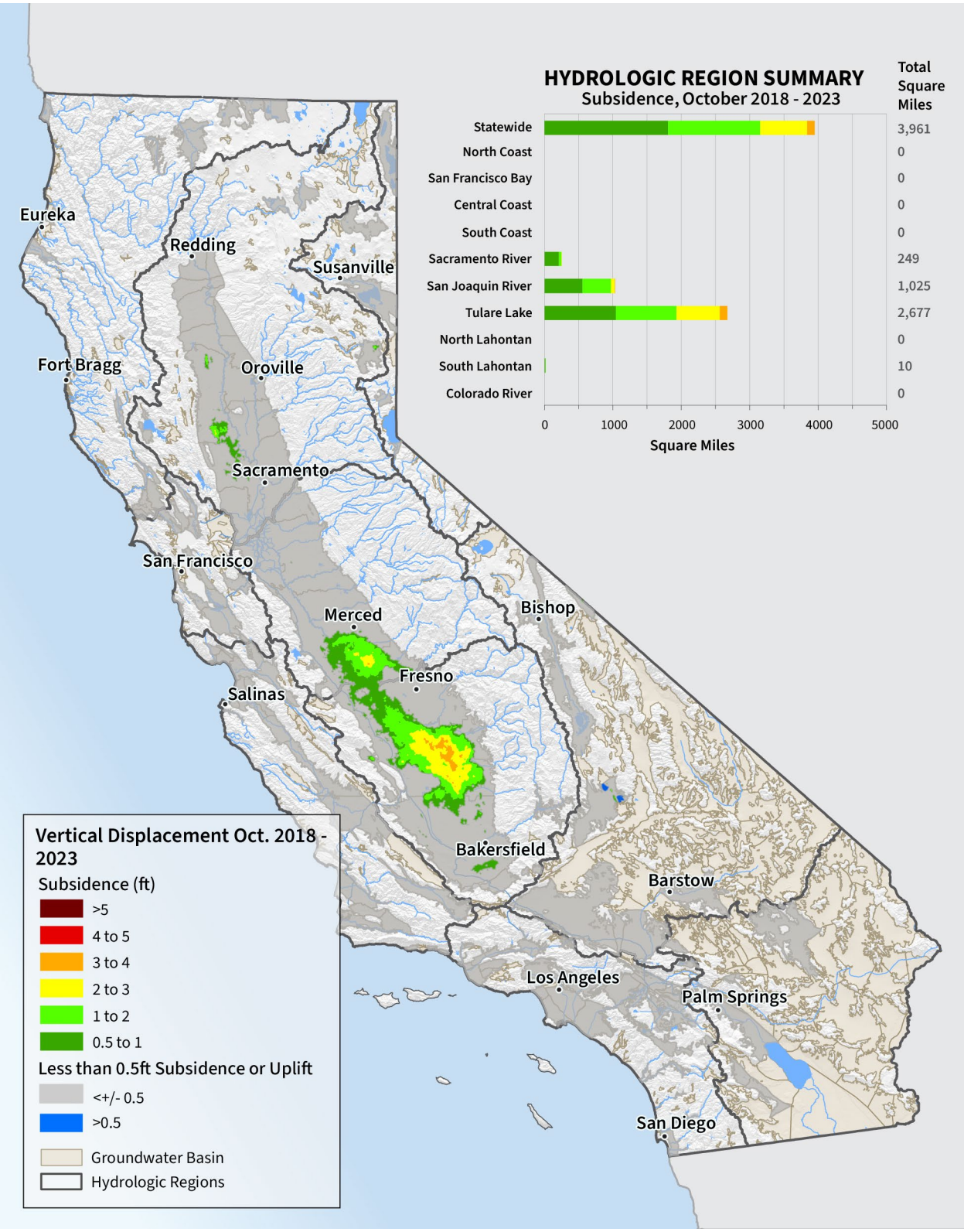


Table 6-22 Total Area (in square miles) of Cumulative Subsidence and Uplift over 5 Years (Water Years 2019–2023)

	Uplift >0.5 ft	Subs. >0.5 ft	Subs. >1 ft	Subs. >2 ft	Subs. >3 ft	Subs. >4 ft	Subs. >5 ft
Five Year Period October 2018–October 2023	29	3,961	2,149	800	113	0	0

6.5.2 Recent Subsidence Conditions and Long-Term Groundwater Level Trends

The groundwater level and subsidence history of an aquifer system determines both the potential for and rate of future subsidence, making them key factors for accurate subsidence forecasting (Galloway et al. 1999). Joint analyses of subsidence records with groundwater-level observations can be used to improve the understanding of the aquifer-system response to changing groundwater levels and to calculate aquifer-system storage properties. This information is beneficial to the calibration of groundwater models and to the establishment of groundwater level targets for preventing further subsidence. Below are examples of the long-term groundwater level and subsidence history summaries at select sites in California's Central Valley. These summaries combine available groundwater level data from monitoring wells with subsidence data from borehole extensometers, and subsidence data from leveling surveys, CGPS monitoring, and InSAR studies.

Figures 6-30 through 6-32 show long-term subsidence and groundwater levels across various aquifer-system intervals at three sites: two in the San Joaquin Valley (Sites A and B) and one in the Sacramento Valley (site C). At sites A (Tule Subbasin) and B (Westside Subbasin), the upper and lower aquifer designation denotes positions above and below the Corcoran Clay, respectively. Subsidence in the San Joaquin Valley was first observed in the 1930s and was attributed to the intensive agricultural development that heavily relied on groundwater for irrigation (Poland et al. 1975). Much of the southern San Joaquin Valley subsidence is linked to groundwater level declines in the lower aquifer system, confined by the Corcoran Clay, a laterally extensive layer of ancient lake deposits up to 160 feet thick (Galloway et al. 1999).

Site A – Tule Subbasin

Shown in Figure 6-30, some of the earliest recorded subsidence in the San Joaquin Valley attributed to chronic groundwater level declines can be observed in the Tule

PUBLIC DRAFT

Subbasin, a location conceptualized by a lower and upper aquifer system separated by the Corcoran Clay. At this site in the Tulare Lake Hydrologic Region, groundwater levels declined by more than 60 feet from 1931 to 1953, resulting in approximately 5.0 feet of subsidence. This site continued to subside through 1970 at rates of about a tenth of a foot per year. Despite groundwater levels being relatively stable during the 1970s, about 0.8 feet of (mostly) residual compaction occurred at the Tule site because of the delayed drainage of the lower (confined) aquifer beneath the Corcoran Clay. After subsidence monitoring was discontinued in this area in the early 1980s, the onset of a more than 40-year-long pattern of groundwater level declines began. These groundwater level declines resulted in an additional 3.0 feet of subsidence between 1970 and 2004 in this area. Beginning around 2004, the pattern of water-level declines accelerated to culminate in the greatest rate of decline since water levels have been recorded at this site. Consequently, the subsidence rate increased to more than 0.5 ft/yr between 2006 and 2020. While groundwater levels have generally rebounded from historical lows in 2020, subsidence rates since 2015 have remained at their greatest magnitudes on record.

Site B – Westside Subbasin

Similar to the Tule site, subsidence in the Westside Subbasin began in the 1930s, coinciding with substantial groundwater level declines. Shown in Figure 6-31, the rapid groundwater level declines in the lower aquifer system at this site resulted in corresponding large annual increases in effective stress from the late 1940s to the late 1960s. These water level declines resulted in a sustained subsidence rate of about a foot per year continuously between 1947 and 1968 for a total of 22 feet of subsidence, the greatest sustained subsidence rate in California to present day. This area remained the epicenter of subsidence in the San Joaquin Valley through the 1970s (Poland et al. 1975). However, by the mid-1970s, groundwater levels had risen, with increases beginning in the mid-1960s, above the critical head, largely halting subsidence in this area. Groundwater levels continued to rise through the late 1980s, then declined between 1989 and 1994 before rebounding and remaining relatively stable until 2005, when levels again began to decline. Declines in the groundwater levels reflect the role of increased groundwater pumping during times of reduced surface water availability (shaded red in Figure 6-31). Since 2005, groundwater levels have both rapidly fallen to near historic lows, likely reaching or declining to levels below the critical head, restarting inelastic subsidence, while also rebounding to levels near historic highs in wet years. In dry/drought years, the subsidence rate has been observed up to 0.4 feet per year while an adjacent wet year shows an uplift of about 0.1 feet per year.

