4.2 PLAN DEVELOPMENT

4.2.1 Decision-making Process

As one of six GSPs being prepared for the Delta-Mendota Subbasin, the Northern & Central Delta-Mendota Region GSP development required decision making at both the GSP- and subbasin-level. Decisions relating to critical GSP components, such as water balance methodology, sustainability indicators, and groundwater dependent ecosystem (GDE) identification and impacts were coordinated through a multi-step process before being finalized first at the GSP-level and then at the subbasin-level. This process is outlined below where differences in the GSP and Subbasin decision-making processes are identified as necessary:

1. The project team develops the initial recommendation
2. The initial recommendation is presented to the Groundwater Sustainability Agencies (GSAs) via the Northern and Central Delta-Mendota Technical Advisory Committee and Northern and Central Delta-Mendota Regional Management Committees at the GSP-level, and to the Delta-Mendota Subbasin Communication and Technical Working Groups and Delta-Mendota Subbasin Coordination Committee at the subbasin-level
3. Feedback from the Northern and Central Delta-Mendota Technical Advisory Committee and Northern and Central Delta-Mendota Regional Management Committees at the GSP-level, and Delta-Mendota Subbasin Working Groups and Delta-Mendota Subbasin Coordination Committee at the subbasin-level are incorporated into the recommendation
4. Step 2 and 3 are repeated as needed
5. The agreed-upon recommendation is presented at a public workshop
6. Feedback from stakeholders is incorporated into the recommendation as appropriate
7. The recommendation is documented in the appropriate GSP section and Subbasin Common Chapter
8. Completed GSP or Common Chapter sections are circulated to the GSAs in the Plan Area or Delta-Mendota Subbasin GSP Working Groups and Coordination Committee for comment
9. Comments on the recommended approach/section are incorporated into the appropriate document(s)
10. The GSP or Common Chapter section is posted online for public review and comment
11. Public comments are collected and documented

As detailed above, the decision-making process includes multiple points for both internal (GSA members) and external (public) stakeholders to contribute to the GSP development. Participation in this process was encouraged through stakeholder outreach, communications, and public workshops conducted throughout GSP development.

4.2.2 Comments Received Regarding the Plan

During the GSP development phase, the Northern & Central Delta-Mendota Region GSP Group posted draft chapters of its Plan to its website (website information provided in **Section 4.3.4**) for 30 days to allow for public review and comment. Upon the release of each chapter, notice was provided to the stakeholder list and an announcement was placed on the GSP website. Comments received on the Public Draft GSP chapters have been compiled and are included in **Appendix C** of this GSP.

4.3 OUTREACH

4.3.1 Noticing

In accordance with GSP Emergency Regulations §357.2(a), the Northern & Central Delta-Mendota Region GSP Group submitted notice to the California Department of Water Resources (DWR) stating the intent to develop a GSP. This notice was submitted to DWR on January 5, 2018, a copy of which is included in **Appendix G**.

Following the initial notice submitted to DWR, the Northern & Central Delta-Mendota Region GSP Group has provided public notices related to major project junctions and milestones. The methods used to circulate these notices are detailed further in **Section 4.3.4** and additional details regarding the stakeholder distribution list is included in the next section.

Finally, upon completion of the GSP, notice was provided to the counties and cities within the Northern and Central Delta-Mendota Regions regarding Plan adoption. This notice was distributed on September 9, 2019, a copy of which is included in **Appendix G**. A notice of intent to adopt the revised GSP was distributed on March 15, 2022, notifying the counties and cities within the Northern and Central Delta-Mendota Regions regarding adoption of the amened Plan, where a copy of this notice is also included in **Appendix G**.

4.3.1.1 GSP Stakeholder List

At the project outset, stakeholder interest was solicited and a contact list was developed to facilitate distribution of project information and notices. The initial stakeholder list included, but was not limited to, representatives from the following groups:

- Public agencies in the Northern and Central Delta-Mendota Regions, other GSAs in the Delta-Mendota Subbasin and adjoining subbasins, including state agencies such as the California Department of Fish and Wildlife
- Farm bureaus and agricultural groups in the Northern and Central Delta-Mendota Regions, in other GSP Regions of the Delta-Mendota Subbasin and adjoining subbasins
- Non-governmental organizations (NGOs) representing environmental interests such as The Audubon Society and The Nature Conservancy
- Private companies and citizens with prior engagement in related planning projects (such as the Integrated Regional Water Management Planning [IRWMP] process)

This stakeholder list was updated throughout the project lifecycle, with new interested parties signing up at public meetings, via email, or through the GSP website. The final stakeholder contact list includes over 500 parties and is included in **Appendix C**.

4.3.2 Opportunities for Public Engagement

Throughout the GSP development process, stakeholders, and the public were encouraged to engage with the GSP development team. Through use of the stakeholder list and other noticing strategies (detailed in **Section 4.3.4**), the Northern & Central Delta-Mendota Region GSP Group invited interested parties to join in deliberation, dialogue, and discussions related to the development of the GSP. The primary opportunity for engagement with the GSP team came during the subbasin-wide public workshops, but additional targeted meetings and events were held as well as direct communications via website-based communications links, email and letters. Public input gathered during the engagement events was documented for consideration during GSP development. The following sections describe the opportunities for public engagement.

4.3.2.1 Public Workshops

The Northern & Central Delta-Mendota Region GSP Group, in coordination with the other five (5) GSP groups in the Delta-Mendota Subbasin, organized and participated in a series of four sets of public workshops throughout the GSP development process. The sets of public workshops were held approximately once a quarter from the initial GSP development kickoff (May 2018) to final content development (May 2019) and were held at multiple locations around the Subbasin (typically with workshops held in the northern, central, and southern portions of the Subbasin). Recognizing the potential limits of the public's schedule, a minimum of three meetings per workshop set (e.g. three meetings were held in the May 2018 set) were organized to provide multiple opportunities for stakeholder engagement. A summary of the topics, dates, and locations of the sets of public workshops is included in **Table 4-2**. Methods used to notify the public of the workshops are discussed in **Section 4.3.4** and presentation materials and meeting sign in sheets from the public meetings are included in **Appendices B and C**.

Table 4-2. Delta-Mendota Subbasin Public Workshops

Meeting Date		Meeting Location	Topics
Spring 2018	May 14	Los Banos: *San Luis & Delta-Mendota Water Authority Office*	SGMA overview, Opportunities to get involved and engage with the project team
	May 16	Patterson: *Hammon Senior Center*	
	May 17	Mendota: *Mendota Branch Library*	
Fall 2018	October 22	Firebaugh: *Firebaugh Middle School Multi-Purpose Room*	Data Collection, HCM, Groundwater Models
	October 24	Los Banos: *College Greens Building*	
	October 25	Patterson: *Hammon Senior Center*	
Winter 2019	February 19	Los Banos: *College Greens Building*	Current and Future Water Budgets, Sustainability Criteria, Projects and Management Action
	February 20	Patterson: *Patterson City Hall*	
Spring 2019	May 20	Patterson: *Patterson City Hall*	Projected Water Budget, Sustainable Yield, Monitoring Network, Projects and Management Actions
	May 21	Los Banos: *College Greens Building*	
	May 22	Santa Nella: Romero Elementary School Multi-Purpose Room	
	May 23	Mendota: *Mendota Branch Library*	

4.3.2.2 Special Environmental Considerations

Given the scope of the GSP and the requirements to consider all users of groundwater (including local ecosystems), the Northern & Central Delta-Mendota Region GSP Group, along with other GSP Groups in the Delta-Mendota Subbasin, sought consultation with NGOs representing environmental interests and natural resources-focused state agencies early in the GSP development process. As discussed in **Section 4.3.1.1**, representatives from organizations representing environmental interests and state agencies were included on the initial stakeholder list and received all project updates and notices, as well as invitations to attend and participate at the public workshops and regularly scheduled committee and workgroup meetings. In addition, representatives from environmental NGOs (from the Audubon Society and The Nature Conservancy) and state agencies (from the California Department of Fish and Wildlife) were invited to participate at GSP development meetings and special workshops.

In addition to the public workshops listed in **Section 4.3.2.1**, two special workshops were held with The Nature Conservancy to review groundwater dependent ecosystem identification and coverage and sustainable management criteria in the GSP. The first workshop (August 24, 2018) was held in conjunction with all GSP groups in the Delta-Mendota Subbasin, while the second meeting (April 29, 2019) was planned and held by the Northern & Central Delta-Mendota Region GSP Group for more targeted discussions. Materials from those special workshops are included in **Appendix C**.

4.3.2.3 Other Opportunities for Public Engagement

In addition to the public workshops described previously, individual GSAs in the Northern & Central Delta-Mendota Region GSP Group planned and held additional, targeted public engagement activities for their communities and stakeholders. Engagement activities conducted by the Northern and Central Delta-Mendota Regions' GSAs started shortly after SGMA legislation was passed. The following is a list of the types of other outreach efforts undertaken by the Northern and Central Delta-Mendota Regions GSAs:

- Presentations and discussions at local club meetings
- Presentations and discussions at local public agency events including, but not limited to, Board of Directors, City Council, Landowner, Grower, and Town Hall meetings
- Local SGMA workshops
- Combined outreach with IRWM outreach efforts
- Requests received via the dmsgma@sldmwa.org email address by interested parties to be added to meeting distribution lists, where interested parties who were not able to attend meetings in person were able to attend and participate via teleconference

In total, the Northern and Central Delta-Mendota Regions' GSAs conducted over 200 additional outreach activities. A log of outreach activities conducted by the various GSA groups is included in **Appendix C**.

4.3.3 Outreach to Diverse Social, Cultural, and Economic Areas of the Population

The Northern and Central Delta-Mendota Regions include a diversity of community types, including many non-native non-English (predominantly Spanish) speakers and disadvantaged communities. In order to reach as much of the population as possible, the following best practices were implemented to increase project visibility and opportunities for engagement:

- All outreach materials (including meeting flyers, fact sheets, frequently asked questions [FAQs], and videos) were translated and made available in Spanish
- Spanish-speaking interpreters were available at public meetings
- Public meetings were held in disadvantaged communities to provide easier access to the GSP process
- Meetings were held both in the late afternoon and the evening to avoid conflicts with work schedules and provide the greatest flexibility for attendance

Further, the Northern & Central Delta-Mendota Region GSP Group coordinated with other community development and planning efforts in the region to reach a greater audience. These efforts include:

- Self-Help Enterprises (SHE), a local community development organization focused on working with low-income families and communities, helped the GSP Group reach a greater number of members of the disadvantaged communities identified within the Plan area.

- SGMA information and materials were incorporated into efforts related to the IRWM Disadvantaged Community Involvement Program (DACIP) and into applicable IRWM documents (including the East Stanislaus, Merced, and Westside-San Joaquin IRWM Regions)

4.3.4 Methods for Disseminating Information

The Northern & Central Delta-Mendota Region GSP Group utilized a variety of communication methods to inform the public and its stakeholders about progress in developing the GSP and information regarding opportunities to engage in the process. The primary methods of communication are discussed below.

4.3.4.1 Informational Documents

As part of the public outreach campaign, the Northern & Central Delta-Mendota Region GSP Group developed a series of informational flyers, brochures, FAQ sheets, and other handouts to educate the public about SGMA and the GSP development process. These documents were made available at public meetings and other events and posted on the GSP website. Copies of the informational documents are included in **Appendix C**.

4.3.4.2 Website

Following the submittal of the notice of the intent to develop a GSP, the Northern & Central Delta-Mendota GSP Group developed a website to serve as a primary means of posting and archiving GSP activities for public access and notice. The GSP website (http://deltamendota.org/learn-more/northern-central-delta-mendota-gsp/) was developed in conjunction with the website for the Delta-Mendota Subbasin as a whole (http://deltamendota.org/).

This website includes five key components. First, the website hosts a variety of SGMA informational material for stakeholders interested in learning more about SGMA and the GSP, including links to DWR informational websites as well as FAQs about the Delta-Mendota Subbasin, Northern and Central Delta-Mendota Regions, and GSAs. Second, the GSP website was used to post information about upcoming public workshops and to house materials from previous public events. Third, the website hosts monthly newsletters documenting progress on the GSP effort. Fourth, the website included a link to sign up for the stakeholder distribution list. Finally, the website was used to share agenda and meeting minutes from various committee meetings held during GSP development and to post public drafts of GSP chapters and to solicit feedback.

4.3.4.3 Email List

As discussed in **Section 4.3.1.1**, a stakeholder list was developed and updated throughout GSP development. The email list was used to provide announcements related to GSP events and actions, such as upcoming public workshops or the posting of new public draft GSP chapters for comment. The final stakeholder contact list is included in **Appendix C**.

4.3.4.4 Newsletters

Monthly newsletters were prepared to provide stakeholders with a brief update regarding recent GSP development actions and upcoming milestones. The newsletters were developed in collaboration with the five (5) other GSP groups in the Delta-Mendota Subbasin. The newsletters were posted to GSP group websites as well as sent via email to the stakeholder list.

4.3.4.5 Public Workshops

Public workshops served as the primary method for disseminating information and directly involving the public in the GSP development process. The four sets of public workshops (listed in **Table 4-2**) provided stakeholders with a chance to engage with the GSP project team and other stakeholders. Stakeholders were provided with an overview of SGMA and GSP milestones and the status of the GSP development while being given an opportunity to provide feedback on the work being presented.

4.3.4.6 Other Outreach Efforts

In addition to the use of the GSP website, emails, newsletters, and public workshops, the Northern and Central Delta-Mendota Regions' GSAs planned additional, targeted public information campaigns. The following is a list of the types of other outreach efforts undertaken by the Northern and Central Delta-Mendota Regions' GSAs:

- Inclusion of SGMA materials with IRWM outreach efforts
- GSA newsletter
- Flyer posting in public utility and government buildings
- Inclusion of flyers in utility bills
- Meetings with farmers in irrigation districts

A log of outreach activities conducted by the various GSAs is included in **Appendix C**.

Section 5

Basin Setting

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5. BASIN SETTING

5.1 OVERVIEW

The Basin Setting chapter to the Northern & Central Delta-Mendota Region Groundwater Sustainability Plan (GSP) contains information about the physical setting and hydrogeologic characteristics of the Northern and Central Delta-Mendota Regions, as well as current condition of the basin and anticipated future conditions. The basin setting serves as a basis for defining and assessing reasonable sustainable management criteria and projects and management actions. This chapter includes four main sections that are pursuant to the GSP Emergency Regulations Article 5. Plan Contents, Subarticle 2. Basin Setting (§ 354.12 – 354.20):

- **Hydrogeologic Conceptual Model (HCM)** – The HCM section (**Section 5.2**) provides the geologic and hydrogeologic information needed to understand how water moves throughout the Plan area and the Delta-Mendota Subbasin. This section includes information about geological formations, aquifers, structural features, and topography.
- **Groundwater Conditions** – The Groundwater Conditions section (**Section 5.3**) describes historical groundwater conditions in the Plan area, including data from January 1, 2015 to recent conditions. Groundwater trends, groundwater levels, hydrographs, contour maps, estimated change in groundwater storage, groundwater quality issues, land subsidence, and interconnected surface water systems over historical conditions through present day are presented in this section.
- **Water Budget** – The Water Budget section (**Section 5.4**) describes the data used to develop the required historic water budget, current water budget, and projected water budgets. This section also discusses the methods used in developing estimates for each water budget scenario. Sustainable yield is also described in this section.

5.2 HYDROGEOLOGIC CONCEPTUAL MODEL

This section describes the hydrogeologic conceptual model (HCM) for the Delta-Mendota Subbasin primarily as a whole based on technical studies and qualified maps that characterize the physical components and interaction of the surface water and groundwater systems, pursuant to Article 5 Plan Contents, Subarticle 2 Basin Setting, § 354.14 Hydrogeologic Conceptual Model of the Groundwater Sustainability Plan (GSP) Emergency Regulations. The physical description of the Delta-Mendota Subbasin included in this section is based on information originally published in the *Western San Joaquin River Watershed Groundwater Quality Assessment Report* (GAR) (Luhdorff & Scalmanini, 2015), *Grassland Drainage Area Groundwater Quality Assessment Report* (Luhdorff & Scalmanini, 2016), and *Groundwater Overdraft in the Delta-Mendota Subbasin* (Schmidt, 2015).

The Northern and Central Delta-Mendota Regions generally include the northern quarter of the Subbasin, the western margin of the central portion of the Subbasin (including the larger portion of the Subbasin near the southwestern boundary and within San Benito County), and the southern tip of the Subbasin (in the Tranquillity area). Due to the disperse nature of the areas covered by this GSP, the HCM presented below has been prepared predominantly on a Subbasin level.

5.2.1 Regional Geologic and Structural Setting

The Delta-Mendota Subbasin is located in the northwestern portion of the San Joaquin Valley Groundwater Basin within the southern portion of the Central Valley (**Figure 5-1**). The San Joaquin Valley is a structural trough up to 200 miles long and 70 miles wide filled with up to 32,000 feet of marine and continental sediments deposited during periodic inundation by the Pacific Ocean and by erosion of the surrounding Sierra Nevada and Coast Range mountains, respectively (DWR, 2006). Continental deposits shed from the surrounding mountains form an alluvial wedge that thickens from the valley margins toward the axis of the structural trough. This depositional axis is slightly west of the series of rivers, lakes, sloughs, and marshes which mark the current and historic axis of surface drainage in the San Joaquin Valley.

The Delta-Mendota Subbasin (California Department of Water Resources [DWR] Basin No. 5-22.07) is bounded on the west by the tertiary and older marine sediments of the Coast Ranges, on the north generally by the San Joaquin-Stanislaus County line, on the east generally by the San Joaquin River and Fresno Slough, and on the south by the Tranquillity Irrigation District boundary near the community of San Joaquin. Surface waters culminate from the Fresno, Merced, Tuolumne, and Stanislaus Rivers into the San Joaquin River, which drains toward the Sacramento-San Joaquin Delta.

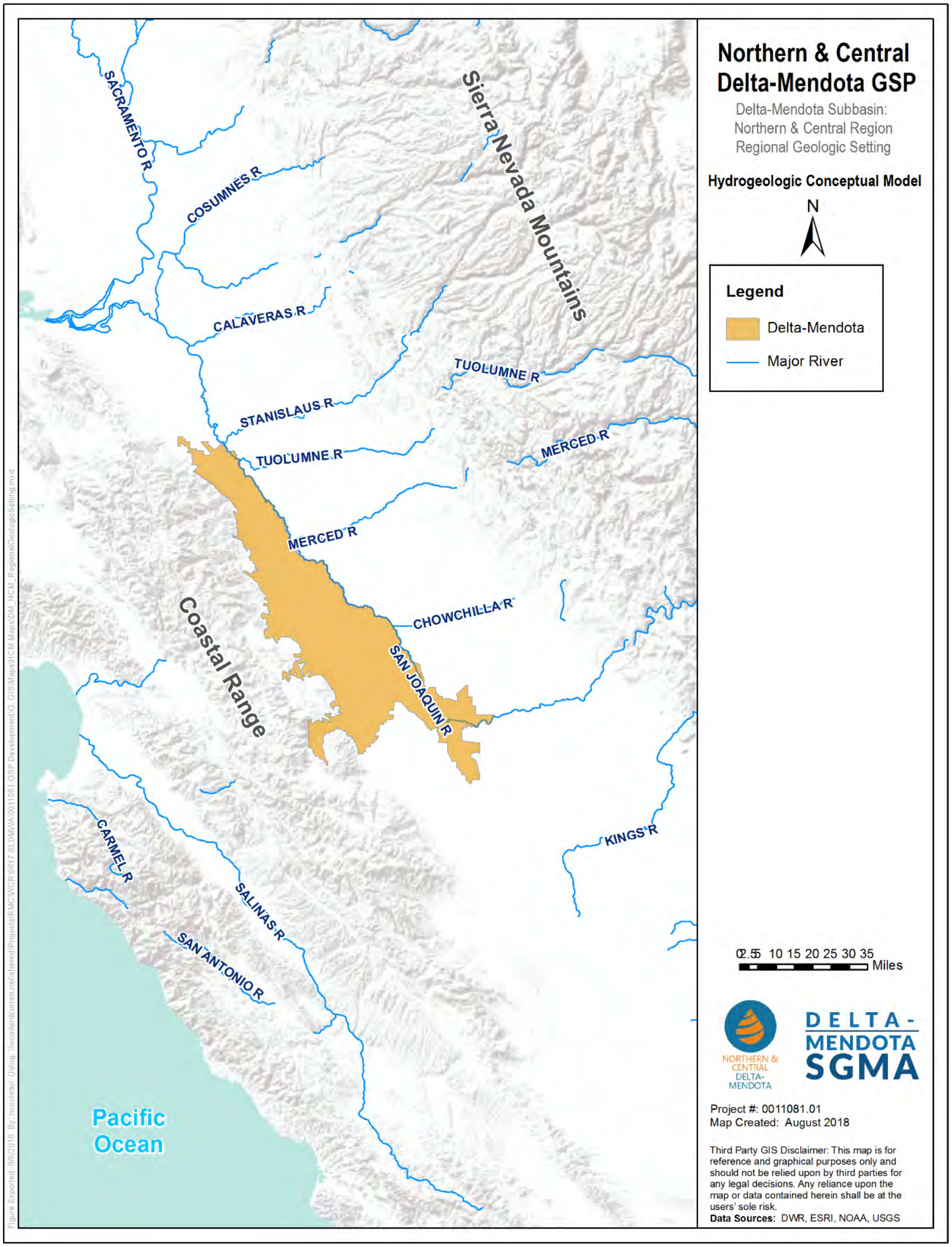

Figure 5-1. Regional Geologic Setting, Delta-Mendota Subbasin

5.2.2 Geologic History

Approximately three million years ago, tectonic movement of the Oceanic and Continental plates associated with the San Andreas Fault system gave rise to the Coast Range which sealed off the Central Valley from the Pacific Ocean (LSCE, 2015). As this occurred, the floor of the San Joaquin Valley began to transition from a marine depositional environment to a freshwater system with ancestral rivers bringing alluvium to saltwater bodies (Mendenhall et al., 1916). The Coast Ranges on the western side of the San Joaquin Valley consist mostly of complexly folded and faulted consolidated marine and non-marine sedimentary and crystalline rocks ranging from Jurassic to Tertiary age (**Figure 5-2**), dipping eastward and overlying the basement complex in the region (Croft, 1972; Hotchkiss and Balding, 1971). The Central Valley Floor within the Delta-Mendota Subbasin consists of Tertiary and Quaternary-aged alluvial and basin fill deposits (**Figure 5-2** and **Figure 5-3**). The fill deposits mapped throughout much of the valley extend vertically for thousands of feet, and the texture of sediments varies in the east-west direction across the valley. Coalescing alluvial fans have formed along the sides of the valley created by the continuous shifting of distributary stream channels over time. This process has led to the development of thick fans of generally coarse texture along the margins of the valley and a generally fining texture towards the axis of the valley (Faunt et al., 2009 and 2010).

Deposits of Coast Range and Sierra Nevada sources interfinger within the Delta-Mendota Subbasin. Steeper fan surfaces, with slopes as high as 80 feet per mile, exist proximal to the Coast Range, whereas more distal fan surfaces consist of more gentle slopes of 20 feet per mile (Hotchkiss and Balding, 1971). In contrast to the east side of the valley, the more irregular and ephemeral streams on the western side of the valley floor have less energy and transport smaller volumes of sediment resulting in less developed alluvial features, including alluvial fans, which are less extensive, although steeper, than alluvial fan features on the east side of the valley (Bertoldi et al., 1991). Lacustrine and floodplain deposits also exist closer to the valley axis as thick silt and clay layers. Lakes present during the Pleistocene epoch in parts of the San Joaquin Valley deposited great thicknesses of clay sediments.