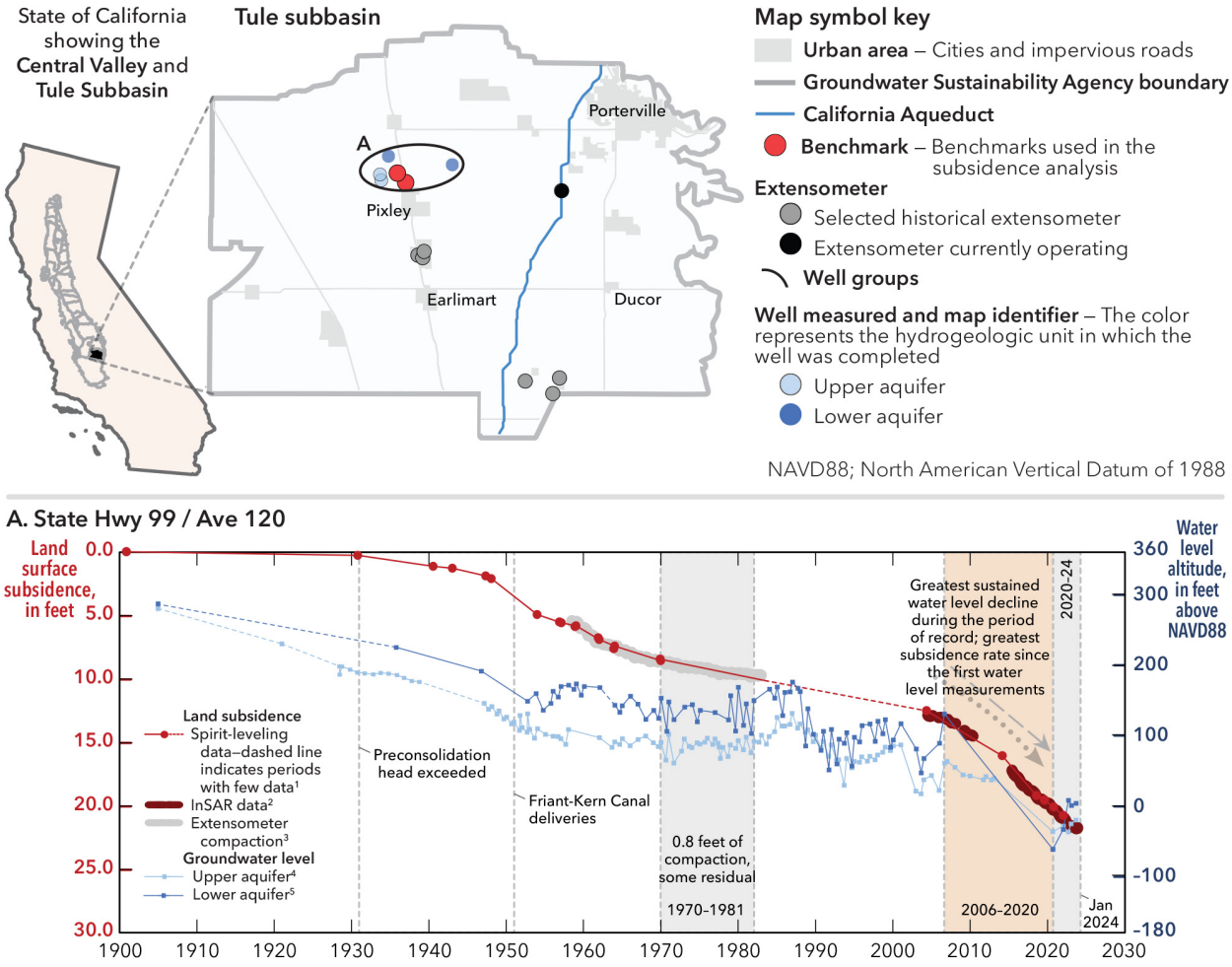
PUBLIC DRAFT

Site C – Yolo Subbasin

While subsidence has historically and recently been more extensive and severe in the Tulare Lake and San Joaquin River hydrologic regions, subsidence in the Sacramento River Hydrologic Region has also been recorded since the early to mid-1900s. Shown in Figure 6-32, a site in the Yolo Subbasin began to subside in the 1940s during a period of chronic groundwater level decline (1942–1959). Groundwater levels remained fairly stable after 1960 until rapid decline occurred again in the mid-1970s before rebounding between 1977 and 1983. Groundwater levels again declined between 1983 and 1991 before rebounding in the early 1990s and then stabilizing until the mid-2000s. This site persistently subsided throughout this time despite rebounds in groundwater levels. Groundwater pumping in the lower aquifer resulted in large seasonal declines in groundwater levels of as much as 80 feet, accelerating the rate of subsidence to 0.22 feet per year from 2008–2024, with a total of about 1.4 feet of subsidence during this period. This time period has the highest historical rate of subsidence. Subsidence at this site may continue, as groundwater levels in the lower aquifer have not recovered and continue to see large seasonal drawdowns.

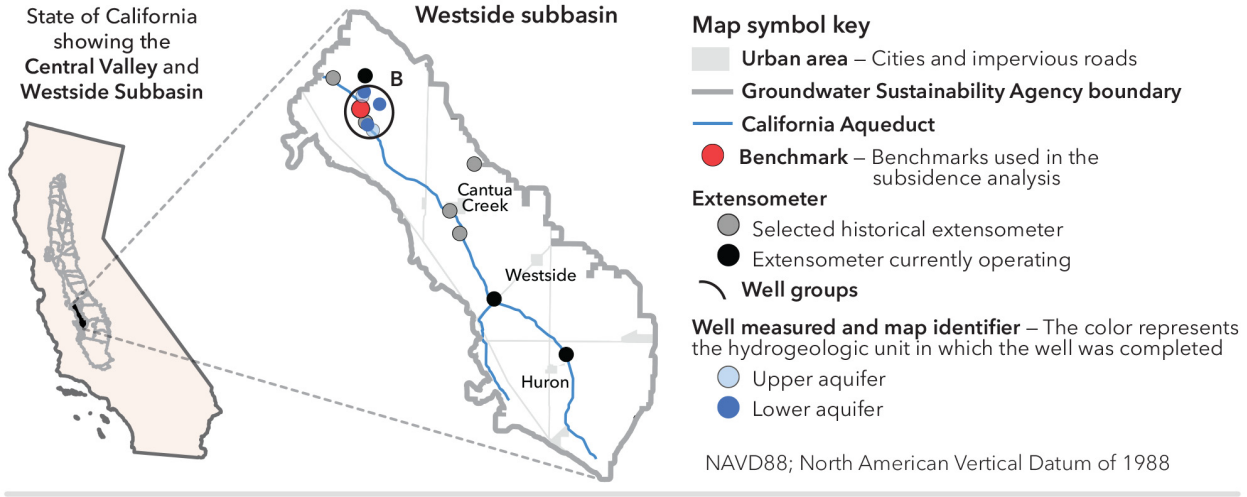
PUBLIC DRAFT

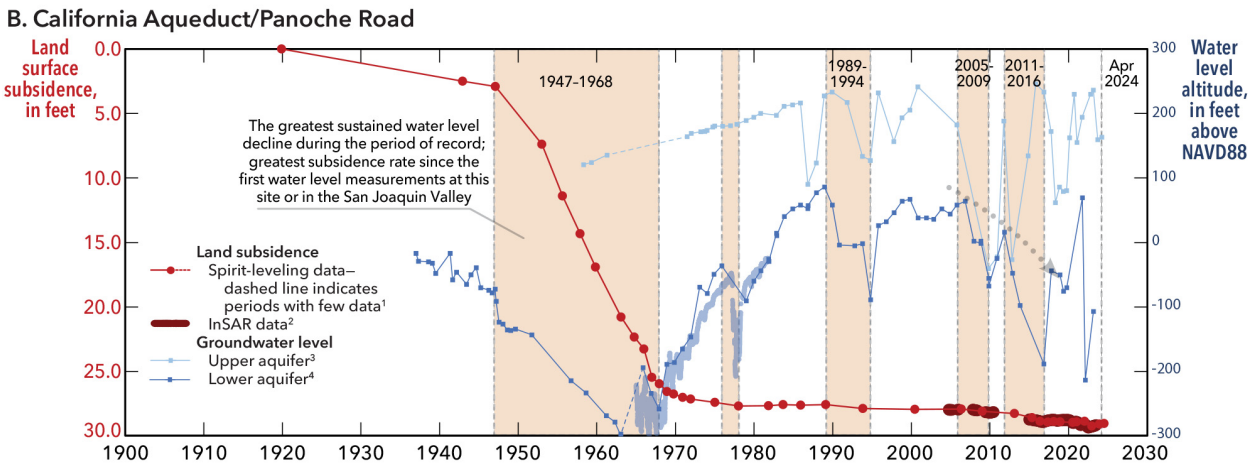
Figure 6-30 Long-term Subsidence and Groundwater Levels: Site A at State Hwy 99 / Ave 120



[1]Benchmarks 272.394, J 88, and QUAIL were used to determine cumulative subsidence from 1901 to 2021. [2]The initial value for the InSAR vertical displacement is registered to the amount of cumulative subsidence determined from spirit leveling. Data obtained from CADWR and extracted at cells containing the benchmark. [3]Extensometer data from extensometer 23S/25E-16N1 operational from 1958 to 1983 located in Pixley. [4]The 1905 and 1921 estimated water levels are from Lofgren and Klausing (1969); 1928–38: 22S24E23A001M; 1947–2023: 22S24E23J001M. [5]The 1905 estimated water level from Lofgren and Klausing (1969); 1935–62: 22S25E14J002M; 1964–2023: RMS well 22S24E01Q001M.

Figure 6-31 Long-term Subsidence and Groundwater Levels: Site B at the California Aqueduct / Panoche Rd

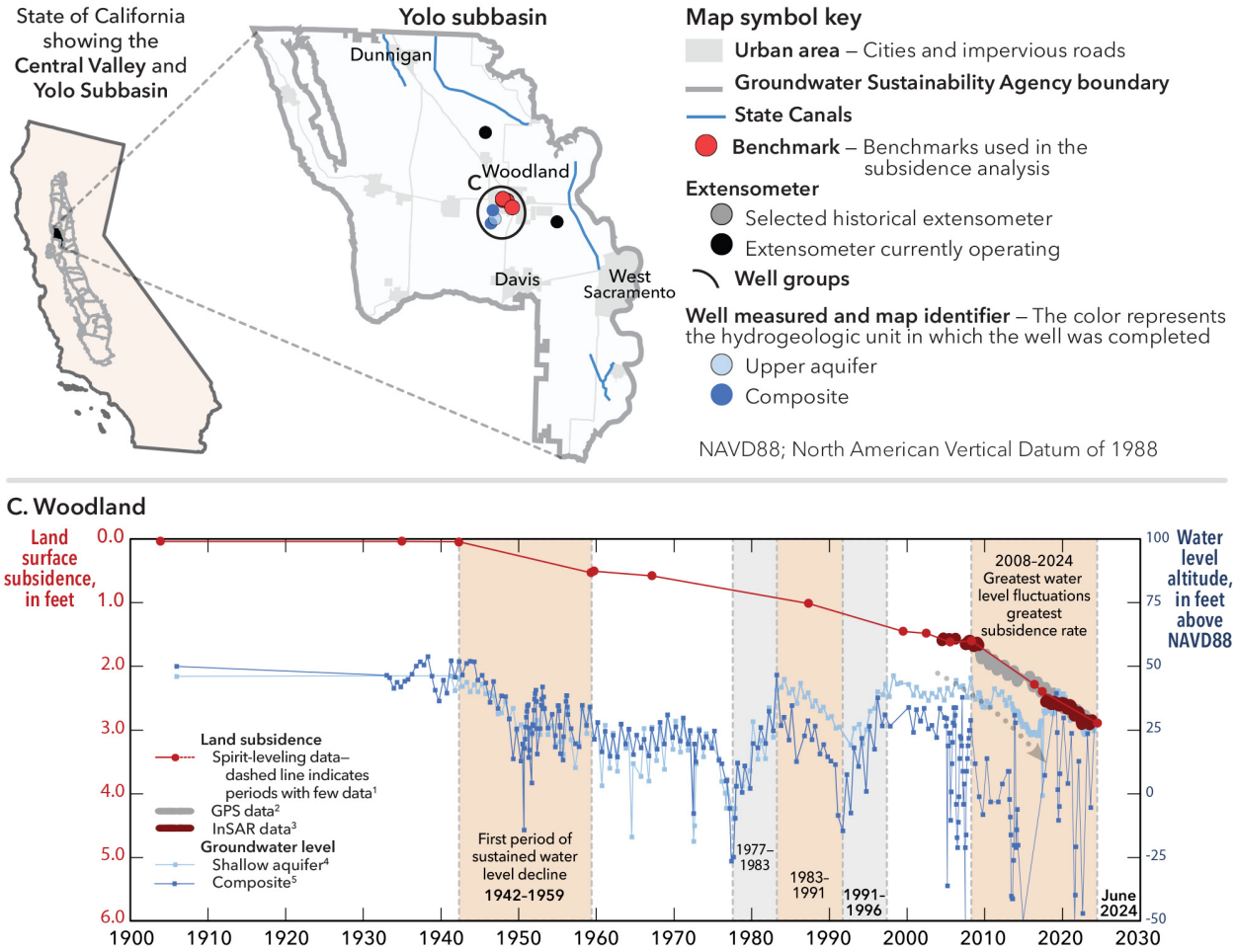




[1]Benchmarks GWM 14, 111.91 L, 111.93 L, and Z 1444 were used to determine cumulative subsidence from 1941 to 2024. From Ireland and others (1984), a total of 2.5 feet of subsidence was estimated from the 1920s to 1943 one mile east of this benchmark site. [2]The initial value for the InSAR vertical displacement is registered to the amount of cumulative subsidence determined from spirit leveling. Data obtained from CADWR and extracted at cells containing the benchmark. [3]1971–77: 15S13E12N004M; 1977–2024: 14S13E23E002M. [4]1937–46: 364109120294101 (USGS); 1947–63: 364102120294101 (USGS); 1965–2009: 14S13E22A001M; 2010–23: 15S13E02P001M. Continuous recorder well 15S13E11D002M located 1.8 miles to the south at historical extensometer 15S/13E-11D2 is also shown. This site is located approximately one mile west of a well-known photo of Dr. Joseph F. Poland standing next to a telephone pole indicating about 30 feet of subsidence between 1925 and 1977 at benchmark S 661.

PUBLIC

Figure 6-32 Long-term Subsidence and Groundwater Levels: Site C at Woodland



[1]Benchmarks B 20, H 201, WOODLANDS RESET, LIBRARY, and Z 1444 were used to determine cumulative subsidence from 1941 to 2024. [2]GPS data from GPS station PLSB using data from JPL and SOPAC. [3]The initial value for the InSAR vertical displacement is registered to the amount of cumulative subsidence determined from spirit leveling. Data obtained from CADWR and extracted at cells containing the benchmark. [4]The 1903–1910 estimated water levels are from Bryan (1923); 1941–1984: 10N02E34M001M; 1984– 2024: 10N02E29A001M. [5]The 1903–1910 estimated water levels are from Bryan (1923); 1933–2005: 09N02E07L001M; 2005–2024: 09N02E06B001M.

6.5.3 Future Subsidence

Future rates and the extent of subsidence will depend on the magnitude and duration of critical head exceedances; the thicknesses, distribution, and hydraulic properties of the fine-grained interbeds and confining units; and the long-term stress history of the region. Raising or maintaining water levels in the aquifers above critical heads, which are specific to each region, can provide the best chance at minimizing ongoing subsidence. This concept is illustrated at the Westside site (Figure 6-31), where rapid groundwater level recovery in the lower aquifer between 1967 and 1974, led to a substantial decrease in the subsidence rate from about one foot per year between 1947 and 1968 to 0.05 foot per year between 1969 and 1989. To minimize subsidence, groundwater extractions need to be reduced in conjunction with other management actions, including managed

aquifer recharge, to let groundwater levels rise and stay above critical heads. For additional discussion on these concepts see Appendix I, "Update on Land Subsidence in California."