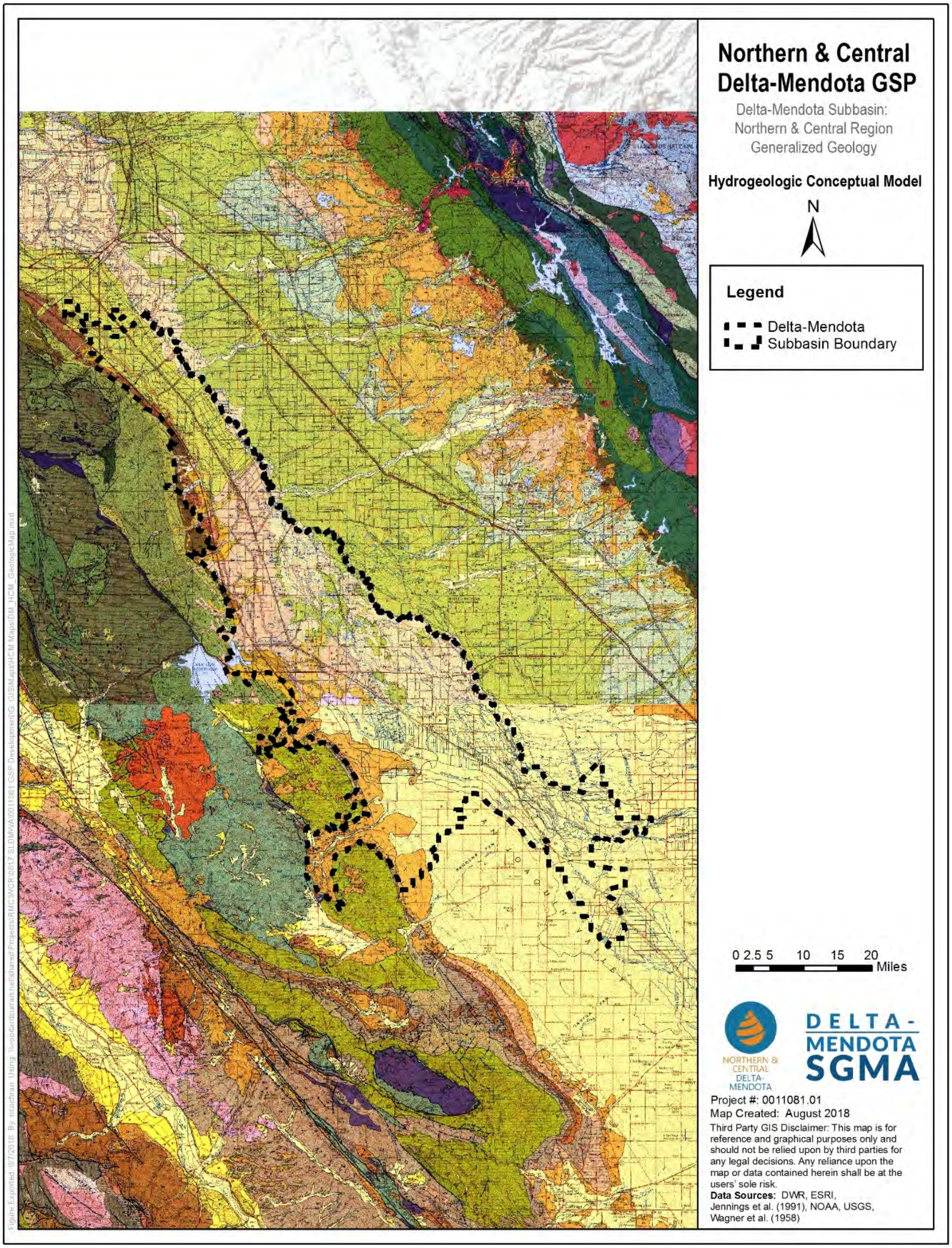

Figure 5-2. Geologic Map, Delta-Mendota Subbasin

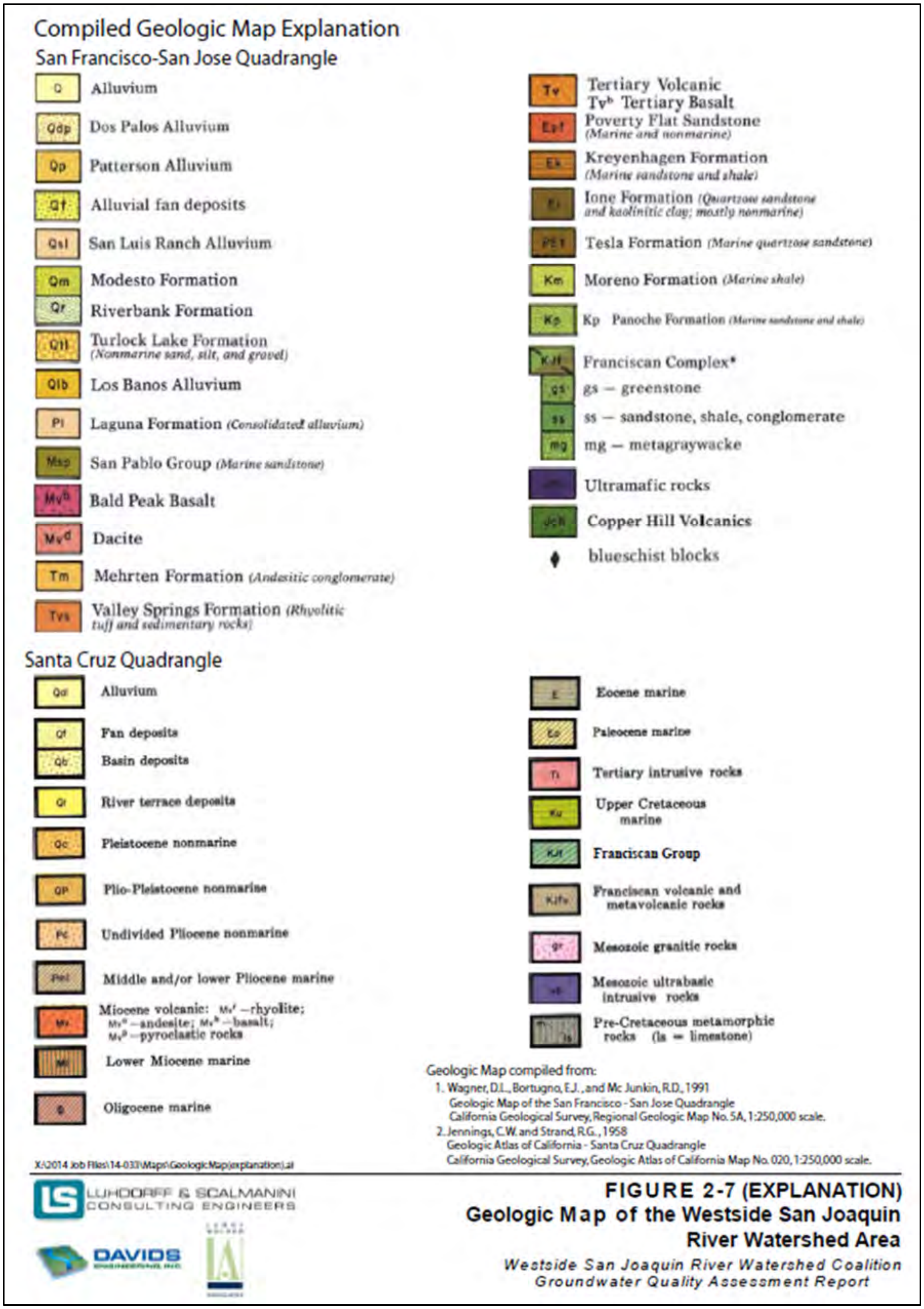

Figure 5-2. Geologic Map, Delta-Mendota Subbasin (continued)

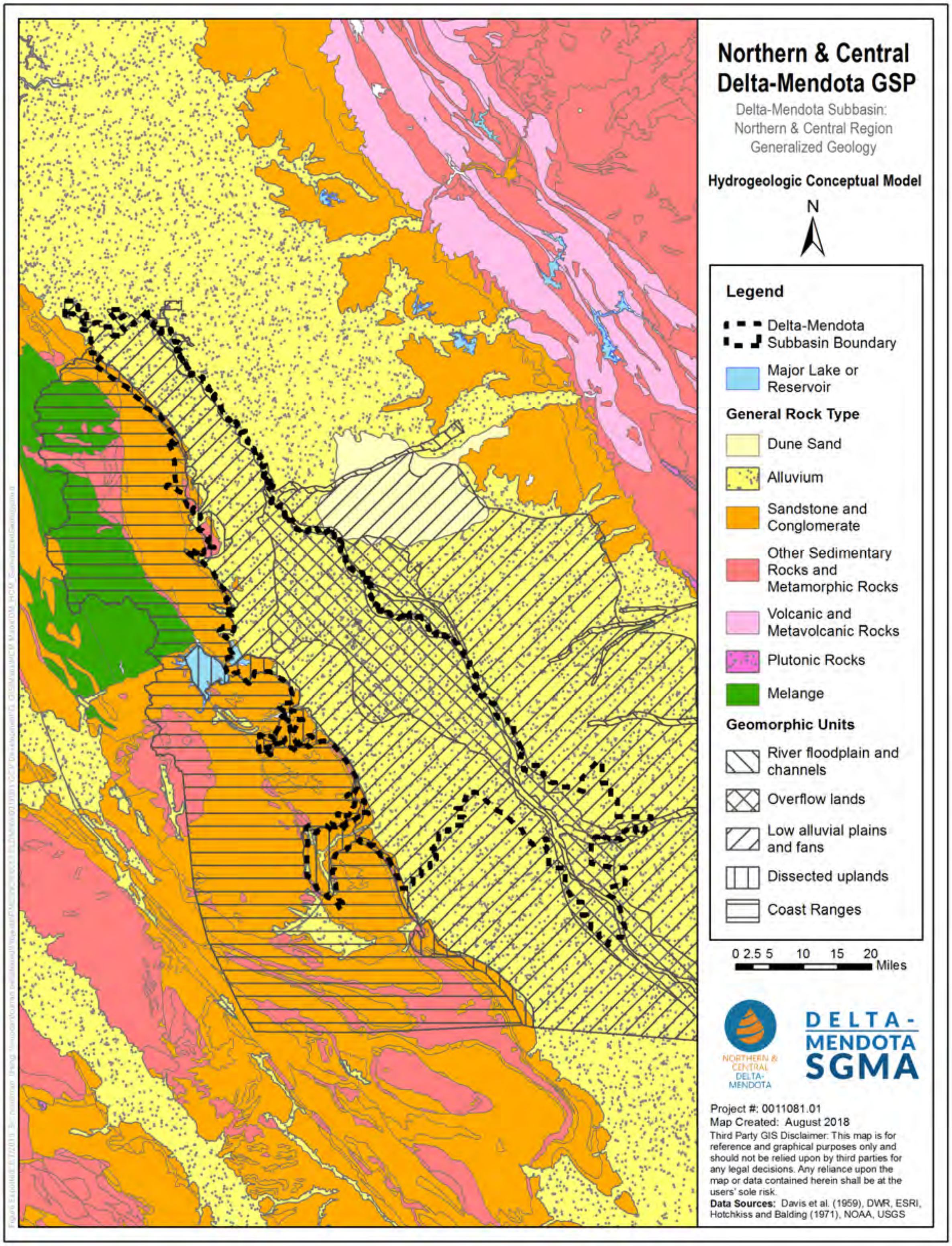

Figure 5-3. Generalized Geology, Delta-Mendota Subbasin

5.2.3 Geologic Formations and Stratigraphy

Distinct geomorphic units exist within the Delta-Mendota Subbasin, defining areas of unique hydrogeologic environments. The geomorphic units are mapped and described by Hotchkiss and Balding (1971) and Davis et al. (1959) and are shown in **Figure 5-3**. The two primary geomorphic units within the Central Valley Floor area of the Delta-Mendota Subbasin include the overflow lands geomorphic unit and the alluvial fans and plains geomorphic unit. Overflow lands are defined as areas of relatively poorly draining soils with a shallow water table. The overflow lands geomorphic unit is located in the southeastern portion of the Subbasin and is dominated by finer-grained floodplain deposits that are the result of historical episodic flooding of this low-land area. This has formed poorly draining soils with generally low hydraulic conductivity characteristics. In contrast, the alluvial fans and plains geomorphic unit is characterized by relatively better drainage conditions, with sediments comprised of coalescing and somewhat coarser-grained alluvial fan materials deposited by higher-energy streams flowing out of the Coast Range (Hotchkiss and Balding, 1971). The alluvial fans and plains geomorphic unit covers much of the Delta-Mendota Subbasin along the western margins of the Central Valley Floor at the base of the Coast Range.

The primary groundwater bearing units within the Delta-Mendota Subbasin consist of Tertiary and Quaternary-aged unconsolidated continental deposits and older alluvium of the Tulare Formation. Subsurface hydrogeologic materials covering the Central Valley Floor consist of lenticular and generally poorly sorted clay, silt, sand, and gravel that make up the alluvium and Tulare Formation. These deposits are thickest along the axis of the valley with thinning along the margins towards the Coast Range mountains (DWR, 2003; Hotchkiss and Balding, 1971). A zone of very shallow groundwater, generally within 25 feet of the ground surface, exists throughout large areas of the Subbasin, with considerable amounts (greater than 50 percent) of farmland in the area estimated to have very shallow depths to groundwater of less than 10 feet (Hotchkiss and Balding, 1971). Many of these areas are naturally swampy lands adjacent to the San Joaquin River.

The Tulare Formation extends to several thousand feet deep and to the base of freshwater throughout most of the area and consists of interfingered sediments ranging in texture from clay to gravel of both Sierra Nevadan and Coast Range origin. The formation is composed of beds, lenses, and tongues of clay, sand, and gravel that have been alternatively deposited in oxidizing and reducing environments (Hotchkiss and Balding, 1971). Terrace deposits of Pleistocene age lie up to several feet higher than present streambeds and are comprised of yellow, tan, and light-to-dark brown silt, sand, and gravel with a matrix that varies from sand to clay (Hotchkiss and Balding, 1971). The water table generally lies below the bottom of the terrace deposits; however, the relatively large grain size of the terrace deposits suggests their value as possible recharge sites. Alluvium is composed of interbedded, poorly to well-sorted clay, silt, sand, and gravel and is divided based on its degree of dissection and soil formation. The flood-basin deposits are generally composed of light-to-dark brown and gray clay, silt, sand, and organic material with locally high concentrations of salt and alkali. Stream channel deposits of coarse sand and gravel are also included.

The Tulare Formation also includes the Corcoran Clay (E-Clay) member, a diatomaceous clay or silty clay of lake bed origin which is a prominent aquitard in the San Joaquin Valley, separating the upper zone from the lower zone and distinguishing the semi-confined Upper Aquifer from the confined Lower Aquifer (Hotchkiss and Balding, 1971). However, the depth and thickness of the Corcoran Clay are variable within the Central Valley Floor, and it is not present in peripheral areas (outside the Central Valley Floor) of the Subbasin. Within the Upper Aquifer, additional clay layers exist within the upper zone and also provide varying degrees of confinement, including other clay members of the Tulare Formation and layers of white clay identified by Hotchkiss and Balding (1971). These clays are variable in extent and thickness, but the white clay is noted to be as much as 100 feet thick in areas providing very effective confinement of underlying zones (Croft, 1972; Hotchkiss and Balding, 1971). The Tulare Formation is hydrologically the most important geologic formation in the Delta-Mendota Subbasin because it contains most of the fresh water-bearing deposits. Most of the natural recharge that occurs in the Subbasin is in the alluvial fan apex areas along Coast Range stream channels (Hotchkiss and Balding, 1971).

5.2.4 Faults and Structural Features

The valley floor portion of the Delta-Mendota Subbasin contains no major faults and is fairly geologically inactive. There are few faults along the western boundary of the Subbasin within the Coast Range mountains, but they are not known to inhibit groundwater flow or impact water conveyance infrastructure (**Figure 5-4**).

5.2.5 Basin Boundaries

The Delta-Mendota Subbasin is defined by both geological and jurisdictional boundaries. The Delta-Mendota Subbasin borders all subbasins within the San Joaquin Valley Groundwater Basin with the exception of the Cosumnes Subbasin (**Figure 5-5**). The following subsections describe the lateral boundaries of the Subbasin, boundaries with neighboring subbasins, and the definable bottom of the Delta-Mendota Subbasin.

5.2.5.1 Lateral Boundaries

The Delta-Mendota Subbasin is geologically and topographically bounded to the west by the Tertiary and older marine sediments of the Coast Ranges, and to the east generally by the San Joaquin River. The northern, central, and southern portion of the eastern boundary are dictated by jurisdictional boundaries of water purveyors within the Delta-Mendota Subbasin.

The northern boundary (from west to east) of the Delta-Mendota Subbasin begins on the west by following the Stanislaus County/San Joaquin County line, then deviates to the north to encapsulate all of the Del Puerto Water District before returning back to the Stanislaus County/San Joaquin County line. The boundary continues east, and then deviates north again to encapsulate all of the West Stanislaus Irrigation District before returning back to the Stanislaus County/San Joaquin County line. The boundary continues to follow the Stanislaus County/San Joaquin County line east until it intersects with the San Joaquin River.

The southern boundary of the Subbasin (from east to west) matches the northerly boundaries of the Westlands Water District legal jurisdictional boundary as last revised in 2006. The boundary then proceeds west along the southernmost boundary of San Luis Water District. The boundary projects westward from this alignment until intersecting the Delta-Mendota Subbasin western boundary delineated by the extent of the Tertiary and older marine sediments.

The eastern boundary (from north to south) follows the San Joaquin River to within Township 11S, where it jogs eastward along the northern boundary of Columbia Canal Company. From there, the boundary continues along the eastern boundary of Columbia Canal Company until intersecting the northern boundary of the Aliso Water District. The boundary then heads east following the northern and then eastern boundary of the Aliso Water District until intersecting the Madera County/Fresno County line. The boundary then heads westerly following the Madera County/Fresno County line to the eastern boundary of the Farmers Water District. The boundary then continues southerly along the eastern boundary of the Farmers Water District and then southerly along the section line to the intersection with the railway lines. The boundary then heads east along the railway line until intersecting with the western boundary of the Mid-Valley Water District. The boundary then heads south along the western boundary of the Mid-Valley Water District to the intersection with the northern boundary of Reclamation District 1606. From there, the boundary heads west and then south following the boundary of Reclamation District 1606 and James Irrigation District until its intersection with the Westlands Water District boundary.

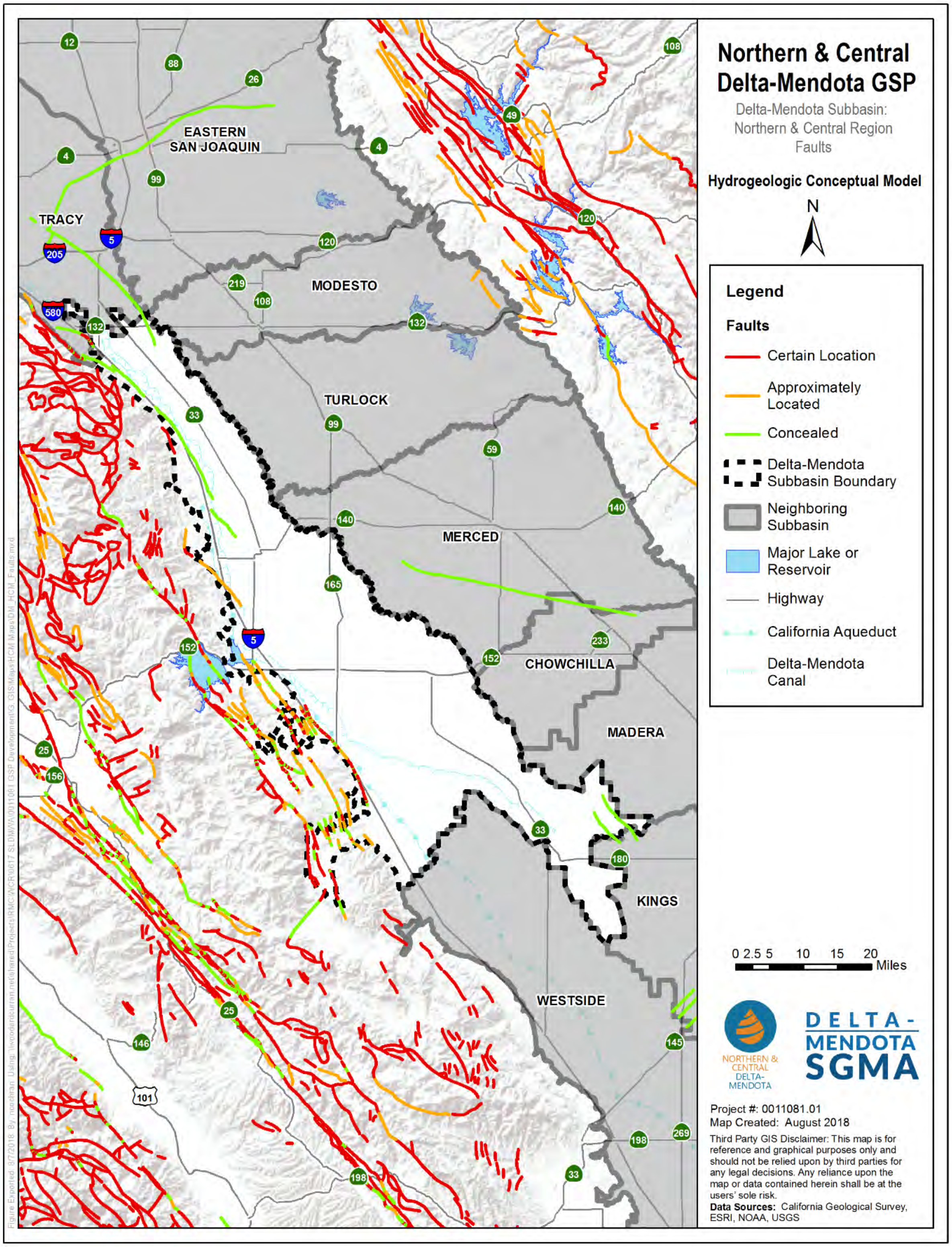

Figure 5-4. Faults, Delta-Mendota Subbasin

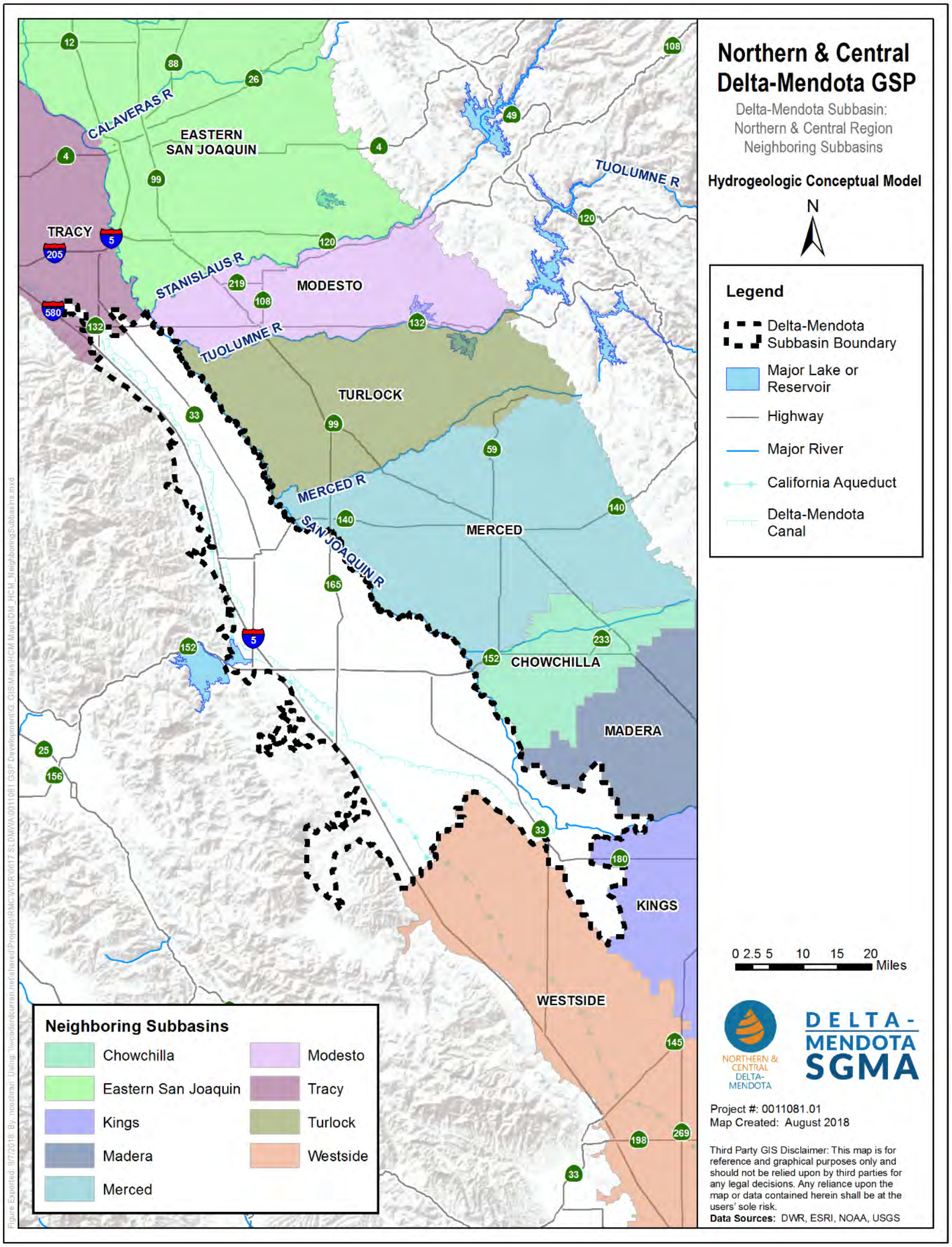

Figure 5-5. Neighboring Subbasins, San Joaquin Valley Groundwater Basin

5.2.5.2 Definable Bottom of Basin

In the San Joaquin Valley, the bottom of the Delta-Mendota Subbasin is typically defined as the interface of saline water of marine origin within the uppermost beds of the San Joaquin Formation. The San Joaquin Formation is characterized by blue and green fine-grained rocks and principally composed of fine-grained silty sands, silt, and clay (Foss and Blaisdell 1968). The San Joaquin Formation is predominantly marine in origin and is considered late Pliocene and possibly early Pleistocene in age. This formation is the upper shaley part of the Pliocene sequence. The top of the San Joaquin Formation is generally encountered around -2,000 feet above mean sea level throughout the Delta-Mendota Subbasin. For the purposes of this GSP, the base of freshwater is defined by a total dissolved solids (TDS) concentration of 3,000 micromhos per centimeter at 25 °C (or about 2,000 mg/L), as presented by Page (1973).