6.6 Depletion of Interconnected Surface Water

SGMA requires groundwater managers to avoid undesirable results associated with depletions of interconnected surface water (ISW) from groundwater pumping. The groundwater managers are required to establish sustainable management criteria that are based on the location, quantity, and timing of the depletions. As of 2024, very few agencies have reported information on ISW caused by groundwater pumping. The limited data submitted to DWR are still being evaluated along with the methods used to determine the depletions caused by groundwater use. As more agencies begin to better understand and estimate the location, quantity, and timing of depletions, DWR will be better positioned to assess and report these conditions in future Bulletin 118 updates.

To assist local agencies in this effort, DWR developed a three-paper series on ISW and depletion of ISW to provide water managers with available tools to determine the location, quantity, and timing of ISW depletion caused by groundwater use.

Paper 1, *Depletions of Interconnected Surface Water: An Introduction*, covers concepts associated with the interaction between surface water and groundwater, including approaches for identifying ISW and defining depletion of ISW from groundwater pumping (California Department of Water Resources 2024a).

Paper 2, *Techniques for Estimating Depletion of Interconnected Surface Water Caused by Groundwater Use*, discusses the data requirements for ISW depletion analyses, the methods that groundwater sustainability agencies (GSAs) or groundwater managers are likely to consider, and the general process that GSAs would follow to implement an ISW depletion analysis using a numerical groundwater model (California Department of Water Resources 2024b).

Paper 3, *Examples for Estimating Interconnected Surface Water Depletion Caused by Groundwater Use*, provides two detailed examples simulating (1) a subbasin with longer response times to groundwater pumping and (2) a basin having a relatively fast response to groundwater pumping using numerical models to evaluate ISW depletion (California Department of Water Resources 2024c).

PUBLIC DRAFT

Understanding depletions of ISW is essential for characterizing groundwater conditions and will provide agencies and interested parties with information needed to manage groundwater conditions. Characterizing depletions of interconnected surface water caused by groundwater extraction may also provide the following foundational components for developing projects and management actions for sustainable groundwater management.

This information is important for basin-scale groundwater management to support:

- An understanding of the overall volume of depletions of ISW, allowing for an assessment of impacts on surface water users.
- An understanding of *which* surface water bodies are being depleted by groundwater pumping, allowing for comparison with the sensitivity of those locations to reduced flow or volume.
- An understanding of *when* surface water bodies are being depleted, allowing for a comparison with the sensitivity of those time periods to reduced flow or volume.

6.7 Seawater Intrusion

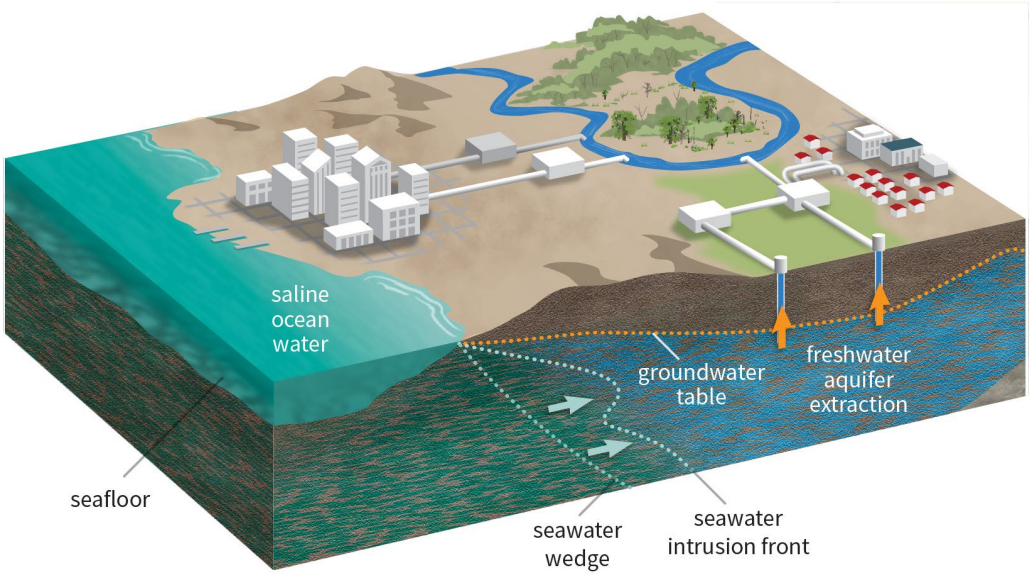
California has 98 groundwater basins adjacent to the ocean, a bay, or a delta where fresh groundwater interacts with seawater. This interaction of fresh groundwater with seawater typically creates a saltwater wedge due to differences in density between the two water types (see Figure 6-33). The interface of freshwater and seawater, referred to as the *saline front* or *seawater intrusion front* for this report, can migrate in the subsurface based on natural conditions and human activities. Any changes to the amount of fresh groundwater storage, such as fluctuations in groundwater pumping, availability of surface water, and climate-related events like drought or sea level rise, can affect the seawater intrusion front. When groundwater levels in onshore aquifers are lowered, the change in hydraulic gradient can result in the seawater intrusion front migrating inland. This phenomenon is commonly referred to as *seawater intrusion*.

The hydraulic gradient of an aquifer is established by several factors related to inflow and outflow from the aquifer. Aquifer inflow relates to the amount of groundwater recharge received through percolation of precipitation, the availability of permeable land surfaces, and anthropogenic recharge methods such as stormwater capture, managed aquifer recharge, irrigation return-flow, and application of recycled water. Outflow is generally comprised of natural drainage, groundwater pumping, and evapotranspiration. Seawater intrusion is influenced by

PUBLIC DRAFT

changes in the hydraulic gradient and the amount of fresh groundwater, as the position of the seawater intrusion front is a function of the different densities of fresh and saline water in the subsurface.

Figure 6-33 Schematic Showing the Seawater Intrusion Front in a Coastal Aquifer



In addition to precipitation and the surface water available for aquifer recharge, many natural factors affect the migration potential of the seawater intrusion front, including localized hydrology, geology, aquifer lithology, and regional climate change. Geologic factors such as the presence or absence of faults, consolidated rocks of lower permeability, fine-grained aquitard material, and discontinuous coastal aquifers could result in a barrier to groundwater flow, affecting the hydraulic gradient and likelihood of seawater intrusion. These natural factors combined with anthropogenic factors such as groundwater pumping, surface water diversions, and urban development, which tends to result in impermeable land surfaces, have a direct influence on the hydraulic gradient of groundwater and the likelihood of seawater intrusion, particularly in coastal aquifers.

This is significant as the hydraulic gradient at the freshwater-seawater interface dictates how far inland seawater can intrude into freshwater aquifers. Thus, the ability and volume of precipitation and other sources of water within a watershed to recharge aquifers is critical toward maintaining a hydraulic gradient capable of keeping denser seawater offshore and not intruding inland toward groundwater wells.

PUBLIC

Recharging groundwater to basin aquifers can be challenging, especially in times of low precipitation or drought. These periods are typically characterized by less surface water availability, less aquifer recharge, and increased groundwater extraction to meet water demands. These conditions can result in declining groundwater levels that change the hydraulic gradient within a basin and could induce seawater intrusion. Accordingly, water managers should conjunctively manage water resources and monitor groundwater conditions to determine if seawater intrusion is occurring. For more information regarding monitoring seawater intrusion, see Seawater Intrusion Monitoring Section in Chapter 5, "Groundwater Monitoring."

6.7.1 Regions of California Subject to Seawater Intrusion

Seawater intrusion cannot be presumed to occur just because a groundwater basin is adjacent to the ocean. Due to variations in hydrology, hydrogeology, and land use, not all coastal groundwater basins have experienced seawater intrusion. Each coastal basin is unique, and understanding of the local conditions would be improved by data regarding geology, lithology, groundwater levels, groundwater quality, and geophysics. There is no repository summarizing statewide seawater intrusion efforts because seawater intrusion is typically locally managed based on feasibility and need.

Department of Water Resources reviewed available literature and data for coastal groundwater basins to identify basins that have or had experienced seawater intrusion, are susceptible to seawater intrusion, and have projects or management actions to mitigate seawater intrusion. The recent status of seawater intrusion for each reviewed coastal basin is shown in Figure 6-34 to 6-35 and Table 6-23. For basins with available data, Table 6-23 also shows the historical status of seawater intrusion for each basin. Recent data in this context are based on any available data since 2010. The data shown in Table 6-23 are summarized below. For more information regarding monitoring, see the Seawater Intrusion Monitoring Section in Chapter 5, "Groundwater Monitoring."