5.2.6 Principal Aquifers and Aquitards

DWR's Groundwater Glossary defines an aquifer as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells, and springs". There are two primary aquifers within the Delta-Mendota Subbasin: a semi-confined aquifer above the Corcoran Clay and a confined aquifer below the Corcoran Clay, with the Corcoran Clay acting as the principal aquitard within the Delta-Mendota Subbasin. **Figure 5-6** shows the locations of the representative cross-sections for the Northern & Central Delta-Mendota Region GSP Plan area, where **Figure 5-7** through **Figure 5-16** show the hydrostratigraphy of the representative cross-sections.

While the two-aquifer system described above is generally true across the Delta-Mendota Subbasin, there are portions of the basin where the Corcoran Clay does not exist (predominantly along the western margin of the Subbasin) and hydrogeology is generally controlled by localized interfingering clays, and/or where local hydrostratigraphy results in shallow groundwater conditions that differ, to some extent, from that seen in the Subbasin as a whole. Additionally, in the southern portion of the Subbasin in the Mendota and Tranquillity areas, there are A and C Clay layers in addition to the Corcoran Clay that inhibit groundwater flow. However, while there are localized complexities throughout the Subbasin, the Corcoran Clay (or E Clay) extends through much of the Delta-Mendota Subbasin generally creating a two-aquifer system.

5.2.6.1 Principal Aquifers

In the Delta-Mendota Subbasin, there are two primary aquifers composed of alluvial deposits separated by the Corcoran Clay (Schmidt, 2015): a semi-confined Upper Aquifer zone (generally the ground surface to the top of the Corcoran Clay), and a confined Lower Aquifer zone starting at the bottom of the Corcoran Clay to the base of fresh water. However, as previously described, the localized presence of the A and C Clay layers in the southern portion of the Subbasin, the absence of the Corcoran Clay at the western margin of the Subbasin and/or local hydrostratigraphy result in differing shallow groundwater conditions and/or perched groundwater conditions in some portions of the Subbasin. To this end, in addition the descriptions of the two principal aquifers in the Delta-Mendota Subbasin, a description of 'Very Shallow Unconfined Groundwater' is also provided for those portions of the basin where such conditions are present.

<u>Upper Aquifer</u>

The Upper Aquifer is represented by materials extending from the upper groundwater table to the top of the Corcoran Clay. The Upper Aquifer includes shallow geologic units of younger and older alluvium and upper parts of the Tulare Formation. Sediments within the upper Tulare Formation have variable sources and subdivision of units can be distinguished between eastern and western sourced materials. Alluvial fan materials above the Corcoran Clay in the Delta-Mendota Subbasin are generally more extensive than older alluvial fan deposits within the Tulare Formation below the Corcoran Clay. As shown in **Figure 5-17** by the depth to the top of the Corcoran Clay, the Upper Aquifer extends to depths ranging between approximately 150 feet and greater than 350 feet. Other notable mapped clay units also exist within the upper part of the Tulare Formation in the Delta-Mendota Subbasin, including the A and C Clay members of the Tulare Formation and a white clay mapped by Hotchkiss and Balding (1971).

The A and C Clay occur near the Mendota and Tranquillity areas in the southeastern portion of the Delta-Mendota Subbasin. The mapped extent and elevation of the A and C Clay layers, as presented by Croft (1972) and Hotchkiss and Balding (1971), are shown in **Figure 5-19** indicating areas where considerable barriers to vertical groundwater movement within the Upper Aquifer are known to exist. As shown in **Figure 5-19,** the extent and thickness of both the A and C Clays are somewhat uncertain, although they have been mapped to exist in the general area of Mendota. The A Clay occurs at elevations ranging from about 100 to 160 feet above mean sea level, corresponding to depths of generally between 100 and 200 feet below the ground surface. The deeper C Clay exists at correspondingly lower elevations from between 20 to 100 feet above mean sea level (**Figure 5-19**).

A traceable continuous white clay layer, mapped by Hotchkiss and Balding (1971), exists within the northern part of the Delta-Mendota Subbasin in the vicinity and north of Patterson. This layer ranges in thickness from 30 to 60 feet at depths between 100 and 200 feet below grade and is an effective confining layer in many areas. Although not explicitly mapped, less extensive and unmapped clay units within the Upper Aquifer also exist in other parts of the Subbasin.

<u>Lower Aquifer</u>

The Lower Aquifer is the portion of the Tulare Formation that is confined beneath the Corcoran Clay, extending downward to the underlying San Joaquin Formation and the interface of saline water of marine origin within its uppermost beds. The Lower Aquifer is generally characterized by groundwater that tends to be dominantly sodium-sulfate type, which is often of better quality than the Upper Aquifer (Davis et al., 1957; Hotchkiss and Balding, 1971). Exceptions to this quality do exist in the Subbasin, particularly in the southwestern portion of the Subbasin. Because of its relatively shallow depth within the Delta-Mendota Subbasin and lower salinity in areas when compared to other groundwater resources, the Lower Aquifer is heavily utilized as a source of groundwater for agricultural and drinking water uses within the Subbasin, where groundwater is beyond suitable for these uses in some areas.

The base of the Lower Aquifer generally decreases from south to north, changing in depth from about 1,100 to 1,200 feet deep in the south to about 600 feet to the north. Depth to the top of the Corcoran Clay ranges from less than 100 feet on the west near Interstate 5 (I-5) to more than 500 feet in the area near Tranquillity. The Corcoran Clay pinches out or is above the water level near the California Aqueduct in the western part of the Subbasin, where the Upper and Lower Aquifers merge into interfingered layers of sand, gravel, and clay.

<u>Corcoran Clay</u>

The Corcoran Clay, as a regional aquitard, is a notable hydrogeologic feature throughout most of the Delta-Mendota Subbasin, impeding vertical flow between the Upper and Lower Aquifers. The Corcoran Clay is present at varying depths across most of the Central Valley floor (**Figure 5-17** and **Figure 5-18**). The depths to the top of the Corcoran Clay ranges between approximately 150 and 500 feet below the ground surface throughout most of the Subbasin, with a general spatial pattern of deepening to the south and east. In the far southeastern area of the Subbasin, in the vicinity of Mendota and Tranquillity, the top of the Corcoran Clay is at depths of greater than 350 feet (**Figure 5-17**). The thickness of the Corcoran Clay, which likely influences the degree of hydraulic separation between the Upper and Lower Aquifers, is greater than 50 feet across most of the Delta-Mendota Subbasin with thicknesses of more than 75 feet in central Subbasin areas in the vicinity of Los Banos and Dos Palos, and 140 feet in the eastern portions of the Subbasin. The Corcoran Clay appears thinner in areas north of Patterson, between Patterson and Gustine, and also in the vicinity of Tranquillity to the south (**Figure 5-18**). Along the westernmost portions of the Delta-Mendota Subbasin, the Corcoran Clay layer is generally non-existent or is exists as Corcoran-equivalent clays (clays existing at the same approximate depth but not part of the mapped aquitard) (**Figure 5-17** and **Figure 5-18**).

Very Shallow Unconfined Groundwater

Floodplain deposits along the eastern side of the Subbasin, and the associated poorly-drained soils, cause naturally percolating water and applied irrigation water to build up in the very shallow zone. Shallow groundwater stagnation (where soils remain saturated within about 5 feet of the land surface) can increase salt accumulation in shallow soils and groundwater resulting from evaporation occurring directly from the water table (Corwin, 2012). The increased presence of the fine-grained floodplain deposits towards the Central Valley axis on the eastern side of the Delta-Mendota Subbasin results in low-permeability shallow soils that restrict the percolation of water, creating very shallow groundwater commonly within 25 feet of the ground surface. The combined effect of the many very shallow fine-grained lenses impeding vertical flow, especially in the distal fan and floodplain areas closer to the valley axis, can be great and represent a more substantial barrier to vertical movement of water (Bertoldi et al., 1991).

Tile drains are typically used in the eastern and southern portions of the Delta-Mendota Subbasin within the zone of Very Shallow Water (0 to 15 feet below ground surface) to manage impacts of shallow groundwater on the root zone. If groundwater within the semi-confined Upper Aquifer rises into the Very Shallow Water zone, tile drains can intercept and route such groundwater to sump pumps for removal via surface drainage networks. Further, it should be noted that some tile drains are likely within perched water zones that are not connected to the principal aquifers. Because of the generally shallow nature and high salinity, very shallow groundwater is not used to provide a major supply of water for agricultural or drinking uses within the Subbasin, although some projects are being developed to reuse this water on more salt-tolerant crops.

5.2.6.2 Aquifer Properties

The following subsections include discussion of generalized aquifer properties within the Delta-Mendota Subbasin. These include hydraulic conductivity, transmissivity, specific yield and specific storage.

DWR defines hydraulic conductivity as the “measure of a rock or sediment’s ability to transmit water” and transmissivity as the “aquifer’s ability to transmit groundwater through its entire saturated thickness” (DWR, 2003). High hydraulic conductivity values correlate with areas of transmissive groundwater conditions with transmissivity generally equaling hydraulic conductivity times the saturated thickness of the formation. Storage of water within the aquifer system can be quantified in terms of the specific yield for unconfined groundwater flow and the storage coefficient for confined flow, respectively (Faunt et al., 2009). Specific yield represents gravity-driven dewatering of shallow, unconfined sediments at a declining water table, but also accommodates a rising water table. The specific yield is dimensionless and represents the volume of water released from or taken into storage per unit head change per unit area of the water table. Specific yield is a function of porosity and specific retention of the sediments in the zone of water-table fluctuation.

Where the aquifer system is confined, storage change is governed by the storage coefficient, which is the product of the thickness of the confined-flow system and its specific storage. The specific storage is the sum of two component specific storages – the fluid (water) specific storage and the matrix (skeletal) specific storage, which are governed by the compressibilities of the water and skeleton, respectively (Jacob, 1940). Specific storage has units of 1 over length and represents the volume of water released from or taken into storage in a confined flow system per unit change in head per unit volume of the confined flow system (Faunt et al., 2009). Therefore, the storage coefficient of a confined flow system is dimensionless and, similar to specific yield, represents the volume of water released from or taken into storage per unit head change.

5.2.6.2.1 Hydraulic Conductivity

Figure 5-20 shows the saturated C-horizon vertical hydraulic conductivity of surficial soils within the Delta-Mendota Subbasin based on the National Resource Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO). Soil survey data for counties within the Subbasin were combined using the weighted harmonic mean of these representative layers to depict the saturated hydraulic conductivity of the C-horizon for each soil map unit. The soil profile represented by these data is variable but commonly extends to a depth of 6 or more feet.

Floodplain deposits are evident as soils with relatively low hydraulic conductivity (less than 0.5 feet per day [ft/day]) blanketing much of the Central Valley Floor, although localized areas of soils with higher hydraulic conductivity are present in association with modern and ancient surface waterways and alluvial fan features (**Figure 5-20**). Coarse soils of distributary alluvial fan sediments deposited by Del Puerto Creek, Orestimba Creek, and Little Panoche Creek, in addition to other ephemeral northeasterly creek flows off the Coast Ranges, are notably apparent as areas of soils of high hydraulic conductivity located along active and inactive stream channels extending eastward from the fan apex areas along the Valley Floor margins to the current alignment of the San Joaquin River in the valley axis. Additionally, soils in areas adjacent to the active channel of the San Joaquin River also exhibit high hydraulic conductivities, including values of greater than 4 ft/day which are particularly apparent in an area north of Mendota. Soils of similarly high hydraulic conductivity trending as linear features in a general northwest-southeast alignment to the north of Dos Palos and Los Banos are likely the result of historical depositional processes and paleochannels associated with the San Joaquin River (**Figure 5-20**). In areas peripheral to the Central Valley floor, soils tend to be characterized by relatively low hydraulic conductivity, although soils of somewhat higher hydraulic conductivity associated with distinct geologic units are mapped across much of the peripheral area to the west of Patterson and Gustine and also in localized bands associated with surface water courses.

5.2.6.2.2 Transmissivity

Transmissivity varies greatly above the Corcoran Clay, within the Corcoran Clay, and below the Corcoran Clay within the Delta-Mendota Subbasin, with transmissivities in the confined Lower Aquifer generally being larger than those in the semi-confined Upper Aquifer. Based on testing conducted at multiple locations within both the Upper and Lower Aquifers of the Delta-Mendota Subbasin, average transmissivities in the Subbasin are approximately 109,000 gallons per day per square foot (gpd/ft^2) (SJRECWA, 2018).

5.2.6.2.3 Specific Yield

DWR defines specific yield as the “amount of water that would drain freely from rocks or sediments due to gravity and describes the proportion of groundwater that could actually be available for extraction” (DWR, 2003). Specific yield is a measurement specific to unconfined aquifers.

The estimated specific yield of the Delta-Mendota Subbasin is 0.118 (DWR, 2006). Within the southern portion of the Delta-Mendota Subbasin, specific yield ranges from 0.2 to 0.3 (Beltiz et al., 1993). Specific yield estimates for the Delta-Mendota Subbasin are fairly limited in literature since the Upper Aquifer above the Corcoran Clay is semi-confined and the Lower Aquifer below the Corcoran Clay is confined. Therefore, specific yield values only characterize the shallow, unconfined groundwater within the Subbasin.

5.2.6.2.4 Specific Storage

Values for specific storage were extracted from the Central Valley Hydrologic Model 2 (CVHM2), which is currently under development by the United States Geological Survey (USGS) and includes refinements for the Delta-Mendota Subbasin. Specific storage varies above, within, and below the Corcoran Clay with CVMH2. Above the Corcoran Clay, specific storage ranges from 1.34×10^{-6} to 6.46×10^{-2} meters^{-1} (m^{-1}) with average values ranging from 6.16×10^{-3} to 1.97×10^{-2} m^{-1}. Specific storage within the Corcoran Clay is considerably smaller than above the Corcoran Clay, ranging between 1.41×10^{-6} and 2.35×10^{-6} m^{-1} and average values between 1.96×10^{-6} and 2.02×10^{-6} m^{-1}. Below the Corcoran Clay, specific storage is comparable to within the Corcoran Clay with overall ranges the same as within the Corcoran Clay and average values ranging from 1.86×10^{-6} to 2.01×10^{-6} m^{-1}. Therefore, specific storage is greatest within the semi-confined aquifer overlying the Corcoran Clay layer, with considerably smaller specific storage values with the low permeability Corcoran Clay and confined aquifer underlying the Corcoran Clay layer.

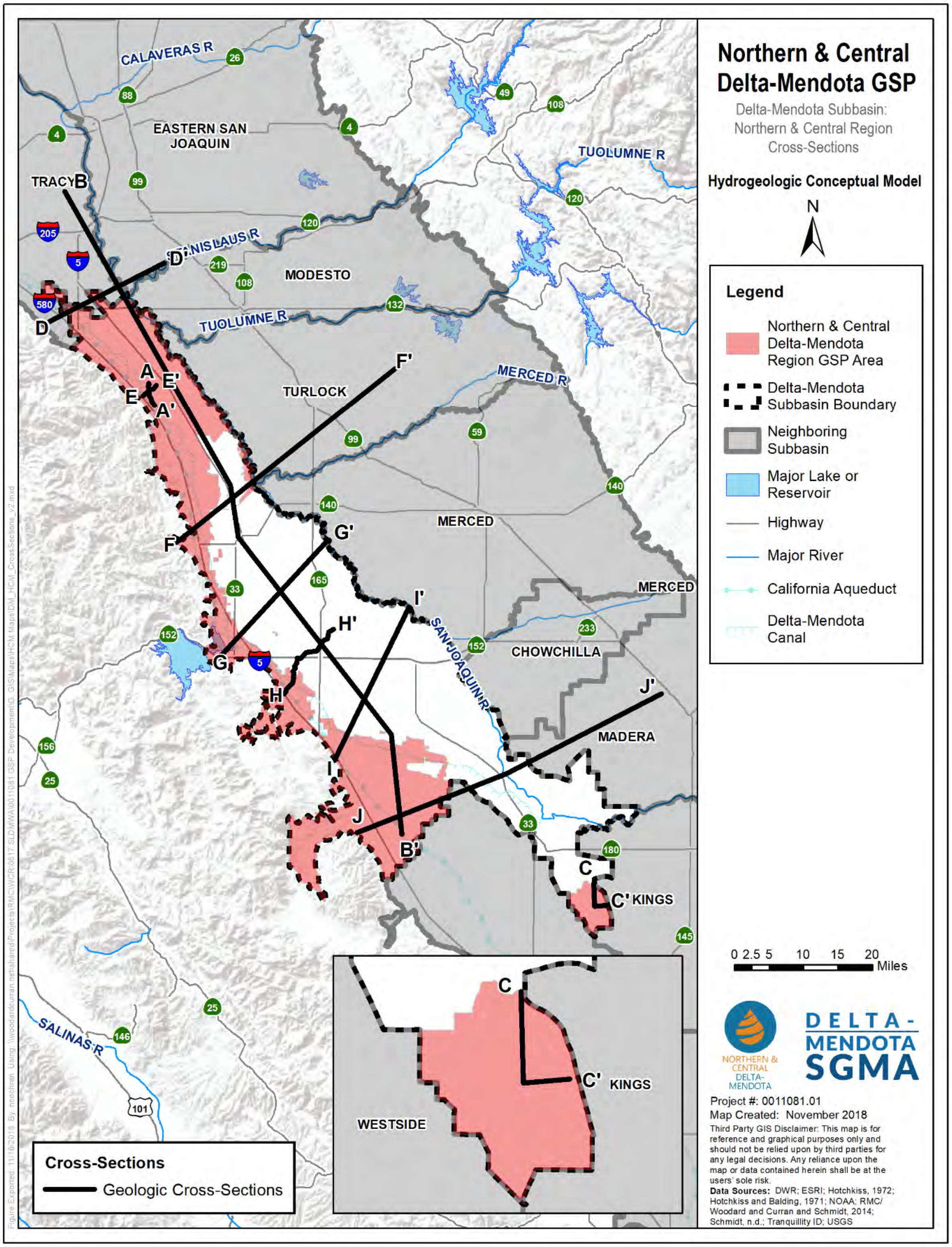

Figure 5-6. Representative Cross-Sections, Northern & Central Delta-Mendota Region GSP

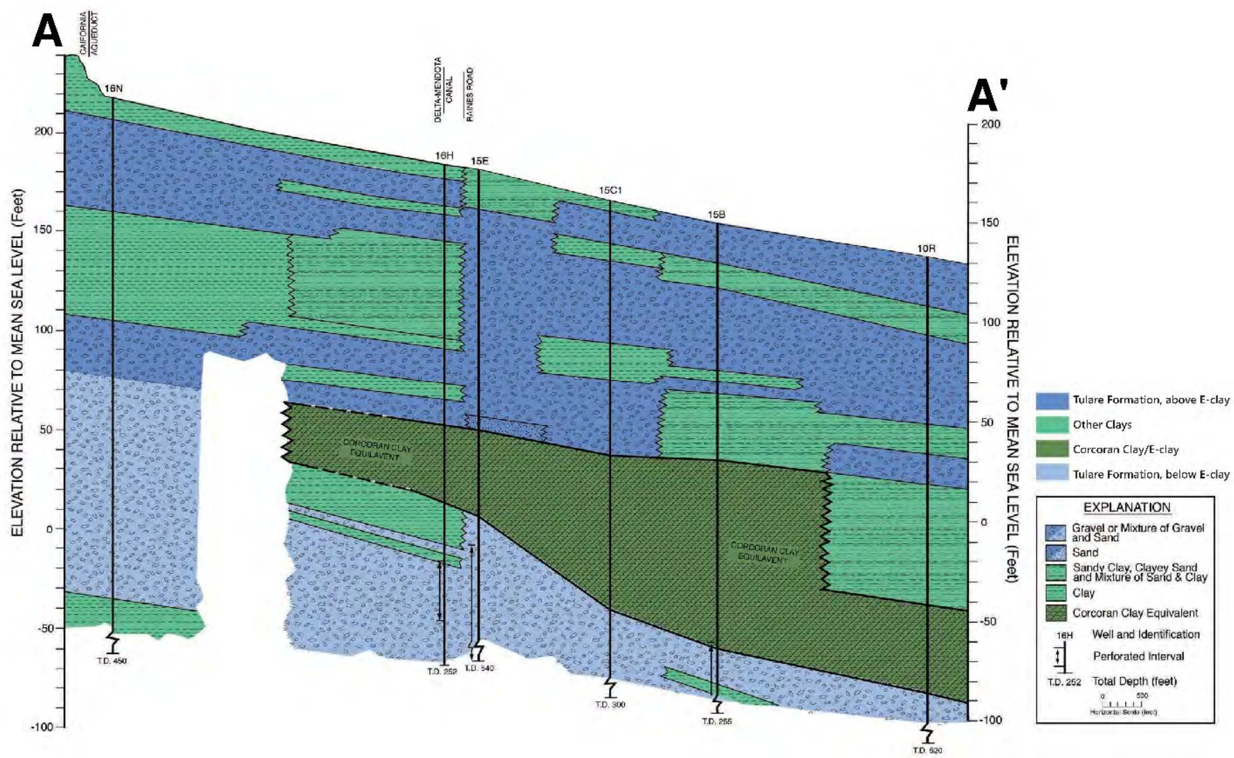

Figure 5-7. Cross-Section A-A' (RMC/W&C and Schmidt, 2014)

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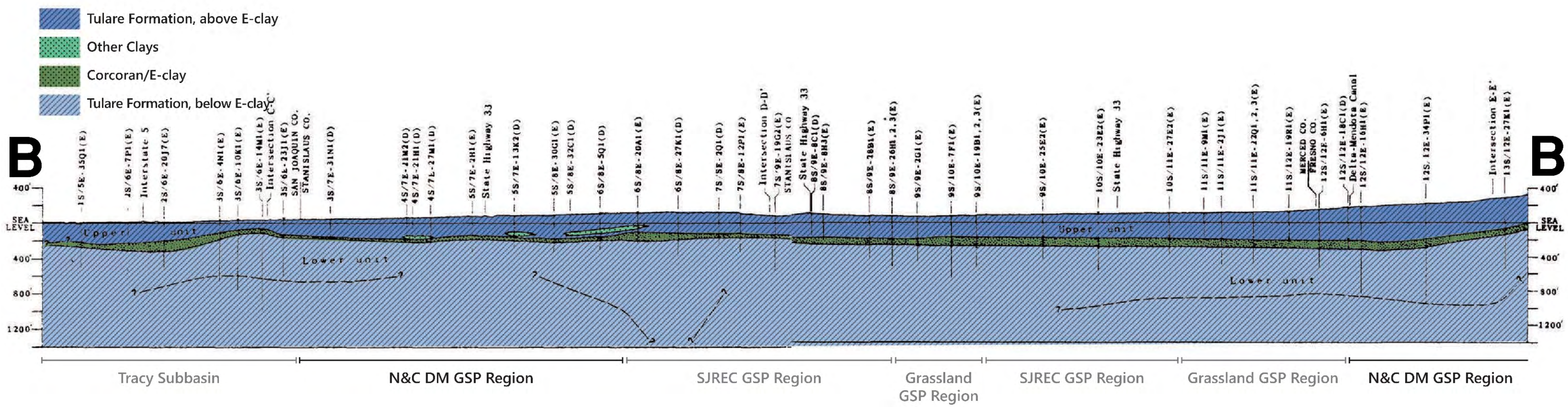

Figure 5-8. Cross-Section B-B' (Hotchkiss, 1972)

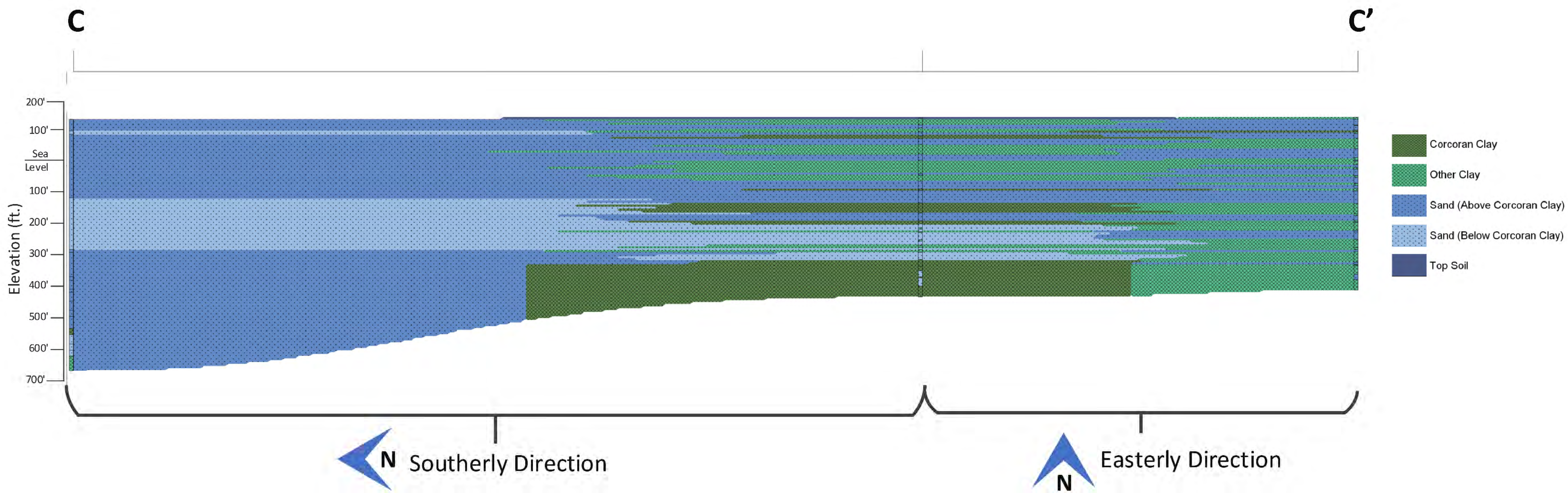

Figure 5-9. Cross-Section C-C' (Tranquillity ID, 1994 and 2000 and LSCE, 2011)

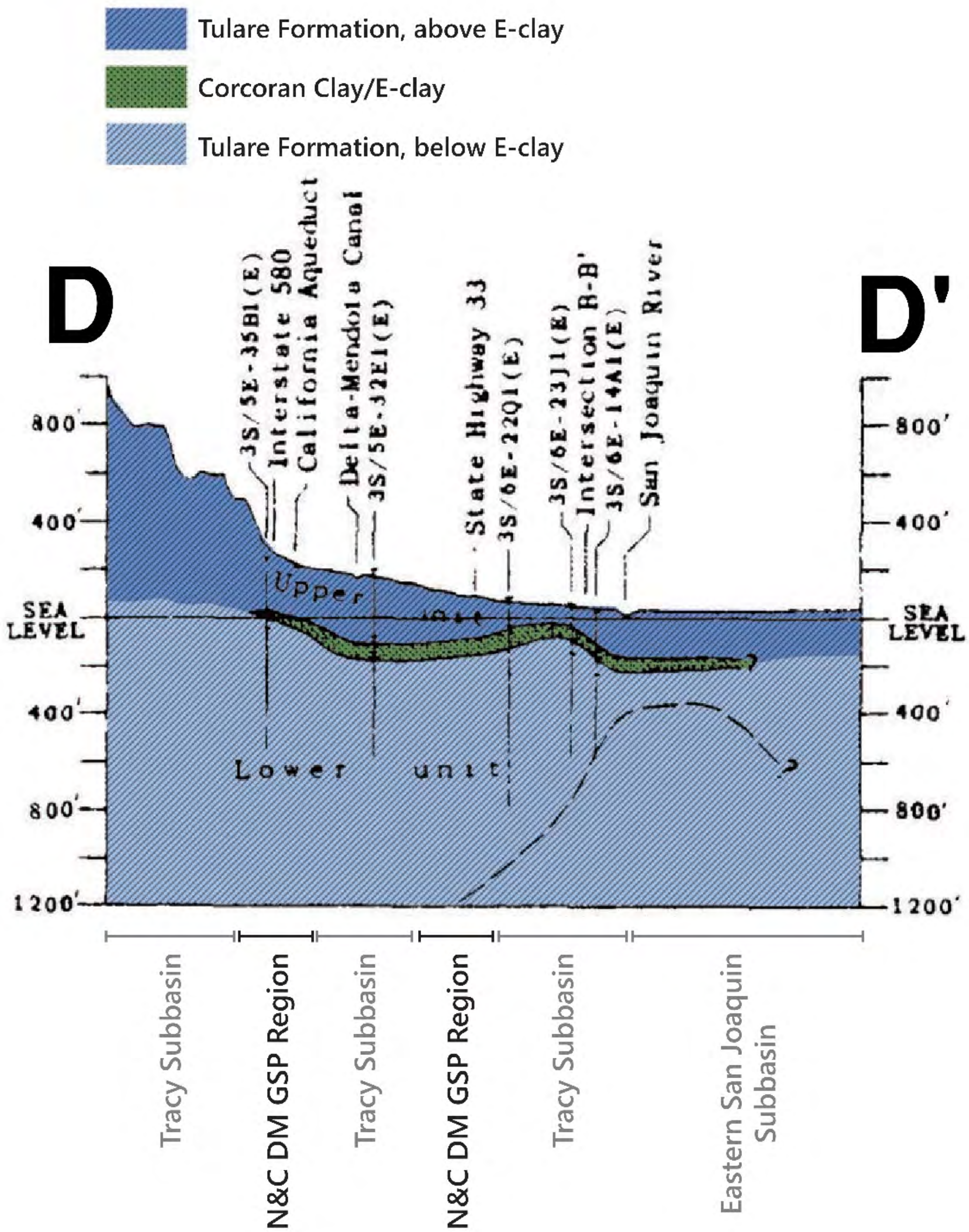

Figure 5-10. Cross-Section D-D' (Hotchkiss, 1972)

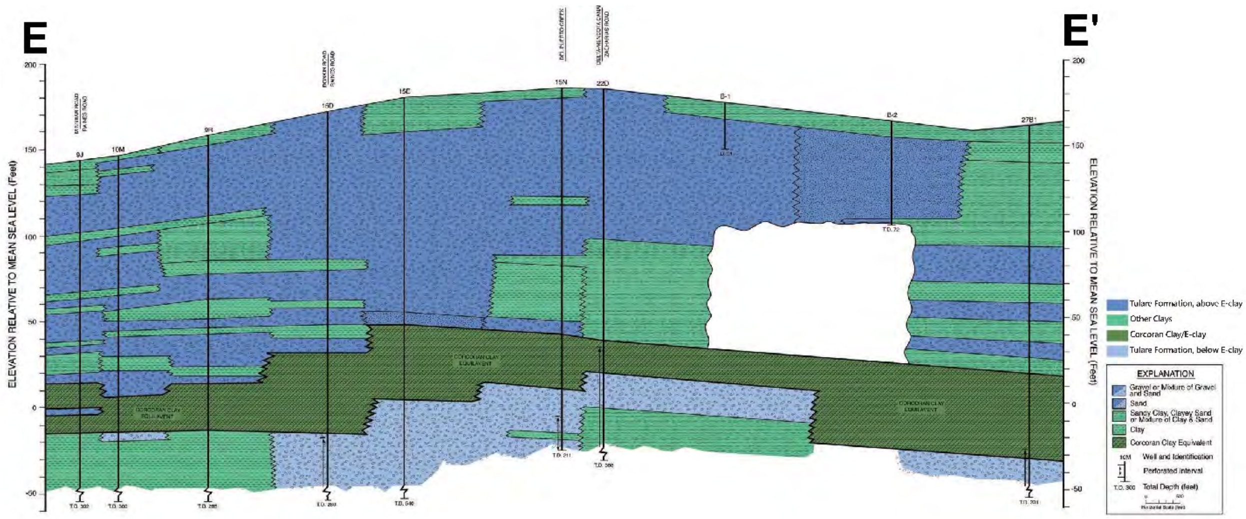

Figure 5-11. Cross-Section E-E' (RMC/W&C and Schmidt, 2014)

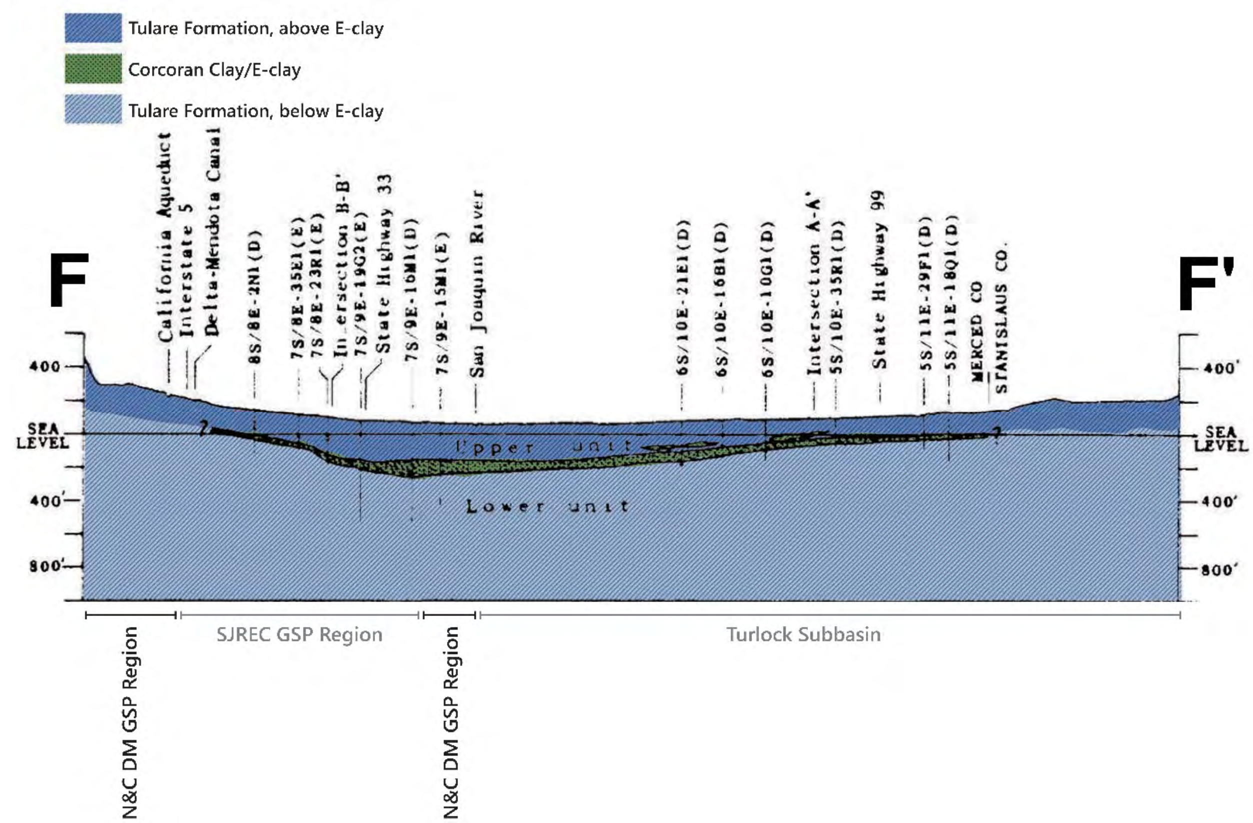

Figure 5-12. Cross-Section F-F' (Hotchkiss, 1972)

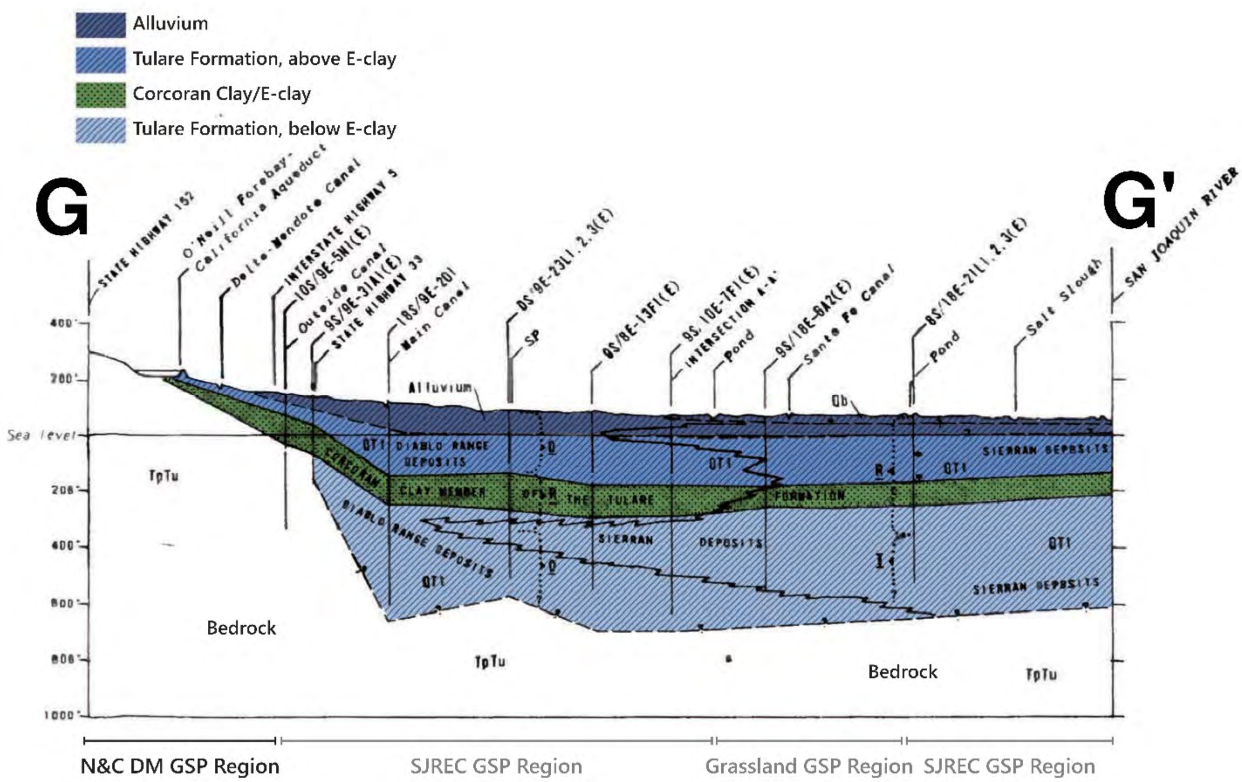

Figure 5-13. Cross-Section G-G' (Hotchkiss & Balding, 1971)

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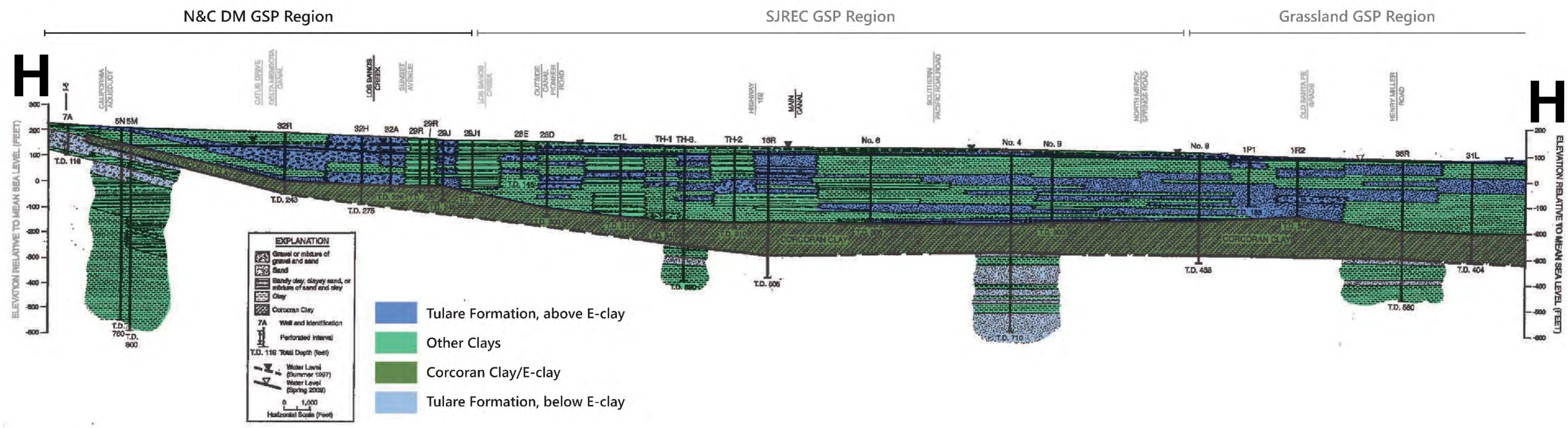

Figure 5-14. Cross-Section H-H' (Schmidt, 2018)

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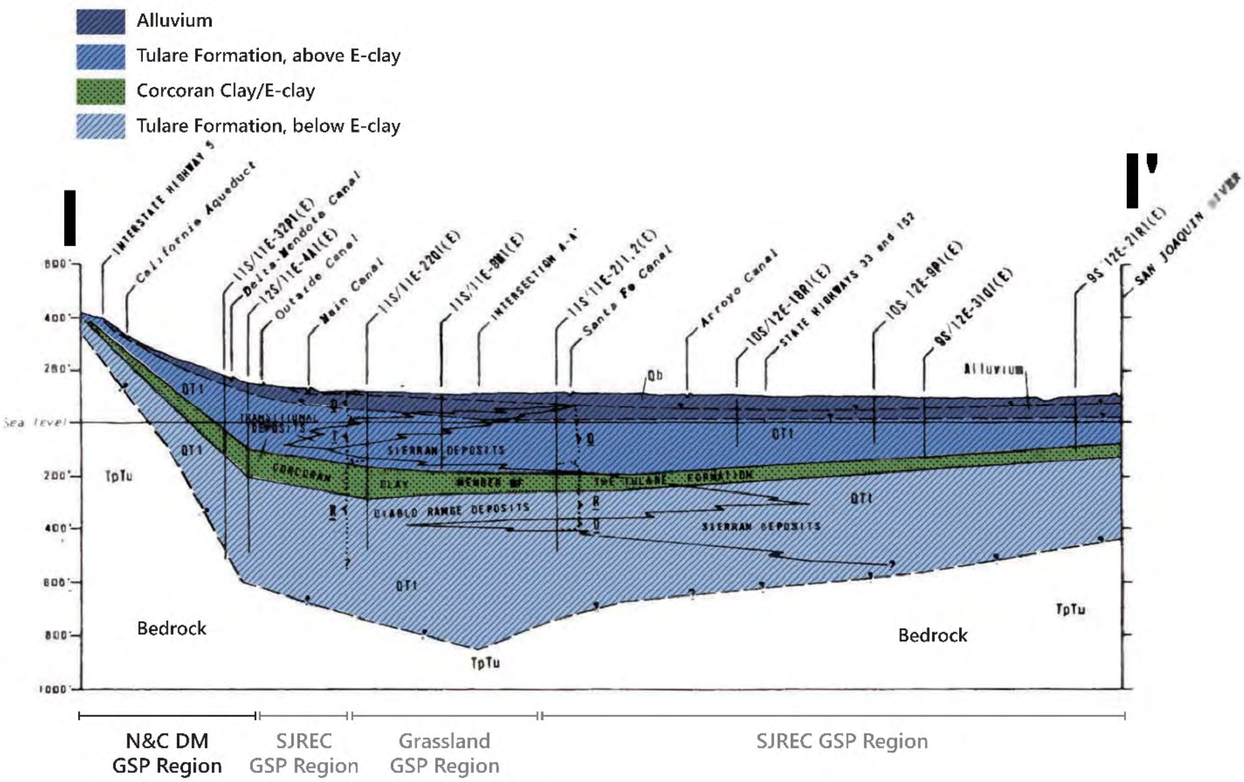


Figure 5-15. Cross-Section I-I' (Hotchkiss & Balding, 1971)

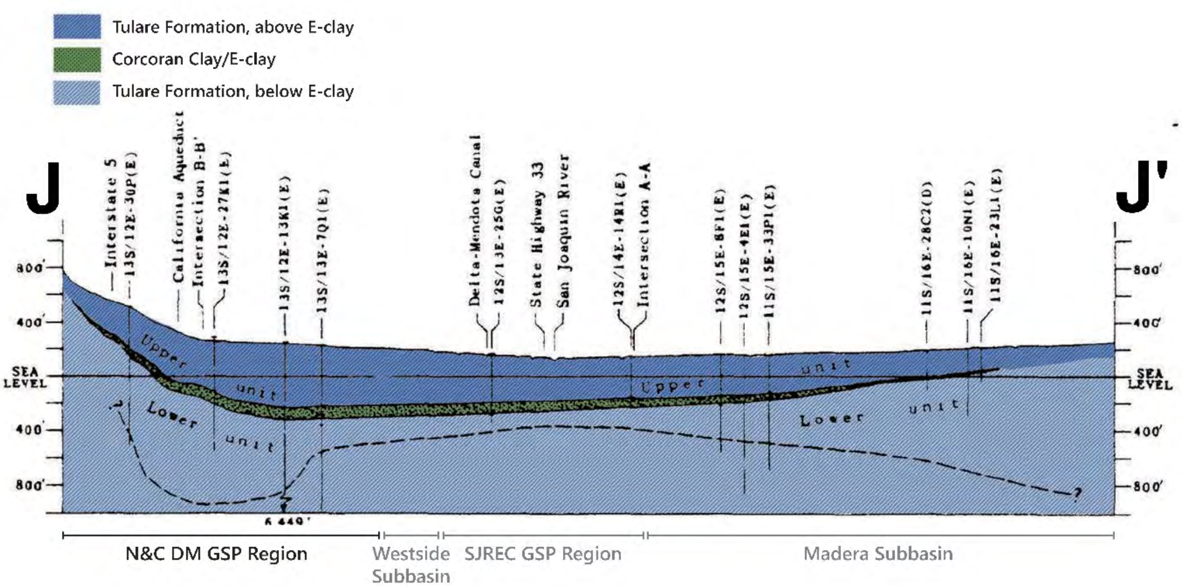


Figure 5-16. Cross-Section J-J' (Hotchkiss, 1972)