Of the 98 groundwater basins near the coast that were evaluated, data for 57 basins indicate potential or actual seawater intrusion has historically occurred, with eight of the ten hydrologic regions having been impacted by seawater intrusion. Recent data do not exist for most of those basins. The available data indicates that recent seawater intrusion has occurred in 24 basins. The actual number of basins affected by seawater intrusion is likely to be higher because data were either inconclusive or not available to determine the recent status of 27 basins previously

PUBLIC DRAFT

known to have experienced seawater intrusion. In addition to the 24 basins with recent seawater intrusion, 33 more basins have the potential to experience seawater intrusion because those basins have historically been impacted.

Data for six of the historically impacted basins show no recent seawater intrusion, suggesting an improvement in these basins since seawater intrusion was detected in the past. Furthermore, three of the basins with historical seawater intrusion are actively and highly managed using projects and management actions.

Monitoring for seawater intrusion is recommended for basins adjacent to a saline source, such as coastal groundwater basins and basins near the Salton Sea or desalination plants, and those basins that have historically experienced seawater intrusion. Thus, ongoing monitoring in susceptible areas and expanded monitoring in data gap areas is important in understanding the extent of seawater intrusion on local beneficial uses of groundwater and whether local uses of groundwater are impacted or could become impacted. Future analyses can evaluate the basins with no available seawater intrusion data to determine if groundwater is relied upon for beneficial uses; if groundwater in these basins is used to meet water demand, that would further increase the importance and urgency of monitoring basin conditions for seawater intrusion. For more information regarding monitoring, see the Seawater Intrusion Monitoring Section in Chapter 5, "Groundwater Monitoring."

PUBLIC DRAFT

Figure 6-34 Status of Seawater Intrusion in Groundwater Basins

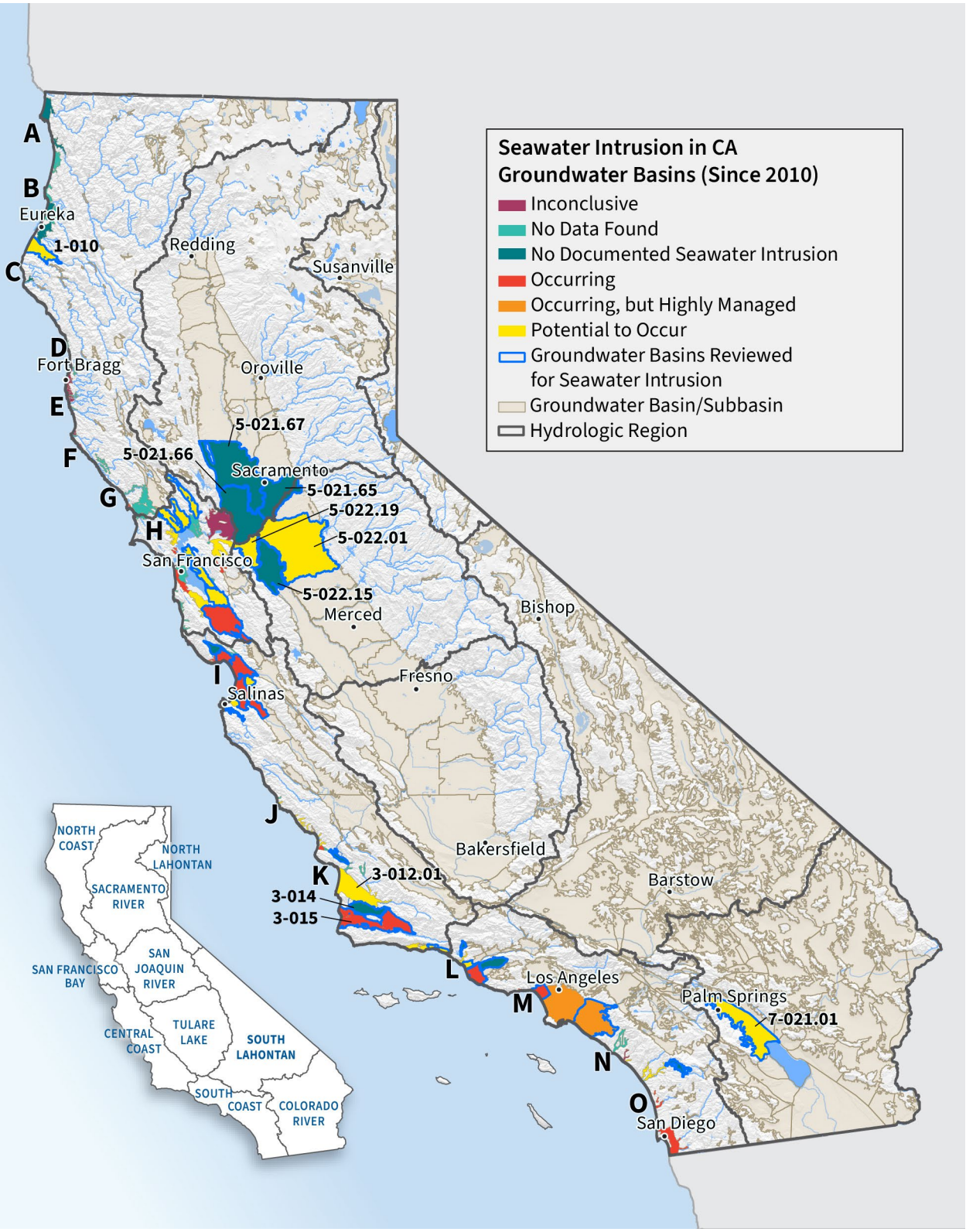


Figure 6-35 Status of Seawater Intrusion in Groundwater Basins (Detailed Inset)

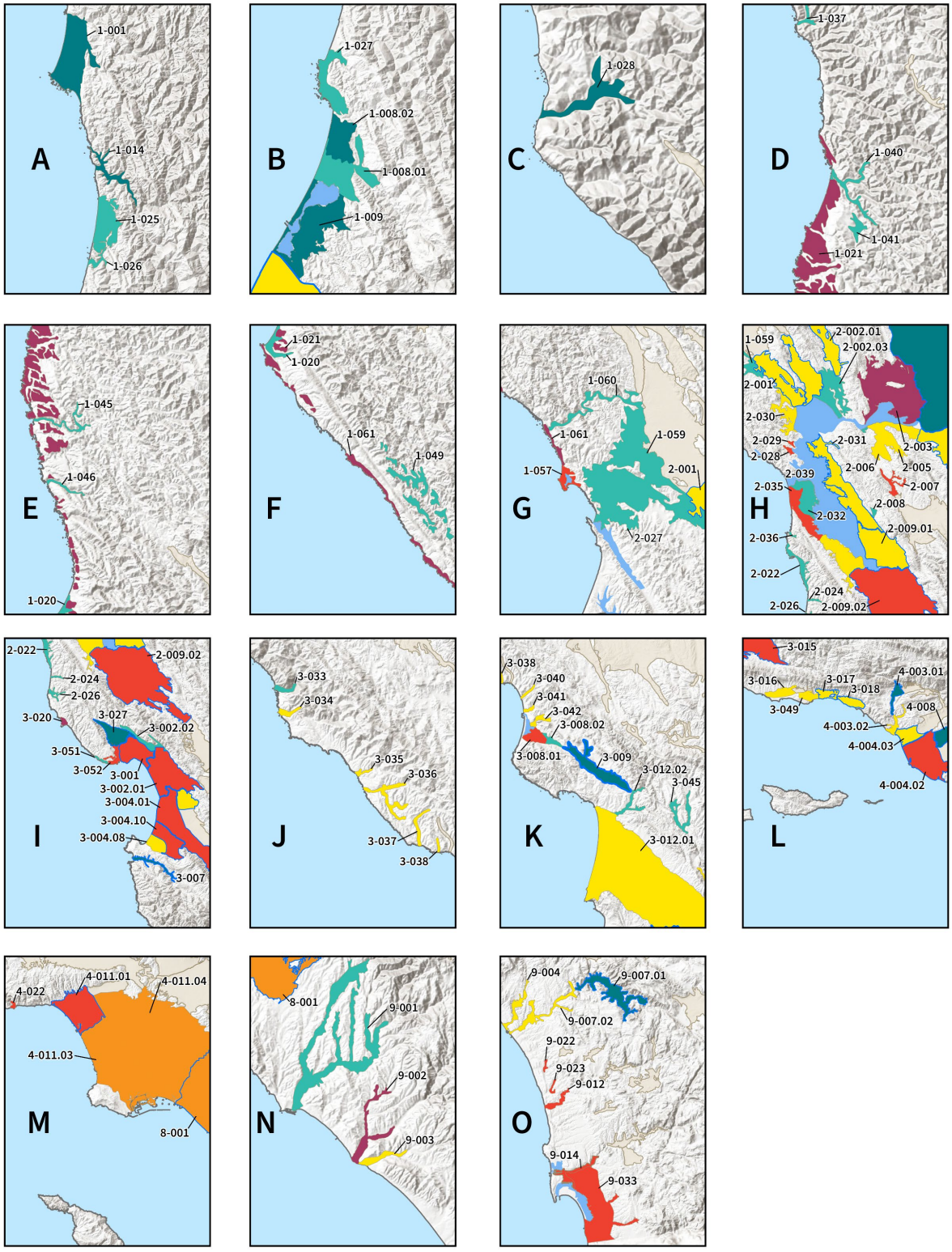


Table 6-23 Status of Seawater Intrusion in Coastal Groundwater Basins

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
1-001	Smith River Plain	Very Low	North Coast	Historical	No documented seawater intrusion
1-008.01	Mad River Lowland	Very Low	North Coast	No data found	No data found
1-008.02	Dows Prairie School Area	Very Low	North Coast	No documented seawater intrusion	No documented seawater intrusion
1-009	Eureka Plain	Very Low	North Coast	No documented seawater intrusion	No documented seawater intrusion
1-010	Eel River Valley	Medium	North Coast	No documented seawater intrusion	Potential to Occur
1-014	Lower Klamath River Valley	Very Low	North Coast	Historical	No documented seawater intrusion
1-020	Garcia River Valley	Very Low	North Coast	No documented seawater intrusion	No data found
1-021	Fort Bragg Terrace Area	Very Low	North Coast	Historical	Inconclusive
1-025	Prairie Creek Area	Very Low	North Coast	No data found	No data found
1-026	Redwood Creek Area	Very Low	North Coast	No data found	No data found
1-027	Big Lagoon Area	Very Low	North Coast	No data found	No data found
1-028	Mattole River Valley	Very Low	North Coast	No documented seawater intrusion	No documented seawater intrusion
1-037	Cottoneva Creek Valley	Very Low	North Coast	No documented seawater intrusion	No data found

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
1-040	Ten Mile River Valley	Very Low	North Coast	No documented seawater intrusion	No data found
1-041	Little Valley	Very Low	North Coast	No documented seawater intrusion	No data found
1-045	Big River Valley	Very Low	North Coast	No documented seawater intrusion	No data found
1-046	Navarro River Valley	Very Low	North Coast	No documented seawater intrusion	No data found
1-049	Annapolis Ohlson Ranch Formation Highlands	Very Low	North Coast	No data found	No data found
1-057	Bodega Bay Area	Very Low	North Coast	Historical	Occurring
1-059	Wilson Grove Formation Highlands	Very Low	North Coast	No data found	No data found
1-060	Lower Russian River Valley	Very Low	North Coast	No data found	No data found
1-061	Fort Ross Terrace Deposits	Very Low	North Coast	Inconclusive	Inconclusive
2-001	Petaluma Valley	Medium	North Coast	Potential to Have Occurred	Potential to Occur
2-002.01	Napa-Sonoma Valley - Napa Valley	High	San Francisco Bay	No documented seawater intrusion	Potential to Occur

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
2-002.02	Napa-Sonoma Valley - Sonoma Valley	High	San Francisco Bay	Potential to Have Occurred	Potential to Occur
2-002.03	Napa-Sonoma Valley - Napa-Sonoma Lowlands	Very Low	San Francisco Bay	No data found	No data found
2-003	Suisun-Fairfield Valley	Low	San Francisco Bay	Potential to Have Occurred	Inconclusive
2-004	Pittsburg Plain	Very Low	San Francisco Bay	Historical	Potential to Occur
2-005	Clayton Valley	Very Low	San Francisco Bay	Historical	Potential to Occur
2-006	Ygnacio Valley	Very Low	San Francisco Bay	Historical	Potential to Occur
2-007	San Ramon Valley	Very Low	San Francisco Bay	Historical	Occurring
2-008	Castro Valley	Very Low	San Francisco Bay	No data found	No data found
2-009.01	Santa Clara Valley - Niles Cone	Medium	San Francisco Bay	Historical	Potential to Occur
2-009.02	Santa Clara Valley - Santa Clara	High	San Francisco Bay	Historical	Occurring

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
2-009.03	Santa Clara Valley - San Mateo Plain	Very Low	San Francisco Bay	Historical	Potential to Occur
2-009.04	Santa Clara Valley - East Bay Plain	Medium	San Francisco Bay	No documented seawater intrusion	Potential to Occur
2-022	Half Moon Bay Terrace	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-024	San Gregorio Valley	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-026	Pescadero Valley	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-027	Sand Point Area	Very Low	North Coast San Francisco Bay	No documented seawater intrusion	No data found
2-028	Ross Valley	Very Low	San Francisco Bay	Historical	Occurring
2-029	San Rafael Valley	Very Low	San Francisco Bay	Historical	Occurring
2-030	Novato Valley	Low	San Francisco Bay	Historical	Potential to occur (2009 data); No data found
2-031	Arroyo Del Hambre Valley	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-032	Visitacion Valley	Very Low	San Francisco Bay	No documented seawater intrusion	No data found

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
2-033	Islais Valley	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-035	Westside	Very Low	San Francisco Bay	Potential to Have Occurred	Occurring
2-036	San Pedro Valley	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-037	South San Francisco	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-038	Lobos	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-039	Marina	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
2-040	Downtown	Very Low	San Francisco Bay	No documented seawater intrusion	No data found
3-001	Santa Cruz Mid - County	High	Central Coast	Historical	Occurring
3-002.01	Corralitos - Pajaro Valley	High	Central Coast	Historical	Occurring
3-002.02	Corralitos - Purisima Highlands	Very Low	Central Coast	No data found	No data found
3-004.01	Salinas Valley - 180/400 Foot Aquifer	High	Central Coast	Historical	Occurring

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
3-004.08	Salinas Valley - Seaside	Very Low	Central Coast	Potential to Have Occurred	Potential to Occur
3-004.09	Langley Area	High	Central Coast	No documented seawater intrusion	Potential to Occur
3-004.10	Salinas Valley - Monterey	Medium	Central Coast	Historical	Occurring
3-007	Carmel Valley	Medium	Central Coast	No documented seawater intrusion	No documented seawater intrusion
3-008.01	Los Osos Valley - Los Osos Area	Very Low	Central Coast	Historical	Occurring
3-008.02	Los Osos Valley - Warden Creek	Very Low	Central Coast	No data found	No data found
3-009	San Luis Obispo Valley	High	Central Coast	No documented seawater intrusion	No documented seawater intrusion
3-012.01	Santa Maria River Valley - Santa Maria	Very Low	Central Coast	Historical	Potential to Occur
3-012.02	Santa Maria River Valley - Arroyo Grande	Very Low	Central Coast	No data found	No data found
3-014	San Antonio Creek Valley	Medium	Central Coast	No documented seawater intrusion	No documented seawater intrusion
3-015	Santa Ynez River Valley	Medium	Central Coast	Historical	Occurring

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
3-016	Goleta	Very Low	Central Coast	No documented seawater intrusion	Potential to Occur
3-017	Santa Barbara	Very Low	Central Coast	Historical	Potential to Occur
3-018	Carpinteria	High	Central Coast	No documented seawater intrusion	Potential to Occur
3-020	Ano Nuveo	Very Low	Central Coast	No data found	Inconclusive
3-026	West Santa Cruz Terrace	Very Low	Central Coast	Historical	Occurring
3-027	Santa Margarita	Medium	Central Coast	No documented seawater intrusion	No documented seawater intrusion
3-033	San Carpoforo Valley	Very Low	Central Coast	No data found	No data found
3-034	Arroyo de la Cruz Valley	Very Low	Central Coast	Potential to Have Occurred	Potential to Occur / No data found
3-035	San Simeon Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-036	Santa Rosa Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-037	Villa Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-038	Cayucos Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-039	Old Valley	Very Low	Central Coast	No data found	No data found