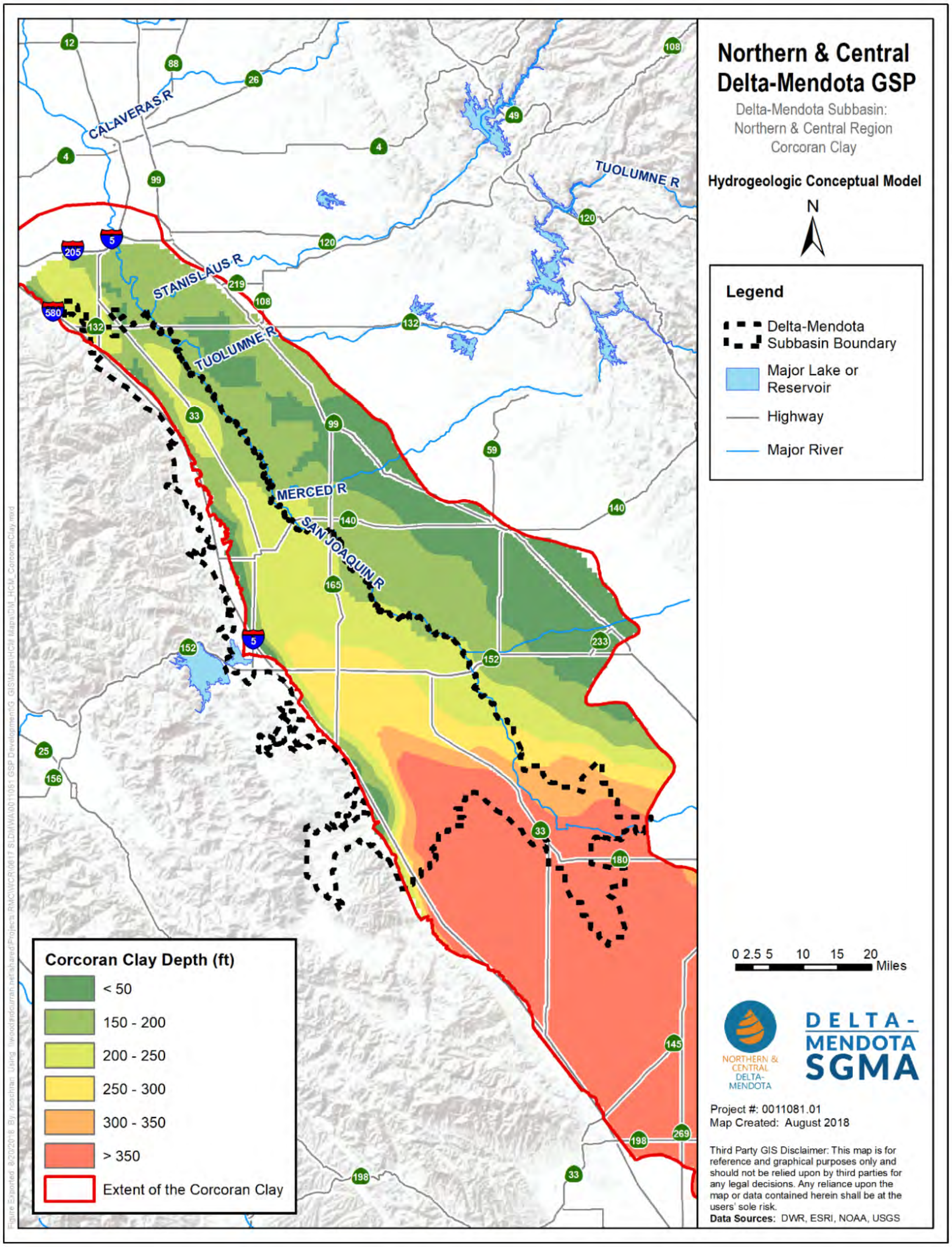


Figure 5-17. Depth to Corcoran Clay, Delta-Mendota Subbasin

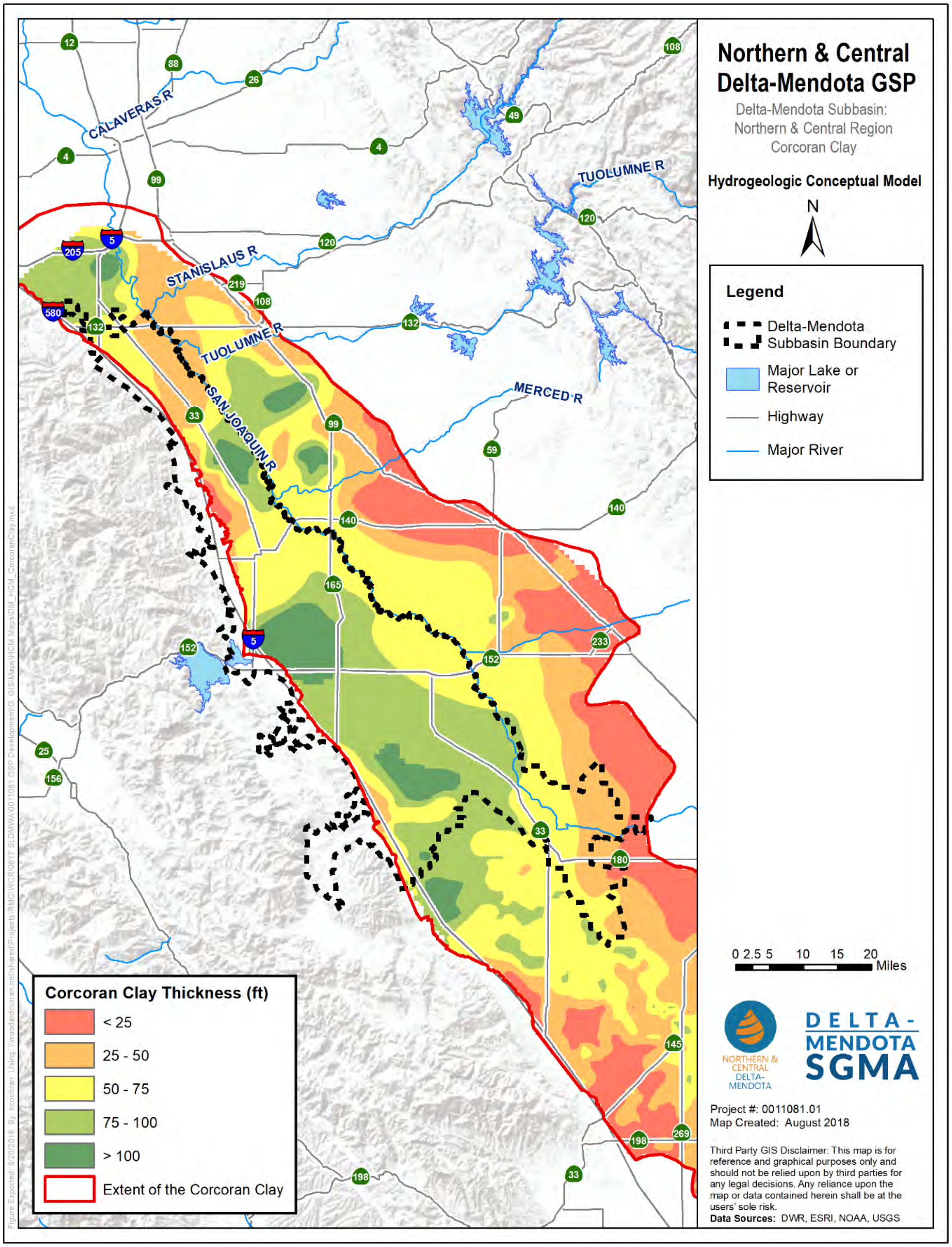


Figure 5-18. Thickness of Corcoran Clay, Delta-Mendota Subbasin

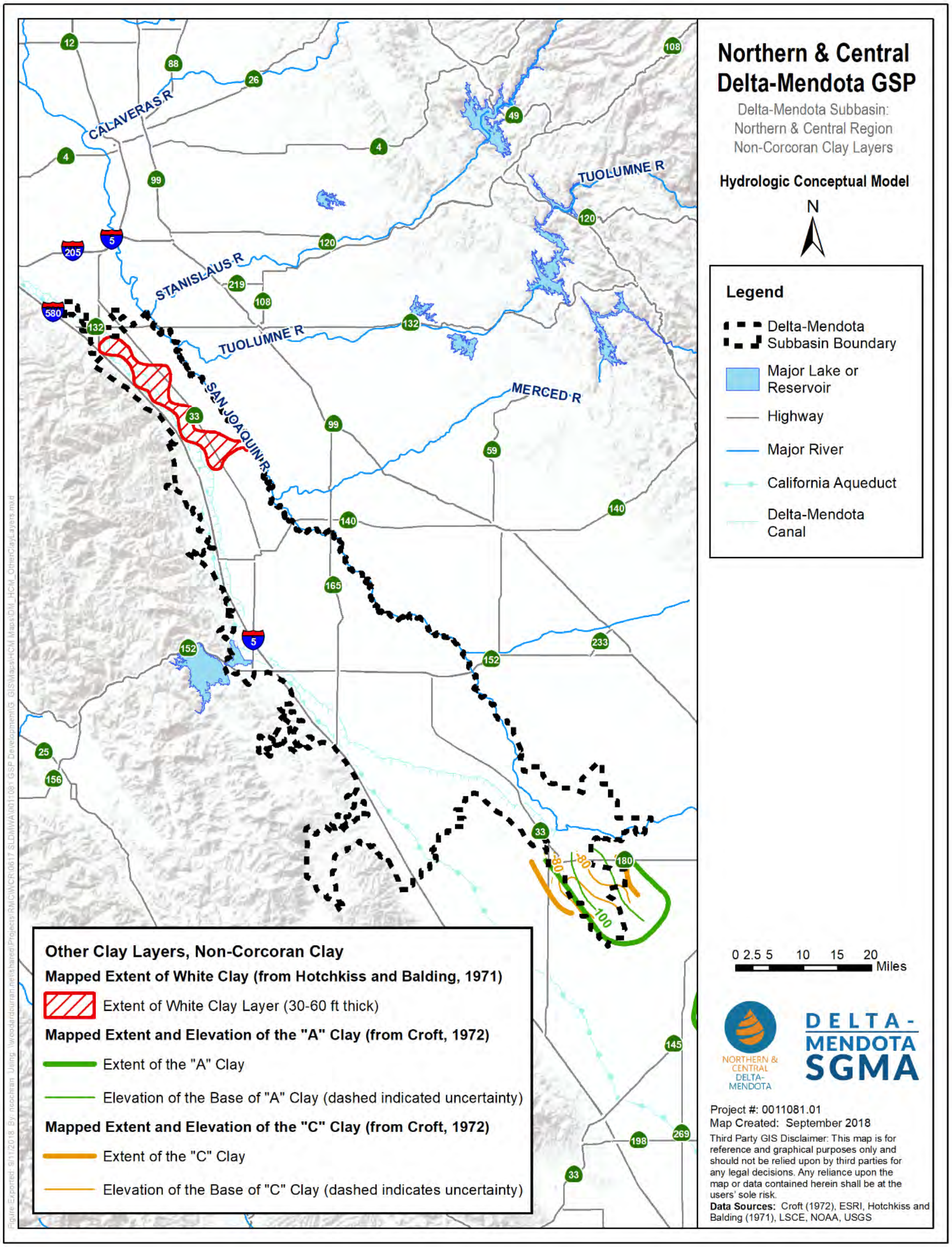


Figure 5-19. Non-Corcoran Clay Layers, Delta-Mendota Subbasin

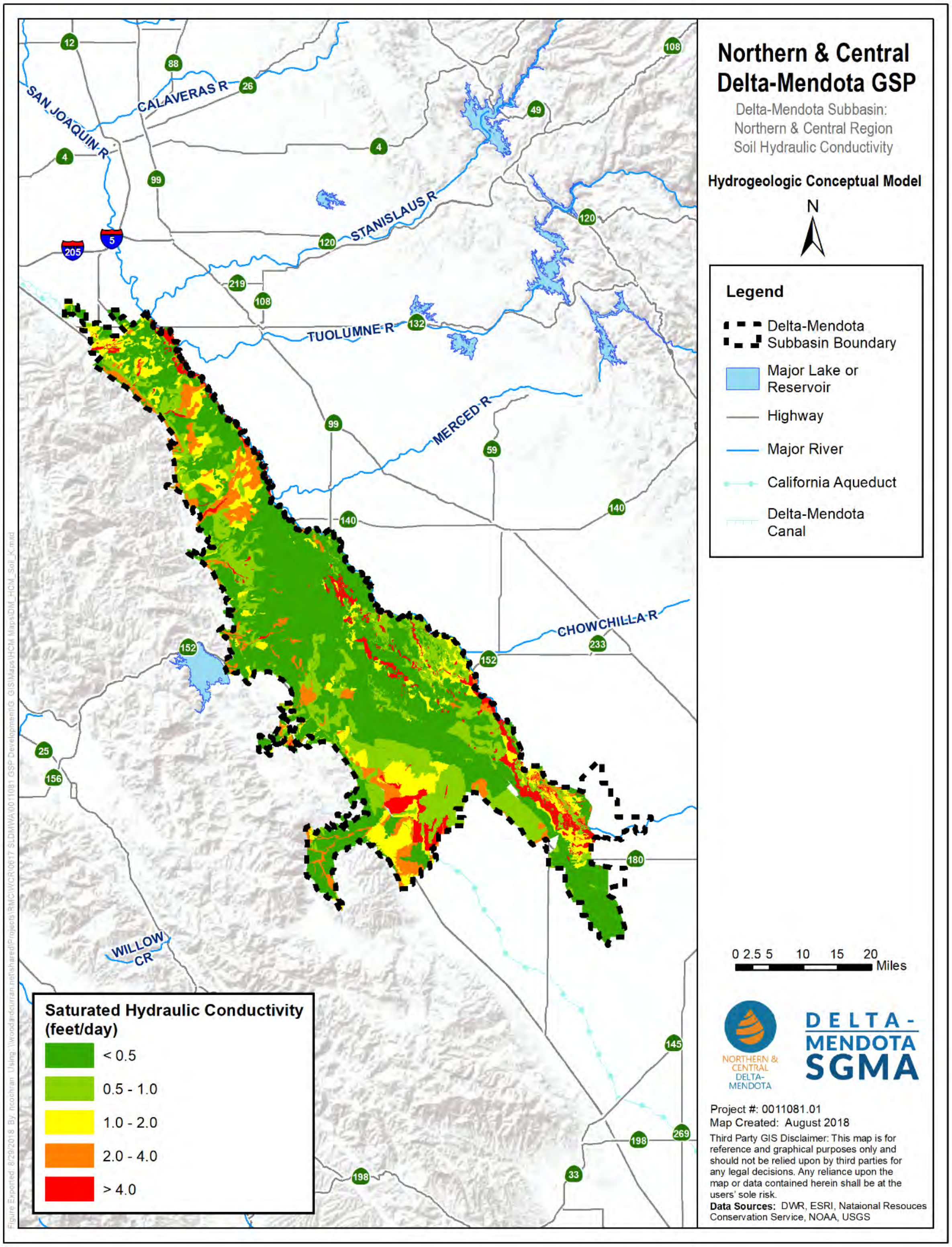


Figure 5-20. Soil Hydraulic Conductivity, Delta-Mendota Subbasin

5.2.7 Structural Properties and Restricted Groundwater Flow

Under natural (pre-development) conditions, the prevailing groundwater flow within the Upper and Lower Aquifer systems of the western San Joaquin Valley was predominantly in a generally northeasterly direction from the Coast Range towards and parallel to the San Joaquin River and the Sacramento-San Joaquin Delta (LSCE, 2015; Hotchkiss and Balding, 1971; Schmidt, 2015). Historically, numerous flowing artesian wells within the Lower Aquifer existed throughout the Delta-Mendota Subbasin (Mendenhall et al., 1916) and the pressure gradient for groundwater flow was upward from the Lower Aquifer to the Upper Aquifer. These flowing artesian conditions have disappeared in many areas as a result of increased development of groundwater resources within the Tulare Formation, changing the vertical flow gradient between groundwater zones (Hotchkiss and Balding, 1971). Additionally, the Delta-Mendota Subbasin has experienced periods of considerable decline in groundwater levels during which hydraulic heads decreased considerably in some areas due to heavy pumping (Bertoldi et al., 1991).

Despite the presence of local pumping depressions within parts of the Subbasin, the prevailing northeastward flow direction for groundwater within the region has remained (AECOM, 2011; DWR, 2010; Hotchkiss and Balding, 1971). Groundwater flows outward from the Delta-Mendota Subbasin, except along the western margin where there is some recharge from local streams and canal seepage (Schmidt, 2015). Within the Upper Aquifer, there are similar groundwater flow directions in most of the Subbasin with groundwater outflow to the northeast or towards the San Joaquin River in much of the Subbasin during wet and dry periods. One exception is in the Orestimba Creek area west of Newman where groundwater flows to the west during drought conditions and east during wet periods. Calculations based on aquifer transmissivity indicate the net groundwater outflow in the Upper Aquifer has been about three times greater during drought periods than during normal periods (Schmidt, 1997a and 1997b).

Within the Lower Aquifer, there is a groundwater divide in the area between Mendota and the point near the San Joaquin River in the Turner Island area, northeast of Los Banos. Groundwater southwest of this divide generally flows southwest toward Panoche Water District. Groundwater northeast of this divide flows to the northeast into Madera and Merced Counties. Net groundwater outflow in the Lower Aquifer under drought conditions has been about two and a half times greater than for normal conditions (Schmidt, 1997a and 1997b). Based on current and historical groundwater elevation maps, groundwater barriers do not appear to exist in the Delta-Mendota Subbasin (DWR, 2006).

The combined effect of pumping below the Corcoran Clay and increased leakage from the Very Shallow zone to the Upper Aquifer has developed a generally downward flow gradient in the Tulare Formation which changes with variable pumping and irrigation over time (Bertoldi et al., 1991). Periods of great groundwater level declines have also resulted in inelastic compaction of fine-grained materials in some locations, particularly between Los Banos and Mendota, potentially resulting in considerable decreases (between 1.5 and 6 times) in permeability of clay members within the Tulare Formation, including the Corcoran Clay (Bertoldi et al., 1991). However, the number of wells penetrating the Corcoran Clay may be enabling vertical hydraulic communication across the Corcoran Clay aquitard and other clay layers (Davis et al., 1959; Davis et al., 1964).

5.2.8 Water Quality

Groundwater in the Delta-Mendota Subbasin is characterized by mixed sulfate to bicarbonate water types in the northern and central portion of the Subbasin, with areas of sodium chloride and sodium sulfate waters in the central and southern portions (DWR, 2003). TDS values range from 400 to 1,600 mg/L in the northern portion, and 730 to 6,000 mg/L in the southern portion of the Delta-Mendota Subbasin (Hotchkiss and Balding, 1971). The Department of Health Services (DHS), which monitors Title 22 water quality standards, reports TDS values in 44 public supply wells in the Subbasin ranging in value from 210 to 1,750 mg/L, with an average value of 770 mg/L. Shallow, saline groundwater also occurs within about 10 feet of the ground surface over a large portion of the Delta-Mendota Subbasin. There are also localized areas of high iron, fluoride, nitrate, selenium, and boron in the Delta-Mendota Subbasin (Hotchkiss and Balding, 1971).

5.2.8.1 Historic Water Quality

Alluvial sediments derived from west-side streams are composed of material derived from serpentine, shale, and sandstone parent rock, which results in soil and groundwater types entirely different from those on the east side of the San Joaquin Valley (LSCE, 2015). In contrast with the siliceous mineralogy of the alluvial sands and gravels on the eastern side of the Central Valley that are derived from the Sierra granitic rocks (which are coarser and more resistant to chemical dissolution), the sulfate and carbonate shales and sandstones of Coast Range sediments on the western side are more susceptible to dissolution processes. Some soils and sediments within the western San Joaquin Valley that are derived from marine rocks of the Coast Range have notably high concentrations of naturally-occurring nitrogen, with particularly higher nitrate concentrations in younger alluvial sediments (Strathouse and Sposito, 1980; Sullivan et al., 1979). These naturally-occurring nitrogen sources may contribute to nitrate concentrations in groundwater within the Delta-Mendota Subbasin, although it is not well known where this may occur and to what degree. Naturally-high concentrations of TDS in groundwater are known to have existed historically within parts of the Subbasin due to the geochemistry of the Coast Range rocks, the resulting naturally-high TDS of recharge derived from Coast Range streams, the dissolvable materials within the alluvial fan complexes, and the naturally-poor draining conditions which tend to concentrate salts in the system. The chemical quality of waters in the Coast Range streams can be closely correlated with the geologic units within their respective catchments. Groundwater flows discharging from these marine and non-marine rocks into streams introduce a variety of dissolved constituents, resulting in variable groundwater types. The water quality and chemical makeup in westside streams can be highly saline, especially in more northern streams, including Corral Hollow and Del Puerto Creeks, where historical baseflow TDS concentrations have typically exceeded 1,000 milligrams per liter (mg/L) with measured concentrations as high as 1,790 mg/L (Hotchkiss and Balding, 1971). This is in contrast with TDS concentrations typically below 175 mg/L in streams draining from the Sierras. The contribution of water associated with these Coast Range sediments has resulted in naturally high salinity in groundwater within and around the Delta-Mendota Subbasin, which has been recognized as early as the 1900s (Mendenhall et al., 1916). Groundwater in some areas within the immediate vicinity of the San Joaquin River is influenced by lower-salinity surface water discharging from the east side of the San Joaquin Valley Groundwater Basin (Davis et al., 1957).

Areas of historical high saline groundwater documented by Mendenhall *et al*. (1916) indicate somewhat high TDS concentrations approaching or greater than 1,000 mg/L in wells sampled throughout many parts of the Delta-Mendota Subbasin. Areas of locally higher TDS concentrations (1,500-2,400 mg/L) have existed between Mendota and Los Banos; whereas the trend in deeper groundwater (average well depth of 450 feet) south of Mendota indicates slightly lower historical salinity conditions, but still somewhat high with an average TDS concentration of greater than 1,000 mg/L. In the northern part of the Subbasin, north of Gustine, the average historical TDS concentration of wells was also relatively high (930 mg/L). Historically low TDS concentrations (<500 mg/L) existed in groundwater from wells with an average depth of 209 feet in the central Subbasin area between Los Banos and Gustine.

The general chemical composition of groundwater in the Subbasin is variable based on location and depth. Groundwater within the Upper Aquifer is largely characterized as transitional type with less area characterized as predominantly of chloride, bicarbonate, and sulfate water types. Transitional water types, in which no single anion represents more than 50 percent of the reactive anions, occurs in many different combinations with greatly ranging TDS concentrations. Chloride type waters occur generally in grasslands areas east of Gustine and around Dos Palos, with sodium chloride water present in northern areas near Tracy and also extending south from Dos Palos. These waters also exhibit greatly varying salinity with typical TDS concentrations, ranging from less than 500 mg/L to greater than 10,000 mg/L and of high sodium makeup (50-75 percent of cations present) (Hotchkiss and Balding, 1971). Areas of bicarbonate groundwater within the Upper Aquifer of relatively lower TDS concentrations are directly associated with intermittent streams of the Coast Range near Del Puerto, Orestimba, San Luis, and Los Banos Creeks. Sulfate water in the central and southern Subbasin areas has TDS concentrations decreasing from west (1,200 mg/L) to east (700 mg/L) towards the San Joaquin River, similar to the bicarbonate water areas, although areas of sulfate water south of Dos Palos have much higher TDS concentrations (1,900 to 86,500 mg/L) (Hotchkiss and Balding, 1971).

Groundwater in the Lower Aquifer below the Corcoran Clay is also spatially variable, consisting of mostly transitional sulfate waters in the northern part of the Delta-Mendota Subbasin to more sodium-rich water further south in the grasslands areas. In the northern part of the Delta-Mendota Subbasin, the Lower Aquifer exhibits relatively lower TDS concentrations, ranging from 400 to 1,600 mg/L, with a sulfate-chloride type makeup near the valley margin trending to sulfate-bicarbonate type near the valley axis. Farther south, TDS concentrations in the Lower Aquifer increase with values ranging as high as 6,000 mg/L of high sodium content (Hotchkiss and Balding, 1971).

Natural conditions of groundwater salinity exist throughout the Upper and Lower Aquifers as a result of the contribution of salts from recharge off the Coast Range mountains. Surface water and groundwater flowing over and through Coast Range sediments of marine origin have dissolved naturally-occurring salts, contributing to the historical and current presence of salinity in groundwater within the Delta-Mendota Subbasin. In addition to natural salinity contributed from the Coast Range sediments, a number of other mechanisms are believed to further contribute to increased salinity in the groundwater in the region. Poorly draining soil conditions are extensive within the southern and eastern areas of the Subbasin, extending from the vicinity of Tranquillity to near Gustine, and these types of soil, combined with a shallow water table, contribute to a build-up of soil salinity.

5.2.8.2 Recent Groundwater Quality

Primary constituents of concern within the Delta-Mendota Subbasin are nitrates, TDS, and pesticides. In the Grassland Drainage Area and southern portions of the Subbasin, both selenium and boron are naturally occurring and are managed to mitigate impacts to irrigated agriculture. The maximum detected concentrations, as well as recent (about 2000 to 2014) concentrations, of these constituents are discussed in the following subsections (LSCE, 2015 and LSCE, 2016).

5.2.8.2.1 Nitrate Concentrations

The maximum nitrate (as N) concentrations observed in all wells throughout the Delta-Mendota Subbasin are depicted in **Figure 5-21**. The majority of wells have maximum concentrations below 5 mg/L; however, several areas exist with a greater density of wells with maximum concentrations exceeding the primary maximum contaminant level (MCL) of 10 mg/L (as N), especially in the area immediately south of Los Banos and trending northwest along Highway 33 to north of Patterson. Historical and current land use in this area consists mainly of alfalfa, almonds, cotton, corn, and tomatoes. There are a few wells around Dos Palos and southward toward Tranquillity with maximum nitrate concentrations exceeding the MCL, but most concentrations are non-detect. **Figure 5-22** shows the most recent nitrate concentrations (for a period of around 2000 to 2014) in all the wells in the Subbasin. The overall picture illustrated by the nitrate data in **Figure 5-22** is very similar, though slightly improving, to that seen in **Figure 5-21** for maximum nitrate concentrations.