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
3-040	Toro Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-041	Morro Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-042	Chorro Valley	Very Low	Central Coast	Historical	Potential to Occur / No data found
3-045	Huasna Valley	Very Low	Central Coast	No data found	No data found
3-049	Montecito	Medium	Central Coast	Historical	Potential to Occur
3-051	Majors Creek	Very Low	Central Coast	No data found	No data found
3-052	Needle Rock Point	Very Low	Central Coast	No data found	No data found
4-003.01	Ventura River Valley - Upper Ventura River	Medium	South Coast	No documented seawater intrusion	No documented seawater intrusion
4-003.02	Ventura River Valley - Lower Ventura River	Very Low	South Coast	No documented seawater intrusion	Potential to Occur
4-004.02	Santa Clara River Valley - Oxnard	High	South Coast	Historical	Occurring
4-004.03	Santa Clara River Valley - Mound	High	South Coast	No documented seawater intrusion	Potential to Occur
4-008	Las Posas Valley	High	South Coast	No documented seawater intrusion	No documented seawater intrusion

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
4-011.01	Coastal Plain of Los Angeles - Santa Monica	Medium	South Coast	Historical	Occurring
4-011.03	Coastal Plain of Los Angeles - Central	Very Low	South Coast	Historical	Occurring, but highly managed
4-011.04	Coastal Plain of Los Angeles - West Coast	Very Low	South Coast	Historical	Occurring, but highly managed
4-022	Malibu Valley	Very Low	South Coast	Historical	Occurring
5-021.65	Sacramento Valley - South American	High	Sacramento River	Historical	No documented seawater intrusion
5-021.66	Sacramento Valley - Solano	Medium	Sacramento River	Historical	No documented seawater intrusion
5-021.67	Sacramento Valley - Yolo	High	Sacramento River	Historical	No documented seawater intrusion
5-022.01	San Joaquin Valley - Eastern San Joaquin	High	San Joaquin River	Historical	Potential to Occur
5-022.15	San Joaquin Valley - Tracy	High	San Joaquin River	Historical	No documented seawater intrusion

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
5-022.19	San Joaquin Valley - East Contra Costa	Medium	San Joaquin River	Historical	Potential to Occur
7-021.01	Coachella Valley - Indio	Medium	Colorado River	No documented seawater intrusion	Potential to Occur
8-001	Coastal Plain of Orange County	Medium	South Coast	Historical	Occurring, but highly managed
9-001	San Juan Valley	Very Low	South Coast	Historical	No data found
9-002	San Mateo Valley	Very Low	South Coast	Inconclusive	Inconclusive
9-003	San Onofre Valley	Very Low	South Coast	Inconclusive	Potential to Occur
9-004	Santa Margarita Valley	Very low	South Coast	Historical	Potential to Occur
9-007.01	San Luis Rey Valley - Upper San Luis Rey Valley	Medium	South Coast	No documented seawater intrusion	No documented seawater intrusion
9-007.02	San Luis Rey Valley - Lower San Luis Rey Valley	Very Low	South Coast	Historical	Potential to Occur
9-012	San Dieguito Creek	Very Low	South Coast	Historical	Occurring
9-014	Mission Valley	Very Low	South Coast	Historical	Occurring

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Basin Priority	Hydrologic Region	Seawater Intrusion Historical Occurrence	Seawater Intrusion Recent Occurrence (since 2010)
9-022	Batiquitos Lagoon Valley	Very Low	South Coast	Historical	Occurring
9-023	San Elijo Valley	Very Low	South Coast	Historical	Occurring
9-033	Coastal Plain of San Diego	Low	South Coast	Historical	Occurring

6.7.2 Impacts of Seawater Intrusion

Seawater intrusion could result in significant degradation of the coastal groundwater aquifer due to the displacement of fresh groundwater storage by seawater, which would significantly increase the concentration of TDS and chloride in the groundwater. The high concentration of TDS and chloride in seawater could degrade the groundwater quality to an extent that compromises its beneficial uses without costly treatment.

The concentration of TDS in seawater is approximately 35,000 mg/L, with chloride being the largest component at approximately 19,000 mg/L (Barlow 2003). These concentrations far exceed the Secondary maximum contaminant level (MCL) for Drinking Water Standards in the California Code of Regulations, Title 22 (22 CCR Section 64449). For comparison, the Secondary MCL and the concentration of seawater for TDS and chloride are shown in Table 6-24.

Table 6-24 Drinking Water Standards of Total Dissolved Solids and Chloride Relative to Seawater

Constituent	Recommended	Upper	Short-Term	Seawater
Total Dissolved Solids (TDS)	500 mg/L	1,000 mg/L	1,500 mg/L	35,000 mg/L
Chloride	250 mg/L	500 mg/L	600 mg/L	19,000 mg/L

The degradation of coastal aquifers because of seawater intrusion could have immediate and lasting effects that require long-term and costly remediation or treatment to conform with drinking water standards or agricultural water quality standards, even if additional freshwater supplies became available in the future to

PUBLIC DRAFT

displace the seawater, pushing the seawater intrusion front seaward. In this scenario where seawater intrusion could be halted or reversed, the inland plume of degraded water quality could result in residual brackish groundwater conditions that exceed the tolerance thresholds for beneficial uses. Table 6-25 shows the TDS concentrations associated with various types of water.

Table 6-25 Total Dissolved Solids Concentrations Based on Water Type

Constituent	Freshwater	Brackish	Saline	Seawater
Total Dissolved Solids (TDS)	up to 1,000 mg/L	1,000–10,000 mg/L	10,000–35,000 mg/L	35,000 mg/L

As a result of a high concentration of TDS and chlorides, some wells in an affected area may need to be abandoned, and alternative sources of water need to be accessed. All of these scenarios have associated costs that could financially and physically impact the beneficial users of the coastal aquifer. Thus, sustainable management of coastal basins used for groundwater supplies require monitoring and proactive conjunctive management of freshwater supplies to maintain protective groundwater levels and a seaward hydraulic gradient that prevents the seawater front from migrating inland.

6.7.3 Groundwater Quality Data Related to Seawater Intrusion Conditions

Groundwater quality constituents commonly used to monitor seawater intrusion include chloride and TDS. Although TDS is used by some water managers to detect and monitor seawater intrusion, there are sources other than the ocean that can contribute to elevated concentrations of TDS. Thus, just because TDS data for a basin shows an elevated level, that does not automatically mean seawater intrusion is occurring; instead, it is important to consider the overall basin conditions, including historical TDS data, available chloride data, groundwater level trends, and sources of TDS. Another parameter that is analyzed with less frequency is specific conductance, which is related to salinity. The specific conductance, also called electrical conductivity, of water is a value associated with the ability of water to conduct electricity based on the concentration of ions in the solution. This method of monitoring is not used as commonly as TDS or chloride. The units of specific conductance vary based on the source of information, so the units are provided in Table 6-26.

All coastal groundwater basins with quantitative results of chloride, total dissolved solids, and specific conductance are shown in Table 6-26. Note that the range of

PUBLIC DRAFT

concentrations for a given basin reflects the available historical data found during the literature review and are not necessarily indicative of the current condition of the basin, the most recent analysis, or a summary of active monitoring. Thus, the minimum and maximum range of concentrations does not necessarily reflect conditions within the same year nor sampling event.