Above Corcoran Clay

Figure 5-23 depicts maximum nitrate concentrations above the Corcoran Clay. Available data are limited for shallow wells above the Corcoran Clay, though the majority of the nitrate concentrations are below the nitrate (as N) MCL of 10 mg/L. The few wells that do exceed the MCL do not have a consistent spatial pattern, except in the southern central portion of the Subbasin where the majority of the drainage water in very shallow wells has maximum concentrations exceeding the MCL of 10 mg/L. Compared to shallow wells (typically less than 50 feet deep), deeper wells in the Upper Aquifer (ranging in depth from 50 feet to the top of the Corcoran Clay) have more wells with maximum nitrate concentrations exceeding the MCL. The majority of these exceedances extend from south of Los Banos northwestward to north of Patterson. Wells around Dos Palos and southeast of Tranquillity tend to have lower concentrations of nitrate, typically less than 2.5 mg/L. Similar spatial patterns are evident in shallow wells presenting the most recent nitrate concentrations, although several wells near Los Banos and Patterson indicate recently improved nitrate concentrations (**Figure 5-24**). The most recent nitrate concentrations in shallow Upper Aquifer wells are lower at many sample locations in the area northeast and east of Los Banos. The most recent nitrate concentrations in deeper wells throughout the Upper Aquifer show the same pattern as the maximum concentrations; however, a fewer number of these wells have concentrations exceeding 10 mg/L.

Tile drains located predominantly in the southern portion of the Subbasin are designed to capture applied water that percolates below the root zone and to drain the water table in areas where it is perched or very shallow. Consequently, it is expected that water sampled from tile drains and from very shallow wells (less than 15 feet) would exhibit higher concentrations of nitrate resulting from land use practices. The most recent nitrate concentrations in deeper wells appear to be slightly improved relative to the maximum concentrations as fewer wells show most recent values above 10 mg/L compared to the maximum nitrate concentrations. Nevertheless, the spatial patterns in the most recent nitrate concentrations shown in **Figure 5-24** are similar to the maximum concentrations evident in **Figure 5-23**.

Below Corcoran Clay

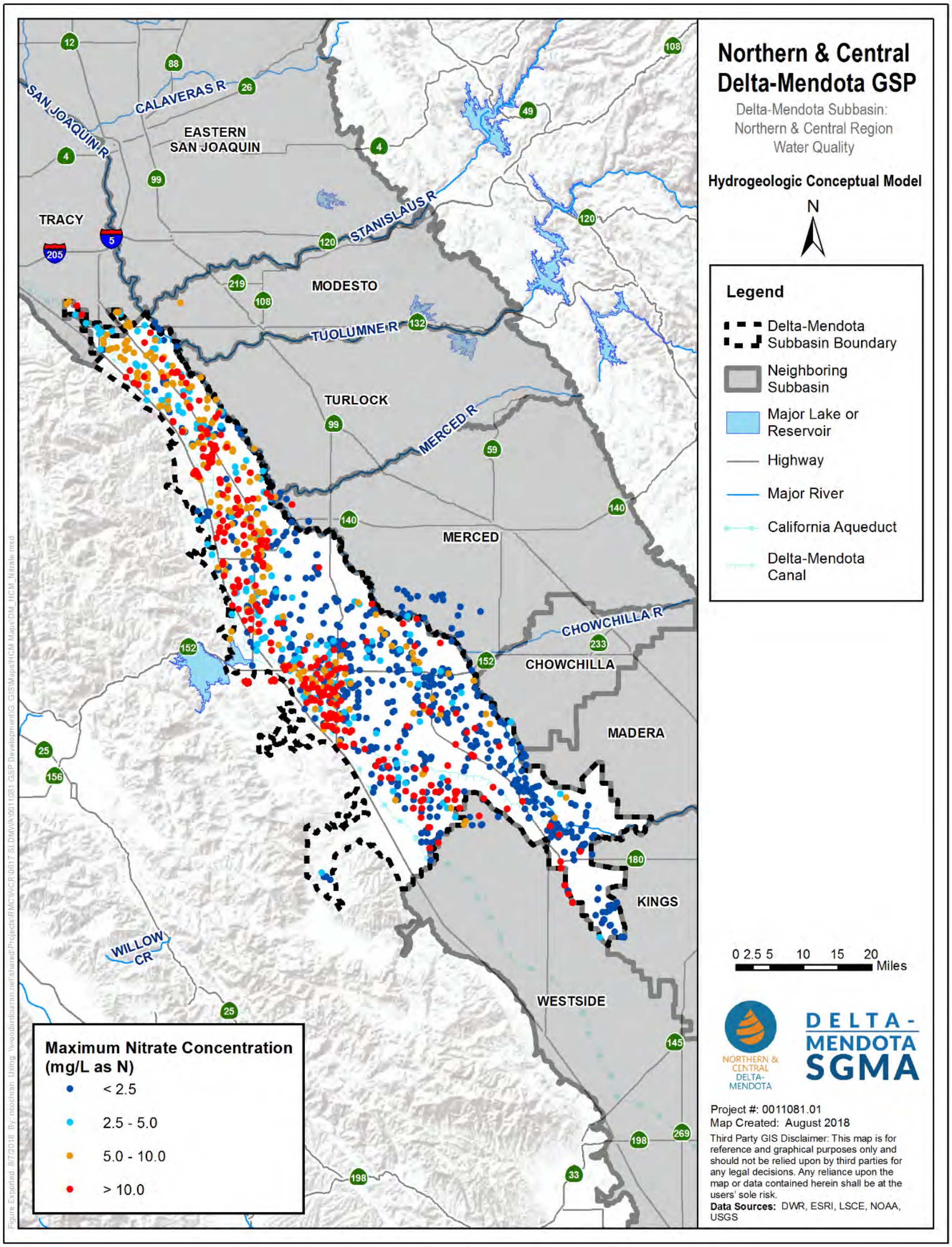
Fewer data are available relating to nitrate concentrations below the Corcoran Clay as compared to above the Corcoran Clay, primarily because most irrigation wells in the Subbasin (from which the predominance of data are available) are completed in the Upper Aquifer. **Figure 5-25** displays the maximum nitrate concentrations in wells interpreted to be in the Lower Aquifer and shows the lack of data southwest of Los Banos. As is evident in **Figure 5-25**, most wells in the Lower Aquifer, from Gustine to north of Patterson and west of Highway 33, have a maximum nitrate (as N) concentration above 5 mg/L. However, in the most recent nitrate data, a fewer number of the Lower Aquifer wells have concentrations exceeding 10 mg/L (**Figure 5-26**). Limited and scattered wells south of Gustine show a maximum nitrate concentration of less than 5 mg/L. Clusters of higher nitrate concentrations in the Lower Aquifer are generally concentrated in areas where the Corcoran Clay is either thin or non-existent as seen in **Figure 5-25**, most notably to the west and northwest of Gustine.

Composite Wells

As seen in **Figure 5-27,** the maximum nitrate concentrations in the composite wells (wells screened both above and below the Corcoran Clay) are mostly above 5 mg/L nitrate as N. The maximum nitrate concentration data in composite wells are similar to the most recent data (**Figure 5-28**), with a few wells with recent results showing improved nitrate concentrations.

Wells of Unknown Depth

Many of the wells for which nitrate data are available could not be classified into a depth category (above or below the Corcoran Clay) because of the lack of information relating to well construction and type. The spatial distribution of nitrate concentrations in these wells of unknown depth is shown in **Figure 5-29** and **Figure 5-30**. The majority of these wells have maximum nitrate as N concentrations below 5 mg/L, although a greater density of wells with maximum nitrate concentrations exceeding 10 mg/L can be seen in the area south of Los Banos (**Figure 5-29**) and extending northwest along Highway 33 to north of Patterson. This area also exhibits elevated nitrate concentrations in both the Upper and Lower Aquifers (**Figure 5-23** through **Figure 5-26**). Other wells exceeding 10 mg/L are more sparsely distributed in the area between Dos Palos and Tranquillity.



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-21. Maximum Nitrate Concentrations, All Wells

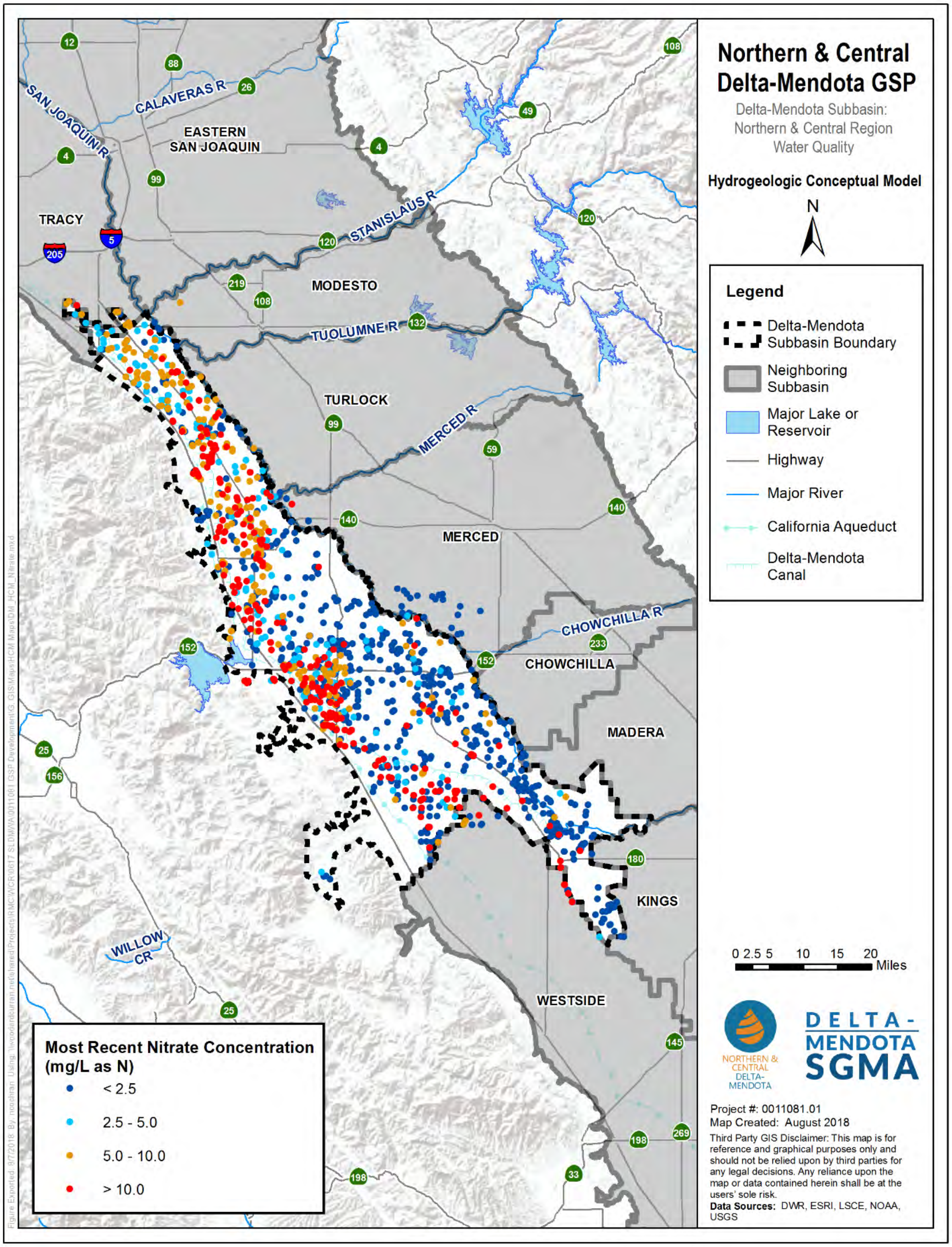
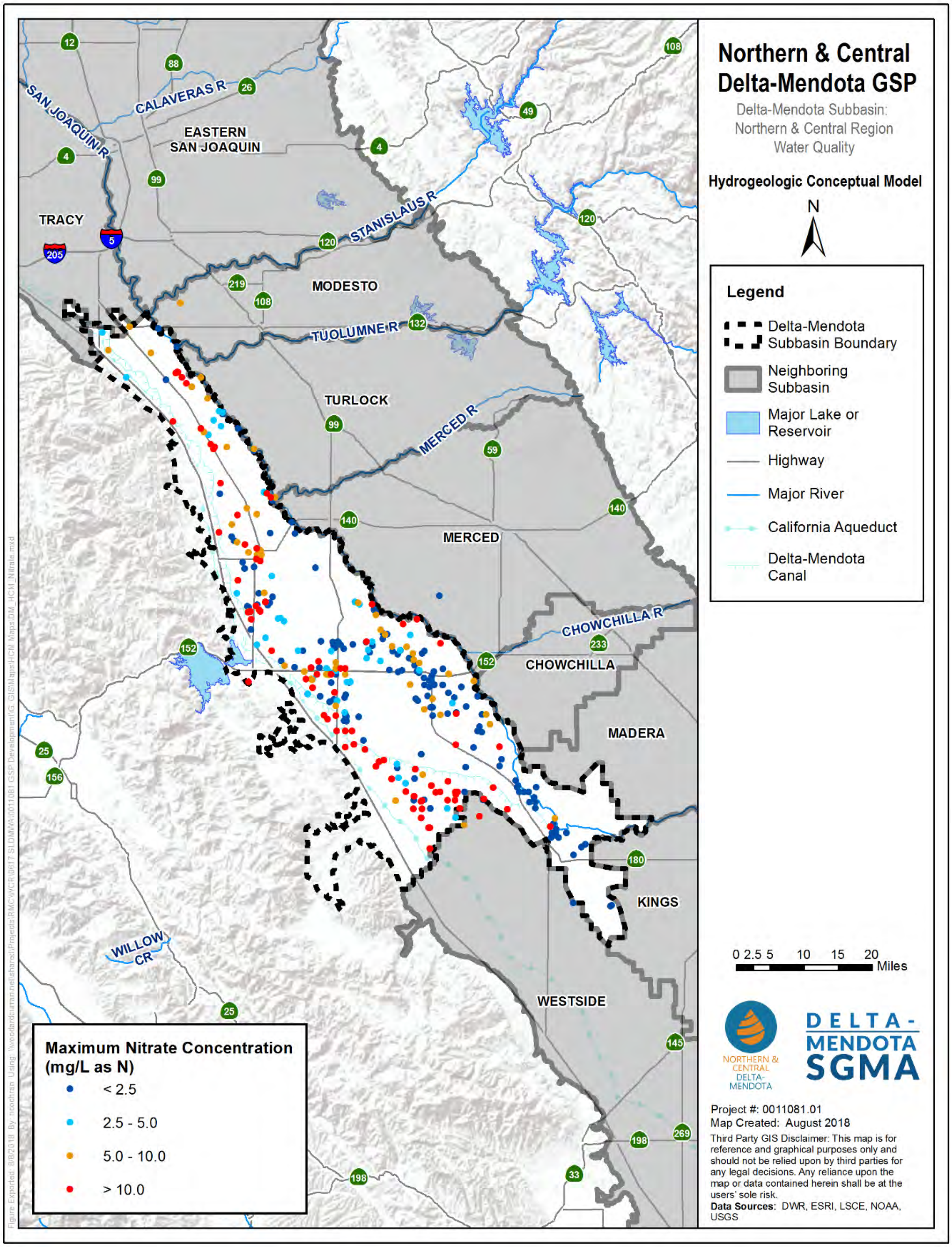


Figure 5-22. Most Recent (2000-2014) Nitrate Concentrations, All Wells



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-23. Maximum Nitrate Concentrations, Above Corcoran Clay

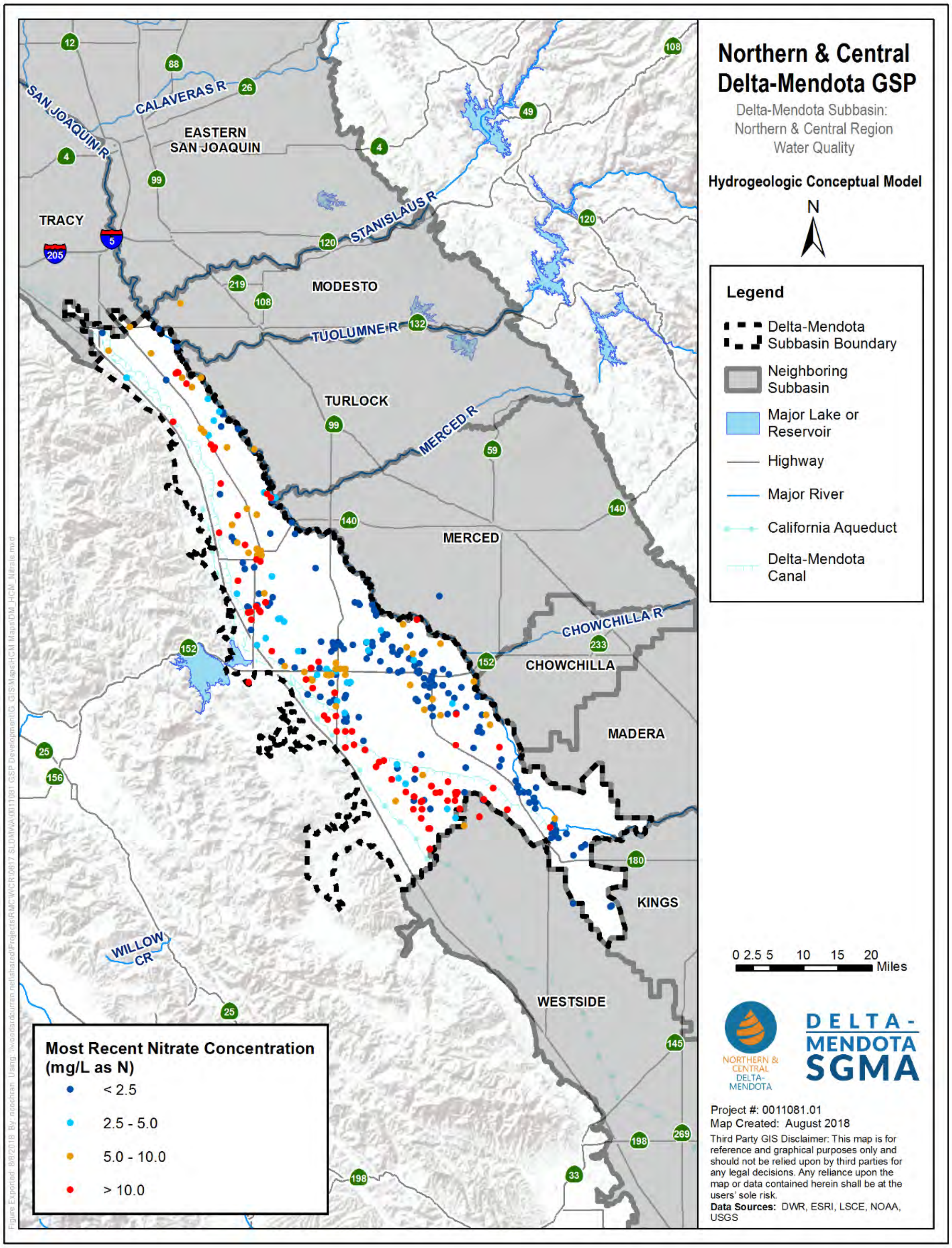
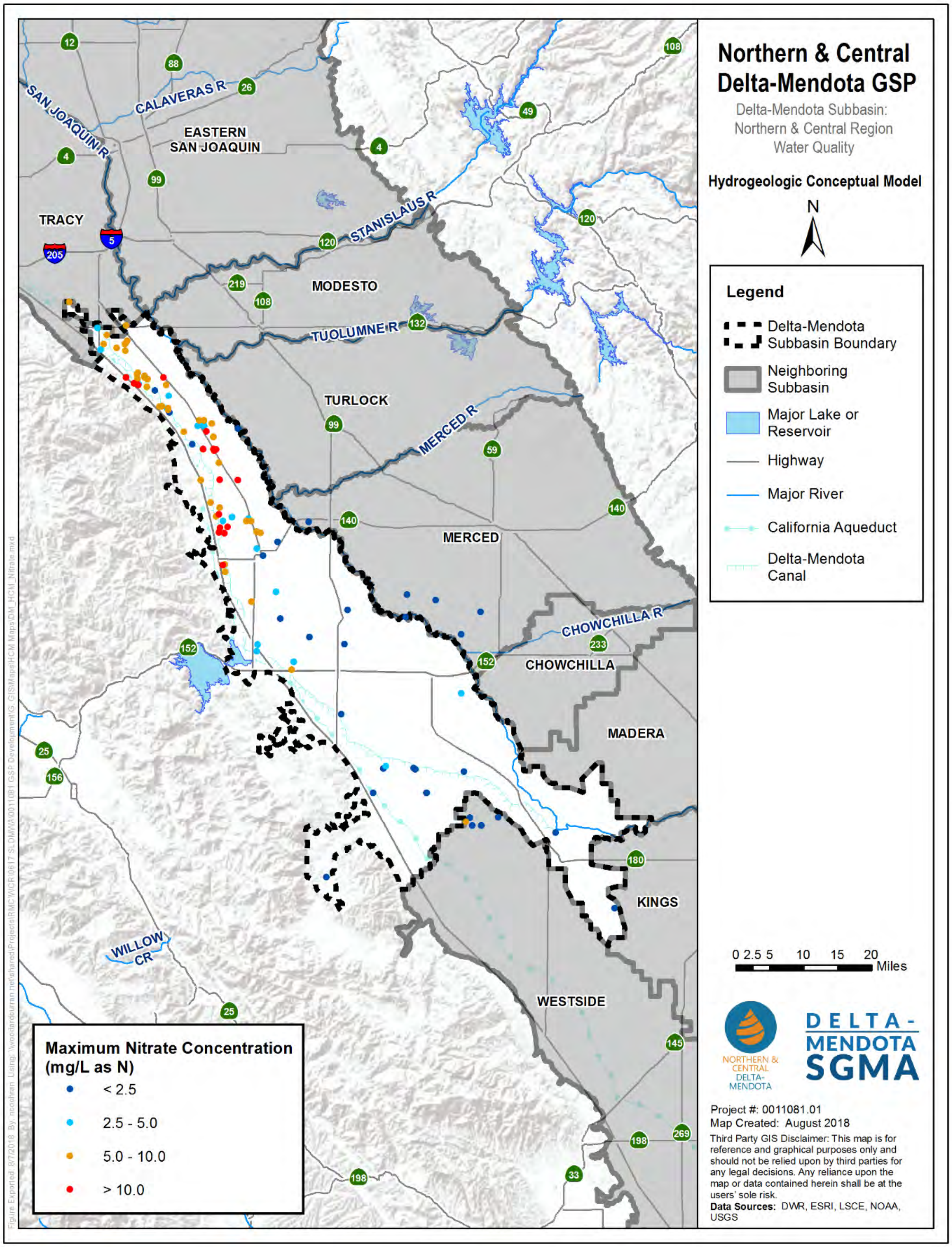


Figure 5-24. Most Recent (2000-2014) Nitrate Concentrations, Above Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-25. Maximum Nitrate Concentrations, Below Corcoran Clay