Table 6-26 Groundwater Quality Data Related to Seawater Intrusion

Basin / Subbasin Number	Basin / Subbasin Name	Hydrologic Region	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Specific Conductance
1-010	Eel River Valley	North Coast	14–10,000	-	-
1-057	Bodega Bay Area	North Coast	average 304	average 868	average 883 µmhos/cm
2-001	Petaluma Valley	North Coast	25– 50	250–1,000	-
2-002.01	Napa-Sonoma Valley - Napa Valley	San Francisco Bay	5–3,970	-	200–17,160 mhos
2-002.02	Napa-Sonoma Valley - Sonoma Valley	San Francisco Bay	6–1,580	250–1,000	203–5,380 mhos
2-004	Pittsburg Plain	San Francisco Bay	~ 40–225	~ 150–1,500	-
2-009.01	Santa Clara Valley - Niles Cone	San Francisco Bay	6–26,383	280–43,000	-
2-009.02	Santa Clara Valley - Santa Clara	San Francisco Bay	40–133	360–1,122	-
2-009.03	Santa Clara Valley - San Mateo Plain	San Francisco Bay	20–578	180–2,330	-
2-009.04	Santa Clara Valley - East Bay Plain	San Francisco Bay	46–15,000	366–27,000	-

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Hydrologic Region	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Specific Conductance
2-028	Ross Valley	San Francisco Bay	> 1,000	-	-
2-029	San Rafael Valley	San Francisco Bay	> 1,000	-	-
2-035	Westside	San Francisco Bay	15–14,000	86–23,000	230–38,000 µmhos/cm
3-001	Santa Cruz Mid - County	Central Coast	20–22,000	95–740	-
3-002.01	Corralitos - Pajaro Valley	Central Coast	< 5–14,600	200–1,400	-
3-004.01	Salinas Valley - 180/400 Foot Aquifer	Central Coast	11–14,000	180–21,800	-
3-004.08	Salinas Valley - Seaside	Central Coast	43–8,660	164–986	308 – 1,527 µS/cm
3-004.10	Salinas Valley - Monterey	Central Coast	-	> 10,000 mg/L	-
3-008.01	Los Osos Valley - Los Osos Area	Central Coast	30–2,900	150–8,340	-
3-009	San Luis Obispo Valley	Central Coast	-	180–3,100	-
3-012.01	Santa Maria River Valley - Santa Maria	Central Coast	29–1500	190–3,690	1,000–2,600 µmhos/cm
3-015	Santa Ynez River Valley	Central Coast	53–2,710	0–5,450	-
3-016	Goleta	Central Coast	37–201	~480-1,600	-
3-017	Santa Barbara	Central Coast	~ 28-17,530	~ 342-34,634	-

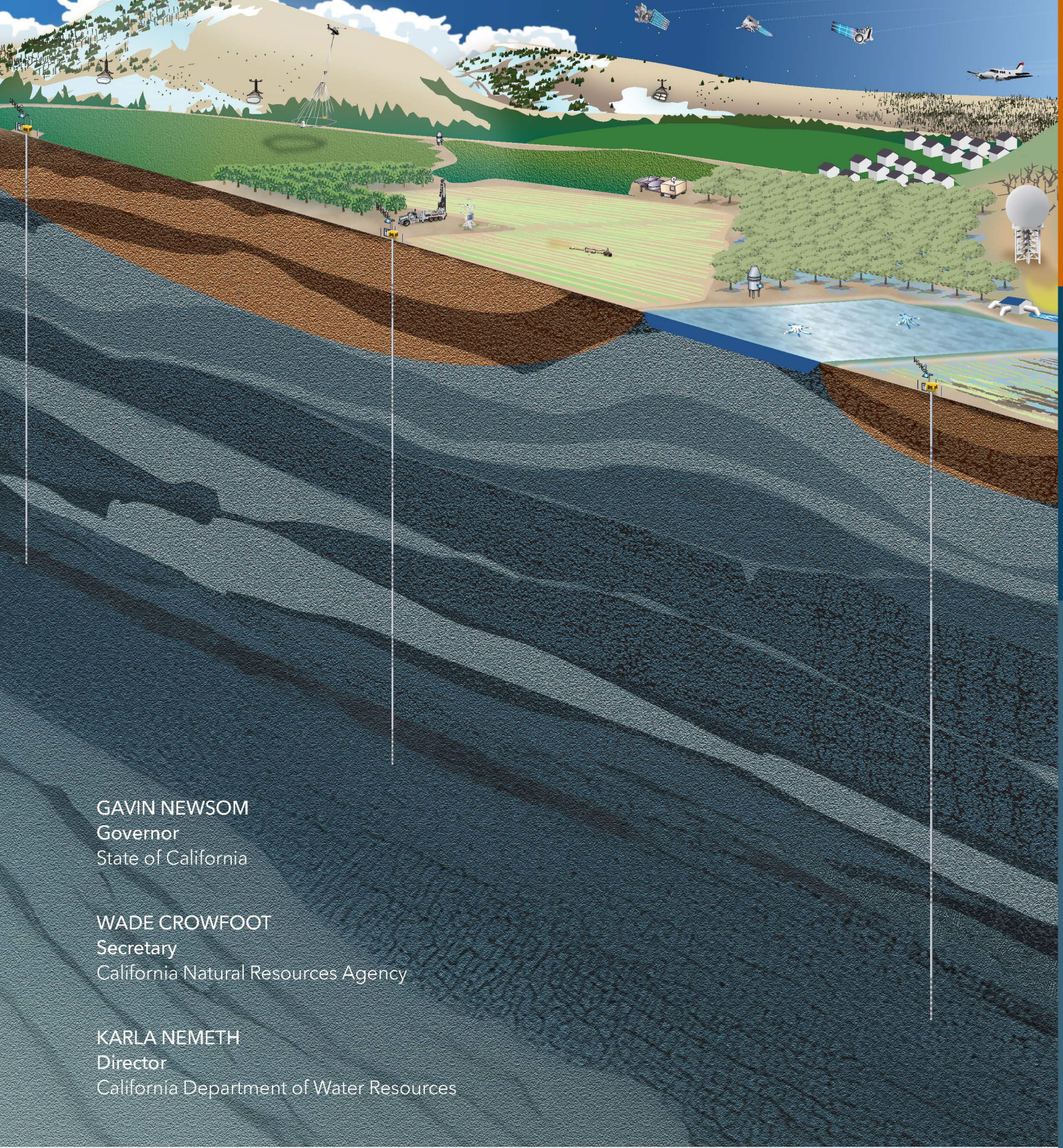
PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Hydrologic Region	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Specific Conductance
3-018	Carpinteria	Central Coast	20–1,350	446–2,210	-
3-049	Montecito	Central Coast	88–2,180	570–1,242	-
4-003.01	Ventura River Valley -Upper Ventura River	South Coast	0–425	375–1,700	-
4-003.02	Ventura River Valley - Lower Ventura River	South Coast	60–305	790–1,860	-
4-004.02	Santa Clara River Valley - Oxnard	South Coast	23–20,700	392–49,600	-
4-004.03	Santa Clara River Valley - Mound	South Coast	45–181	-	-
4-011.01	Coastal Plain of Los Angeles - Santa Monica	South Coast	51–530	310–2,780	-
4-011.03	Coastal Plain of Los Angeles - Central	South Coast	5–24,000	204–4,090	-
4-011.04	Coastal Plain of Los Angeles - West Coast	South Coast	28–6,800	282–12,600	-
4-022	Malibu Valley	South Coast	170–244	2,000–2,200	-
5-021.65	Sacramento Valley - South American	Sacramento River	-	97–1,360	-

PUBLIC DRAFT

Basin / Subbasin Number	Basin / Subbasin Name	Hydrologic Region	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Specific Conductance
5-021.67	Sacramento Valley - Yolo	Sacramento River	-	-	292 – 6,100 µmhos/cm
5-022.01	San Joaquin Valley - Eastern San Joaquin	San Joaquin River	0–3,750	94–1,180	-
5-022.15	San Joaquin Valley - Tracy	San Joaquin River	1–2,400	82–4,500	-
5-022.19	San Joaquin Valley - East Contra Costa	San Joaquin River	11–4,900	86–20,400	-
7-021.01	Coachella Valley - Indio	Colorado River	0–370	130–7,400	-
8-001	Coastal Plain of Orange County	South Coast	~250–15,000	~300–1,052	-
9-012	San Dieguito Creek	South Coast	380–2,480	1,080–5,990	-
9-014	Mission Valley	South Coast	1,080–1,090	2,260–2,330	4,110–4,190 µS/cm
9-033	Coastal Plain of San Diego	South Coast	125–16,900	476–32,300	858–47,300 µS/cm

PUBLIC DRAFT



GAVIN NEWSOM
Governor
State of California

WADE CROWFOOT
Secretary
California Natural Resources Agency

KARLA NEMETH
Director
California Department of Water Resources

California Department of Water Resources
715 P Street
Sacramento, California 95814
water.ca.gov