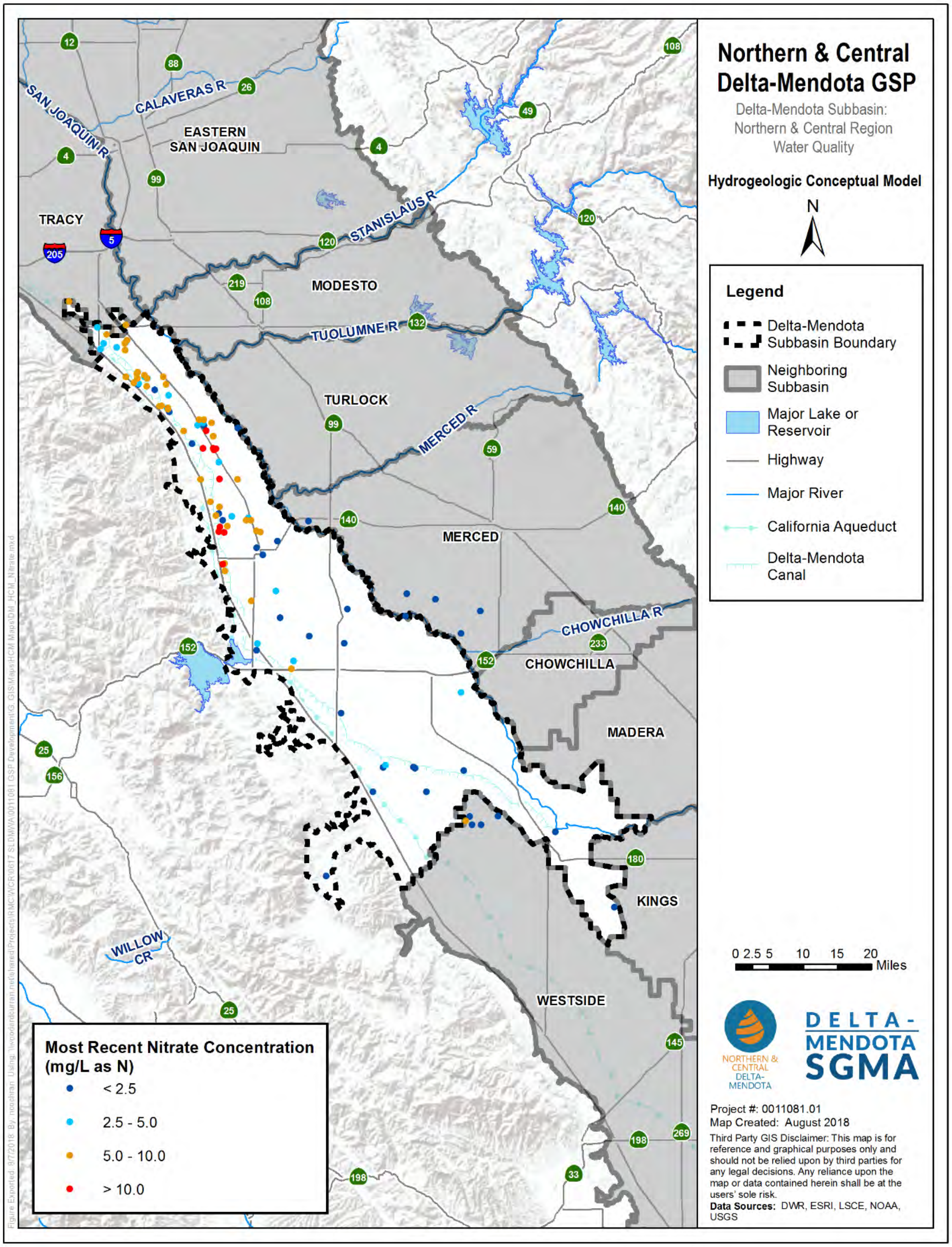
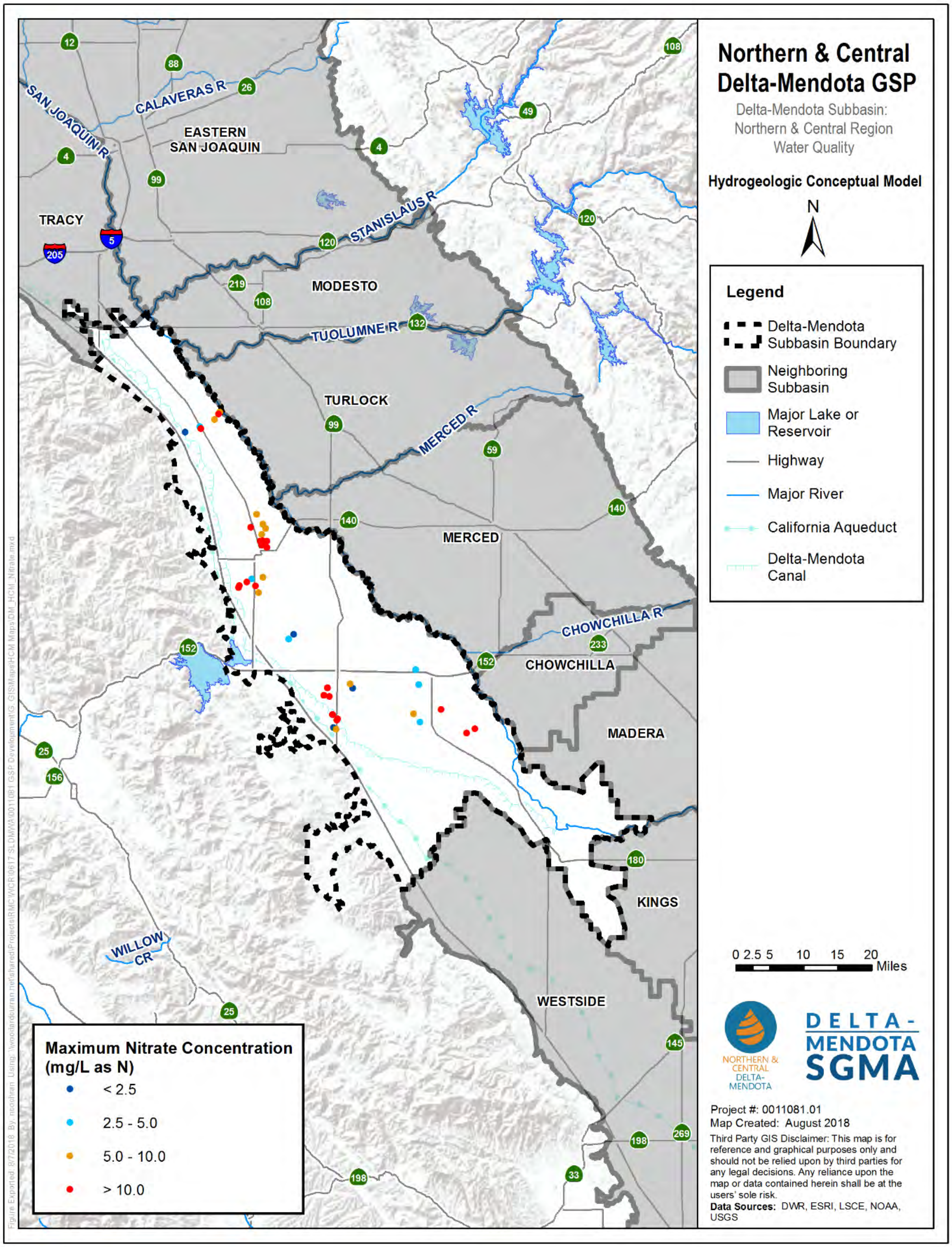


Figure 5-26. Most Recent (2000-2014) Nitrate Concentrations, Below Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-27. Maximum Nitrate Concentrations, Composite Wells

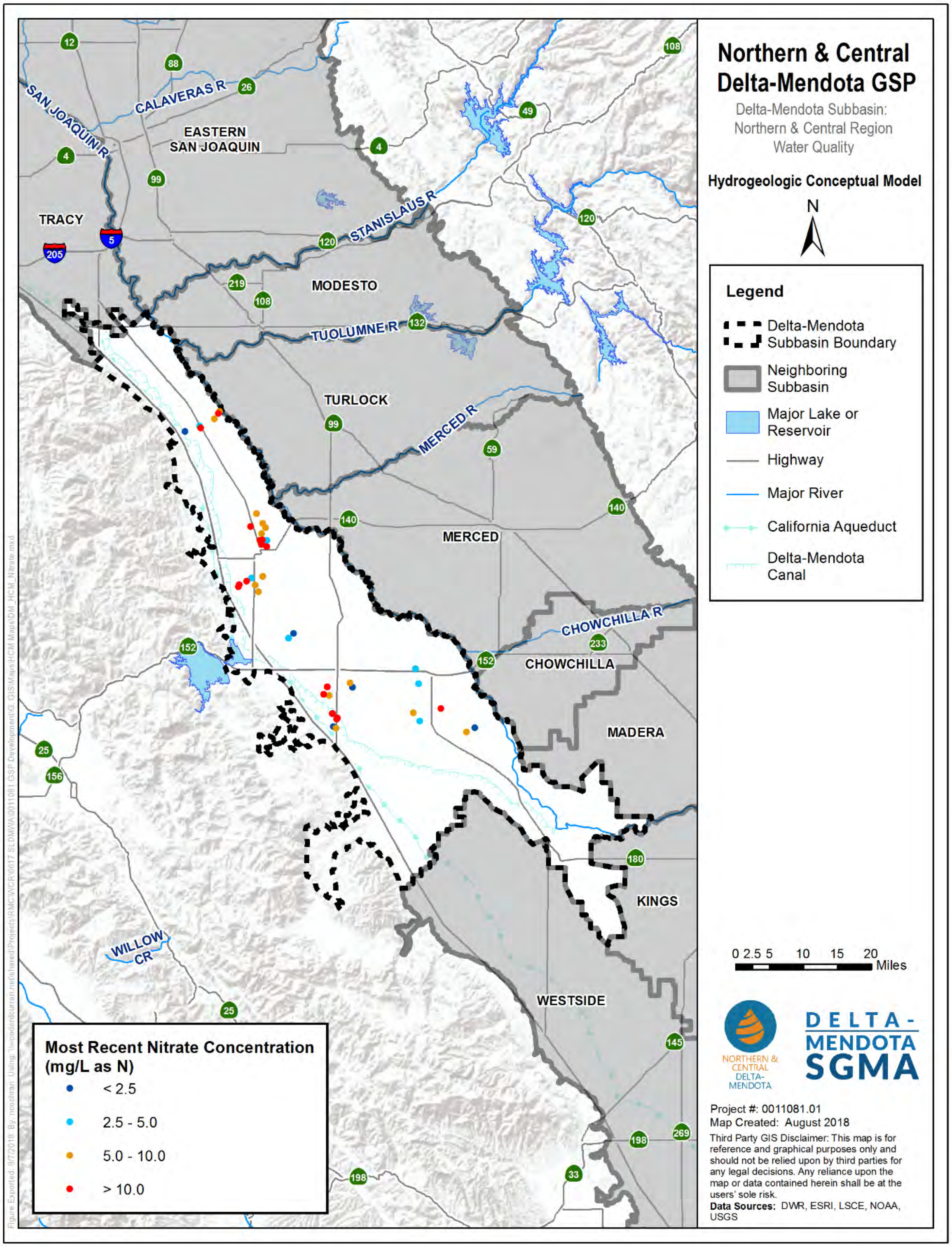
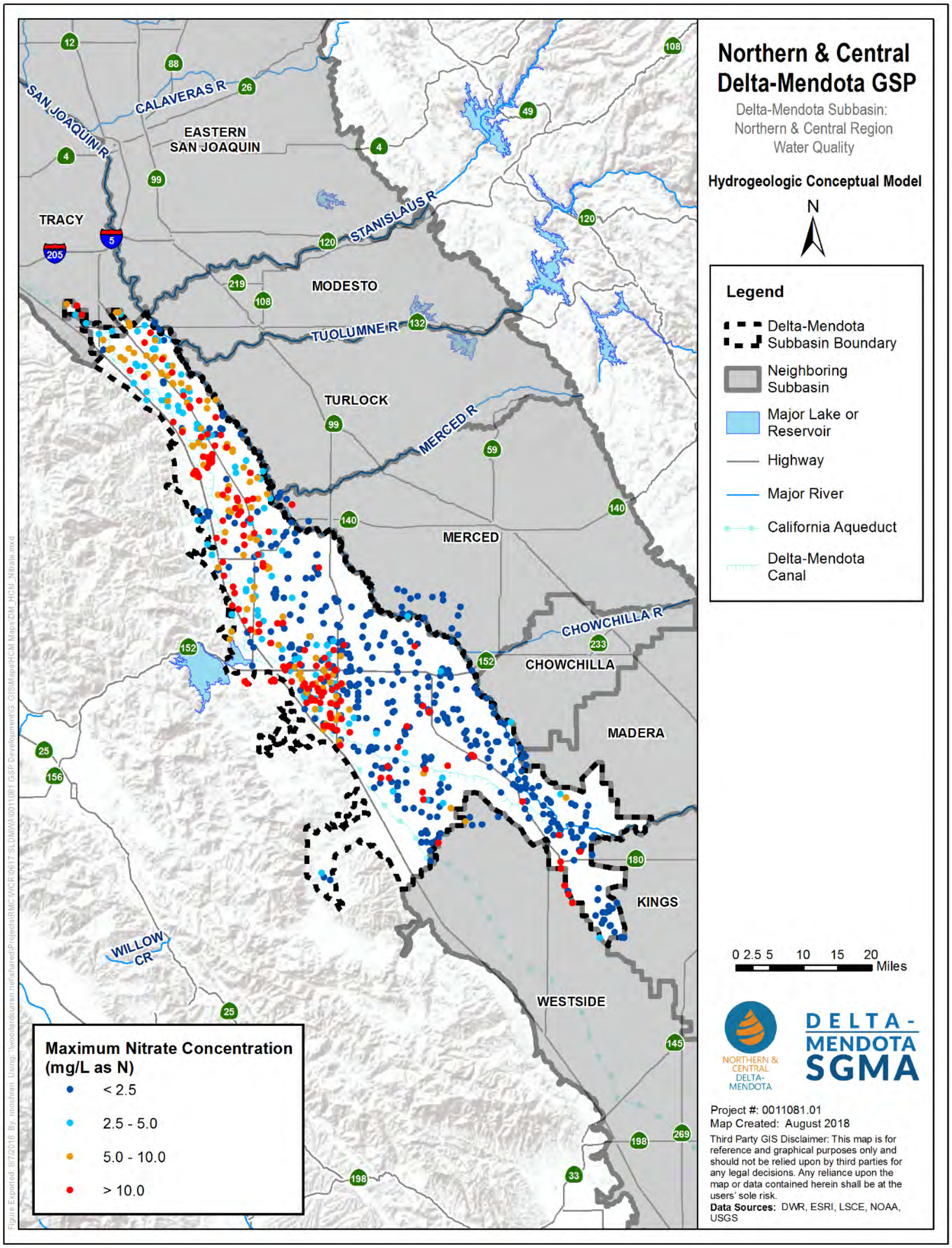


Figure 5-28. Most Recent (2000-2014) Nitrate Concentrations, Composite Wells



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-29. Maximum Nitrate Concentrations, Wells of Unknown Depth

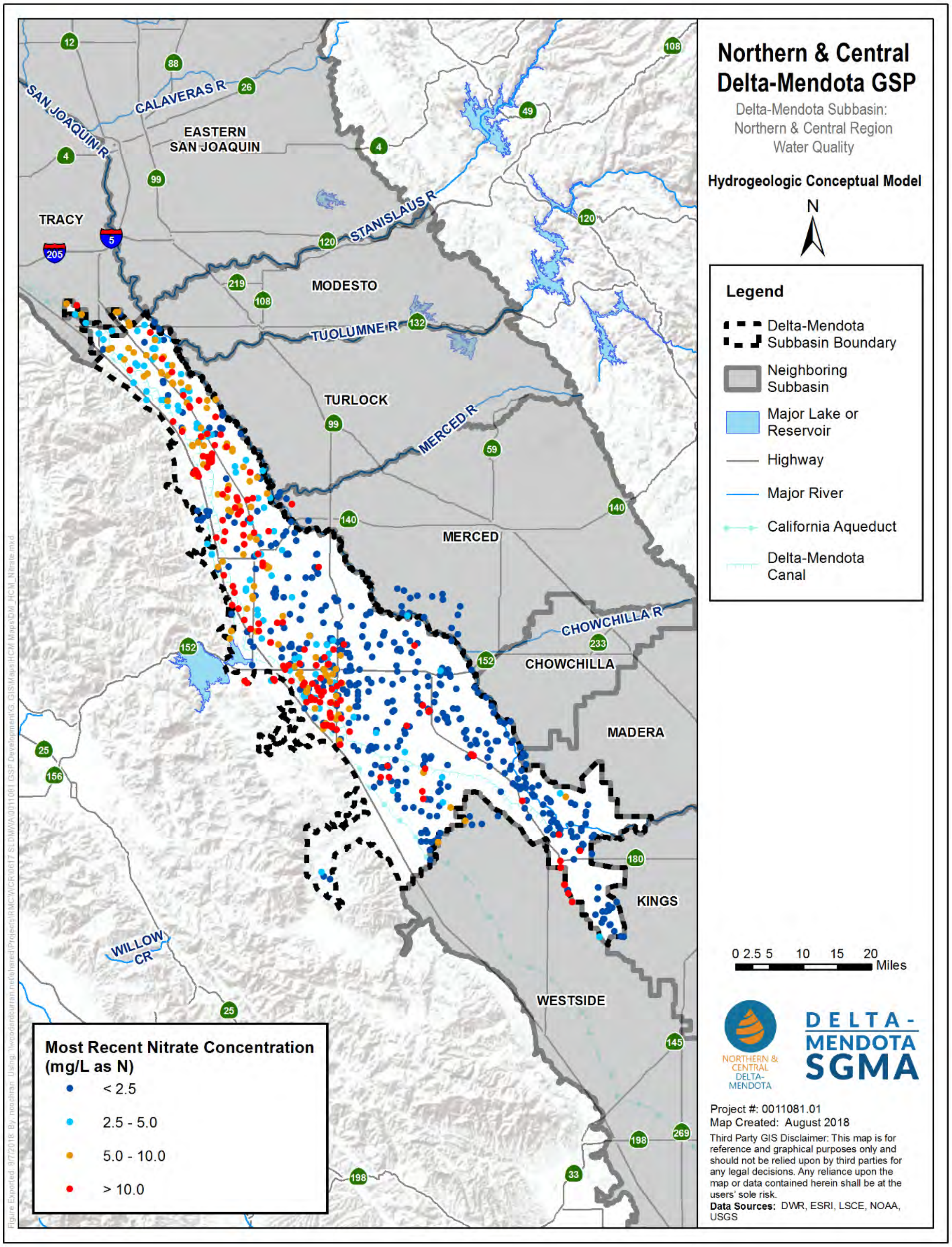


Figure 5-30. Most Recent (2000-2014) Nitrate Concentrations, Wells of Unknown Depth

5.2.8.2.2 TDS Concentrations

Figure 5-31 through **Figure 5-40** present the maximum and most recent (for the period around 2000-2014) TDS concentrations in wells within the Delta-Mendota Subbasin and indicate the general salinity of groundwater. The concentration of TDS in drinking water is regulated as a Secondary Drinking Water Standard and the standards are established for aesthetic reasons such as taste, odor, and color and not based on public health concerns. TDS concentrations in groundwater, as shown in **Figure 5-31** through **Figure 5-40**, are symbolized by five classes related to the Secondary MCL (SMCL): less than 500 mg/L, a concentration which is equivalent to the recommended SMCL; 500 to 1,000 mg/L (1,000 mg/L is equivalent to the upper level of the SMCL); 1,000 to 1,500 mg/L; 1,500 to 3,000 mg/L, equivalent and greater than the short-term level of the SMCL; and greater than 3,000 mg/L. The spatial distribution of available TDS data is similar in density to the nitrate data.

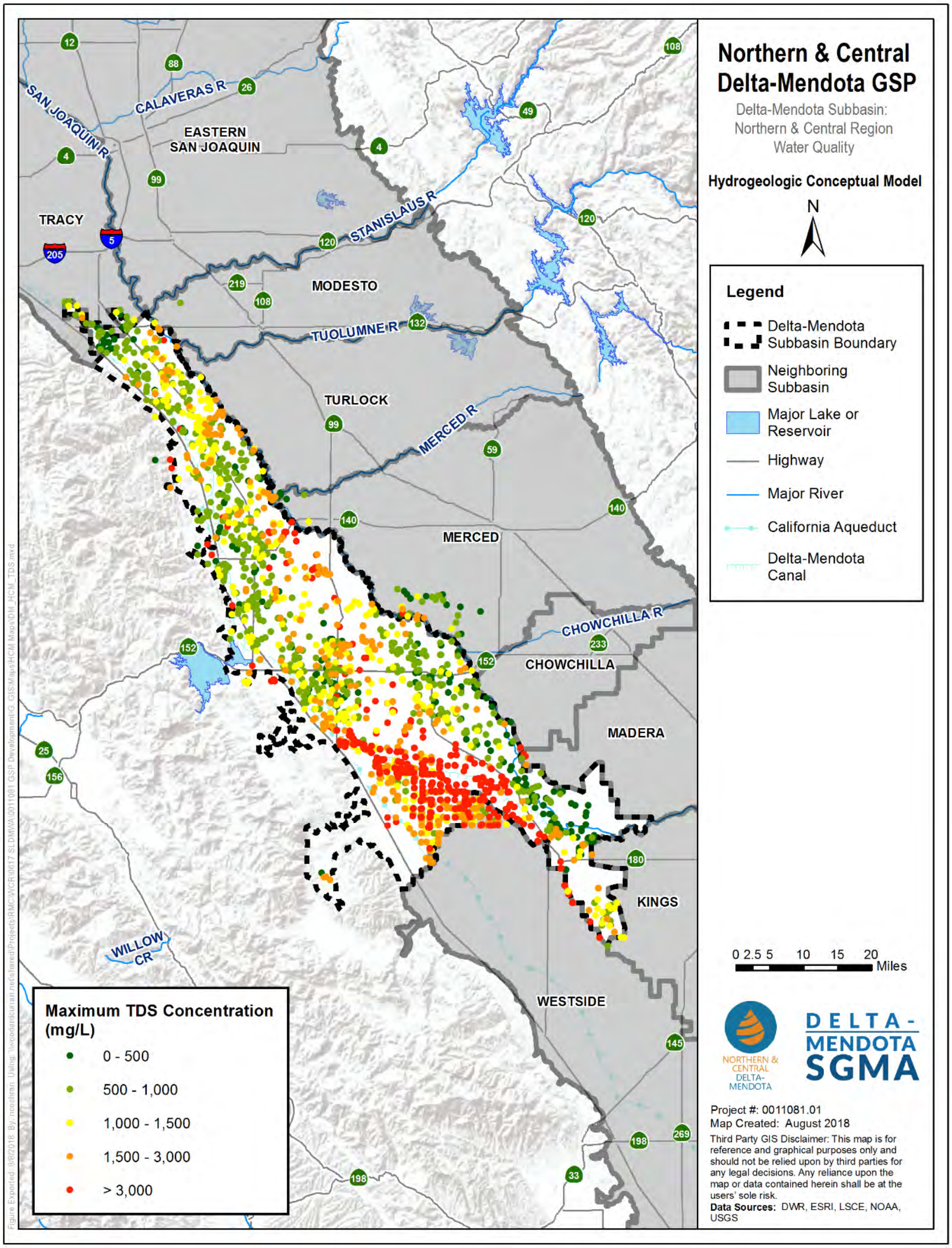
The majority of wells within Delta-Mendota Subbasin have maximum TDS concentrations below 1,000 mg/L, and a general spatial pattern of lower TDS from north of Dos Palos to Mendota is evident in **Figure 5-31** and **Figure 5-32**. An apparent higher density of wells with TDS concentrations greater than 1,500 mg/L is evident in wells from south and southwest of Dos Palos, northwestward to north of Patterson (**Figure 5-31**). The most recent TDS concentrations (**Figure 5-32**) are generally below 1,500 mg/L indicating a slight improvement in some wells since the maximum TDS sample was taken.

Above Corcoran Clay

The majority of shallow wells in the Delta-Mendota Subbasin have TDS concentrations that are below 1,500 mg/L and are located near Los Banos and east of Dos Palos (**Figure 5-33**). Shallow wells with TDS concentrations above 1,500 mg/L are scattered between the area south of Dos Palos to north of Patterson. The most recent TDS concentration data show a similar pattern (**Figure 5-34**) with a few shallow wells near Los Banos with improving TDS concentrations. No TDS data for shallow wells are available for the Mendota and Tranquillity area. Higher TDS concentrations (greater than 1,500 mg/L) in deeper wells above the Corcoran Clay are observed in the area south of Los Banos and to the north and along the San Joaquin River where poor drainage conditions may exist. TDS concentrations in the remaining Subbasin are largely below 1,500 mg/L (**Figure 5-33**). The most recent data (**Figure 5-34**) show very similar patterns as the maximum concentration data with some wells showing improved TDS concentrations.

The majority of very shallow wells (<50 feet in depth) in the southern-central portion of the Subbasin have concentrations exceeding 3,000 mg/L (**Figure 5-33**). Wells to the south of W. Nees Avenue and east of N. Fairfax Avenue have relatively lower TDS values concentrated. There is a lack of data for very shallow wells in the proximity of the California Aqueduct. A clear trend of decreased TDS values can be seen when comparing the most recent TDS concentrations with the historical maximum values for very shallow wells (**Figure 5-34**). The area with the greatest number of wells with decreased TDS values is the area bounded by the Delta-Mendota Canal, Merced-Fresno County line, and W. Nees Avenue. For shallow wells, there is a gap in data to the north of the Delta-Mendota Canal (**Figure 5-33**). A clear trend of increasing TDS values to the east is evident in **Figure 5-33** with a majority of the wells located to the east of N. Russell Avenue exceeding 3,000 mg/L. This is in contrast with a considerably high number of wells to the west of N. Russell Avenue having concentrations below 1,000 mg/L.

TDS concentrations seem to be improving in shallow wells (**Figure 5-33** and **Figure 5-34**). Specifically, the most prevalent reductions in TDS concentrations can be observed in the area enclosed by the Delta-Mendota Canal, Merced-Fresno County line, W. Nees Avenue and N. Russell Avenue. TDS data for wells deeper in the Upper Aquifer are sparse (**Figure 5-33** and **Figure 5-34**); all available data points exceed 1,000 mg/L.



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-31. Maximum TDS Concentrations, All Wells

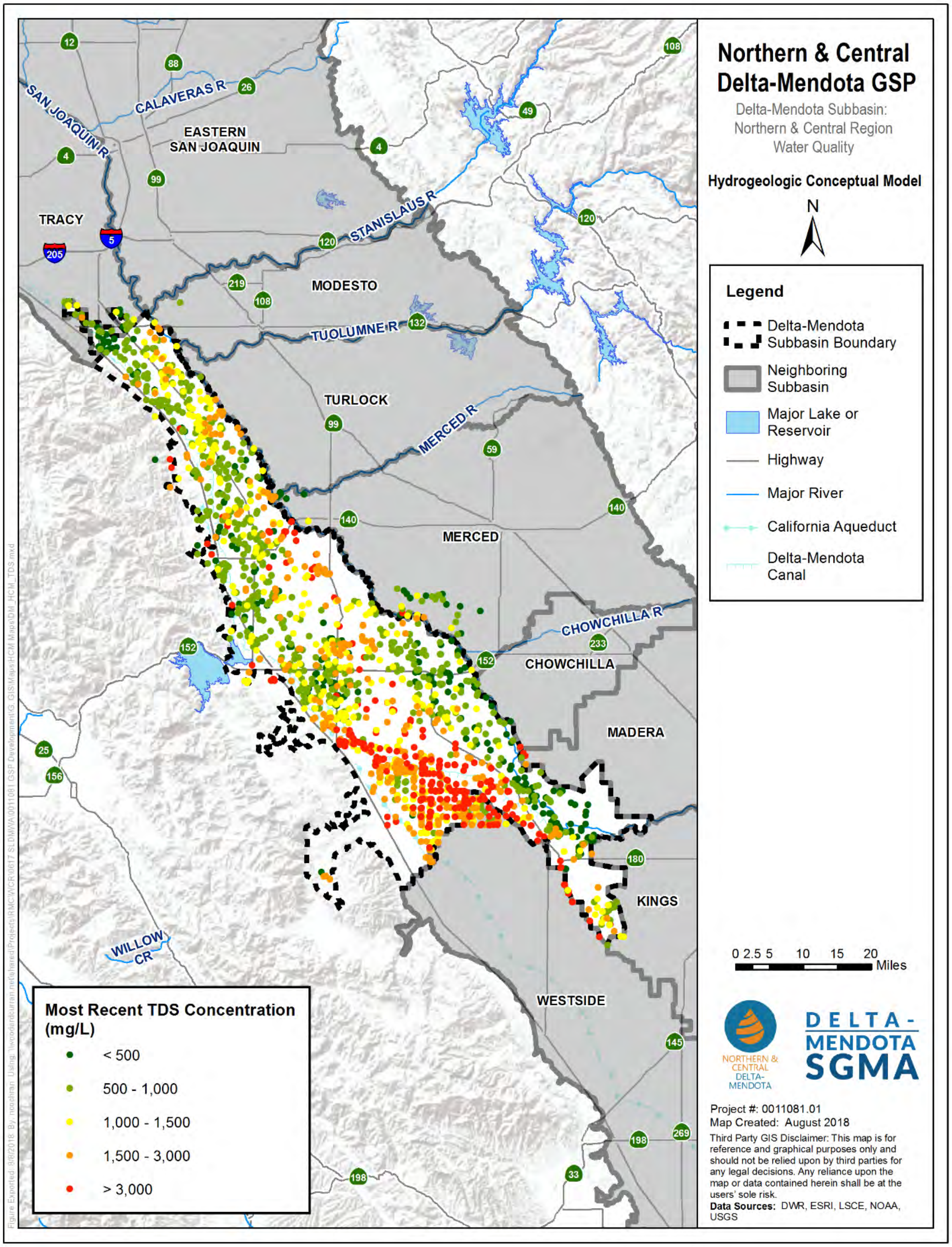
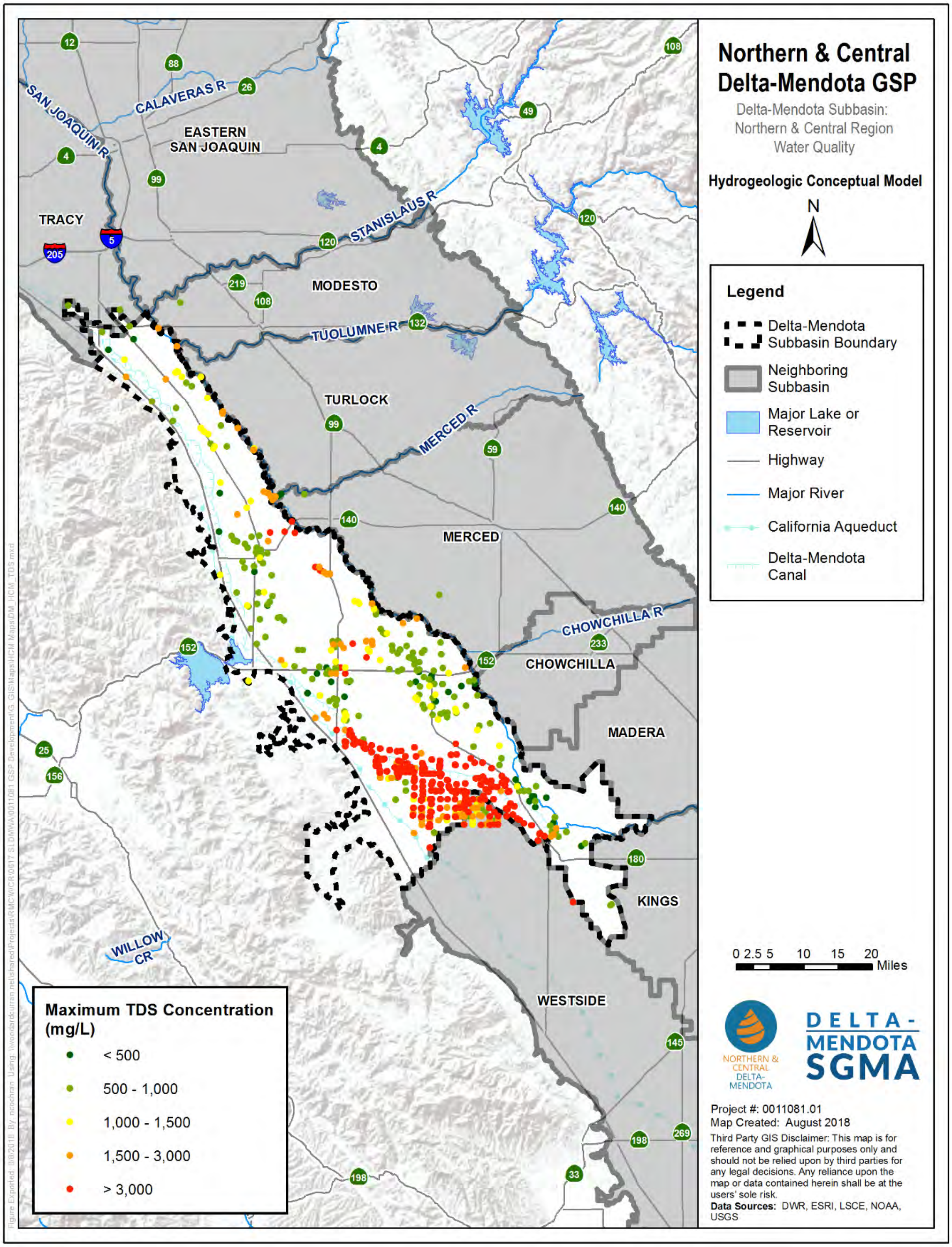


Figure 5-32. Most Recent (2000-2014) TDS Concentrations, All Wells



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-33. Maximum TDS Concentrations, Above Corcoran Clay

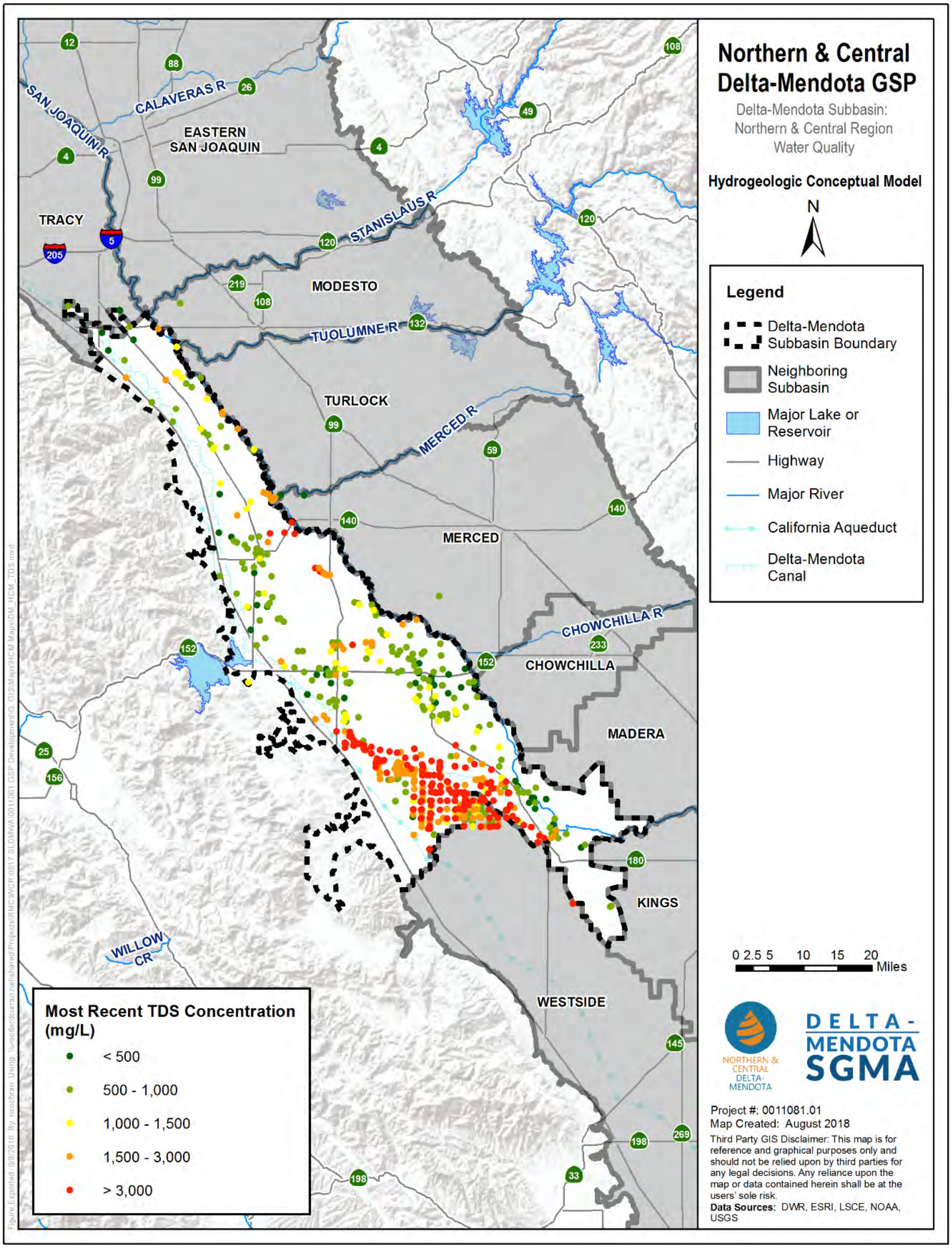


Figure 5-34. Most Recent (2000-2014) TDS Concentrations, Above Corcoran Clay

Below Corcoran Clay

As seen in **Figure 5-35** and **Figure 5-36**, TDS concentration data for wells below the Corcoran Clay are limited compared to above the Corcoran Clay well data and are notably scarce between Los Banos and Tranquillity. However, TDS concentrations north of Los Banos indicate overall lower salinity in the Lower Aquifer than is evident in the Upper Aquifer. A majority of the wells in the Lower Aquifer show maximum TDS concentrations below 1,500 mg/L with maximum TDS concentrations below 1,000 mg/L in most wells along the northwestern edge of the Delta-Mendota Subbasin (**Figure 5-35**). A few wells with TDS concentrations above 1,500 mg/L are scattered between Los Banos and north of Patterson. The most recent data (**Figure 5-36**) highlight the same patterns evident in the maximum concentration data. Few TDS concentration data exist southeast of Los Banos for the Lower Aquifer, although the minimally available data suggest deeper TDS concentrations in these areas are mostly less than 1,500 mg/L.

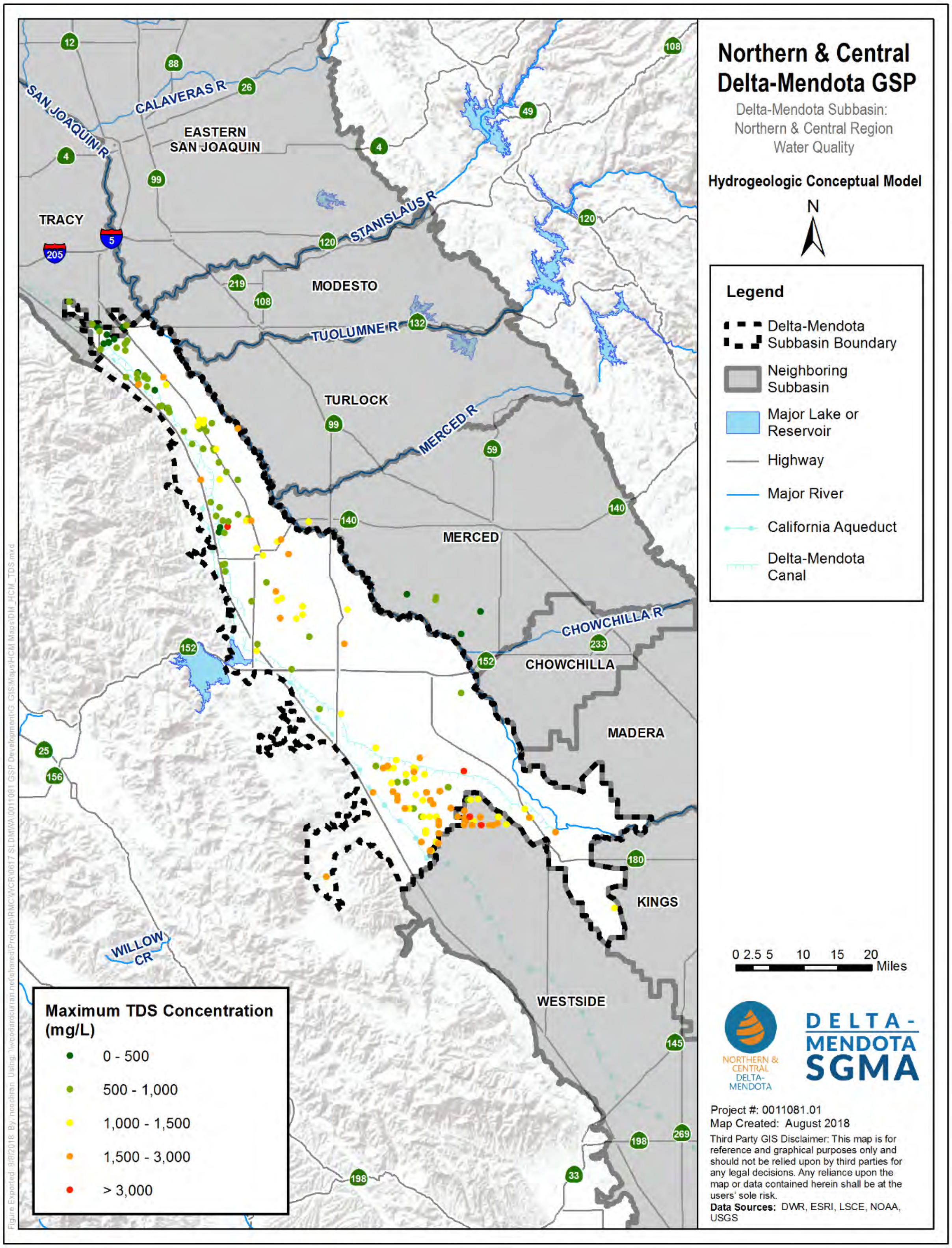
In the south-central portion of the Subbasin, the majority of data points from the Lower Aquifer exceed 1,000 mg/L (**Figure 5-35**). Wells with data are dispersed throughout this portion of the Subbasin with very little data available north of the Delta-Mendota Canal. A similar data distribution is seen in **Figure 5-36** with very little data available north of the Delta-Mendota Canal. Most recent TDS concentrations also reflect historic maximums with most samples exceeding 1,000 mg/L.

Composite Wells

Figure 5-37 depicts maximum TDS concentration data for composite wells screened both above and below the Corcoran Clay, whereas **Figure 5-38** presents the most recent concentration data for composite wells. Very few TDS concentrations are available for the composite well category, but most results are below 1,500 mg/L.

Wells of Unknown Depth

As shown in **Figure 5-39** and **Figure 5-40**, much TDS concentration data exist for wells of unknown depth. These figures show a similar pattern to the Upper Aquifer TDS Concentration maps (**Figure 5-33** and **Figure 5-34**) with the exception of a band of wells that exceed 1,500 mg/L south of Dos Palos and also south of Mendota that may be related to the saline front originating in the Coast Range. Several areas with higher densities of wells with lower TDS concentrations can be seen in **Figure 5-39** and **Figure 5-40**. The area north of Dos Palos, and also the area between Dos Palos and Mendota, have a particularly high density of wells of unknown depth with lower TDS concentrations that are mostly less than 1,000 mg/L.



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-35. Maximum TDS Concentrations, Below Corcoran Clay

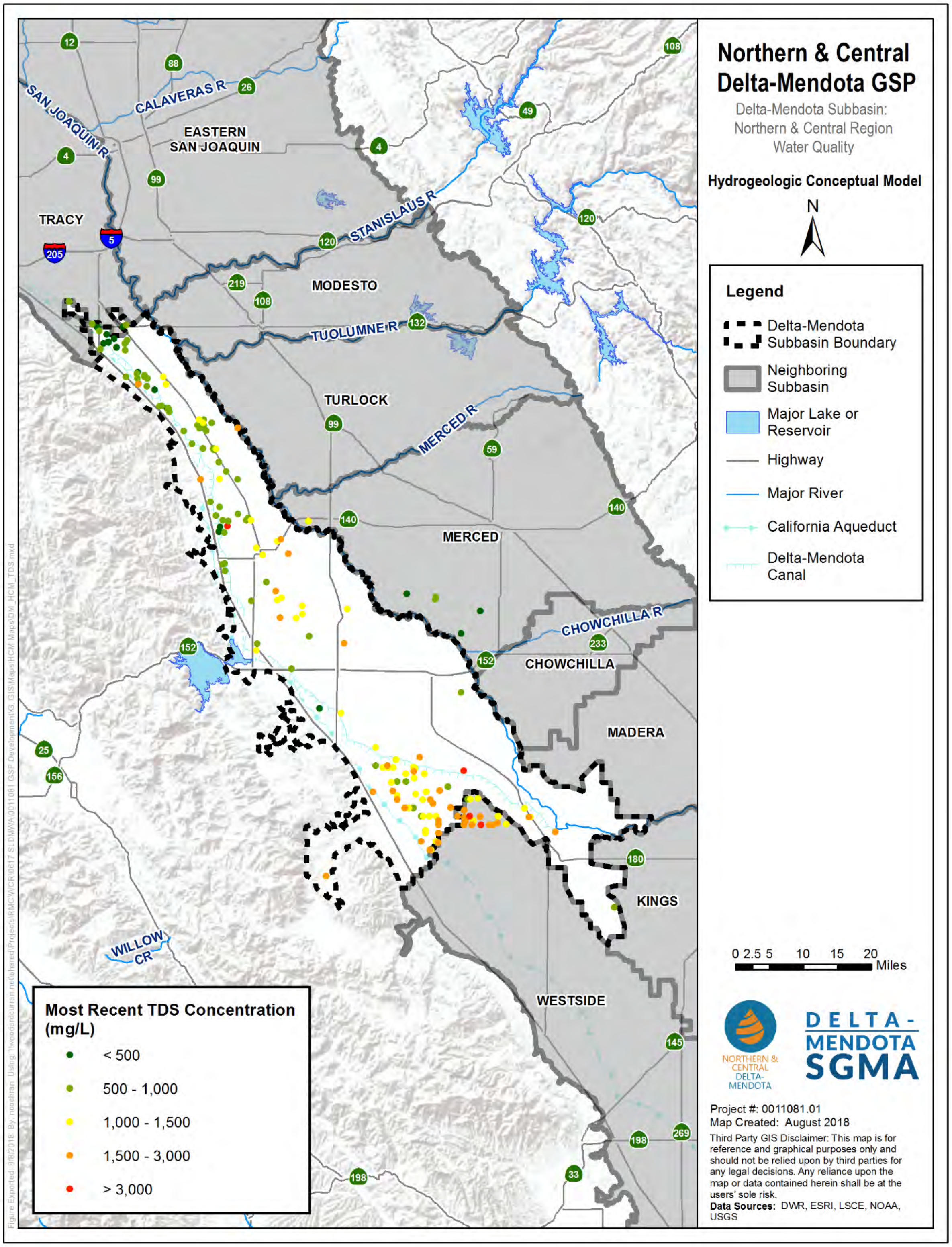
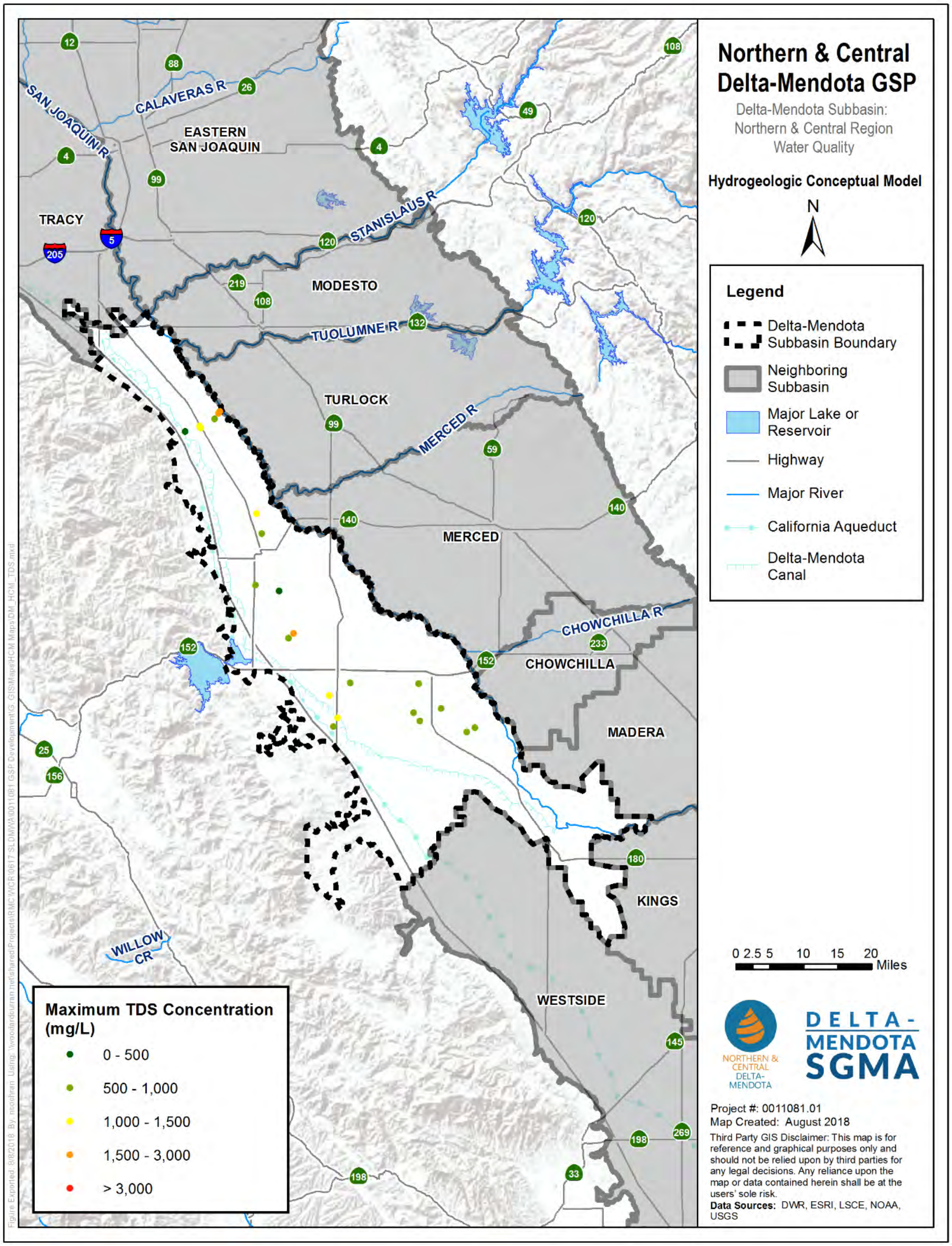


Figure 5-36. Most Recent (2000-2014) TDS Concentrations, Below Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-37. Maximum TDS Concentrations, Composite Wells

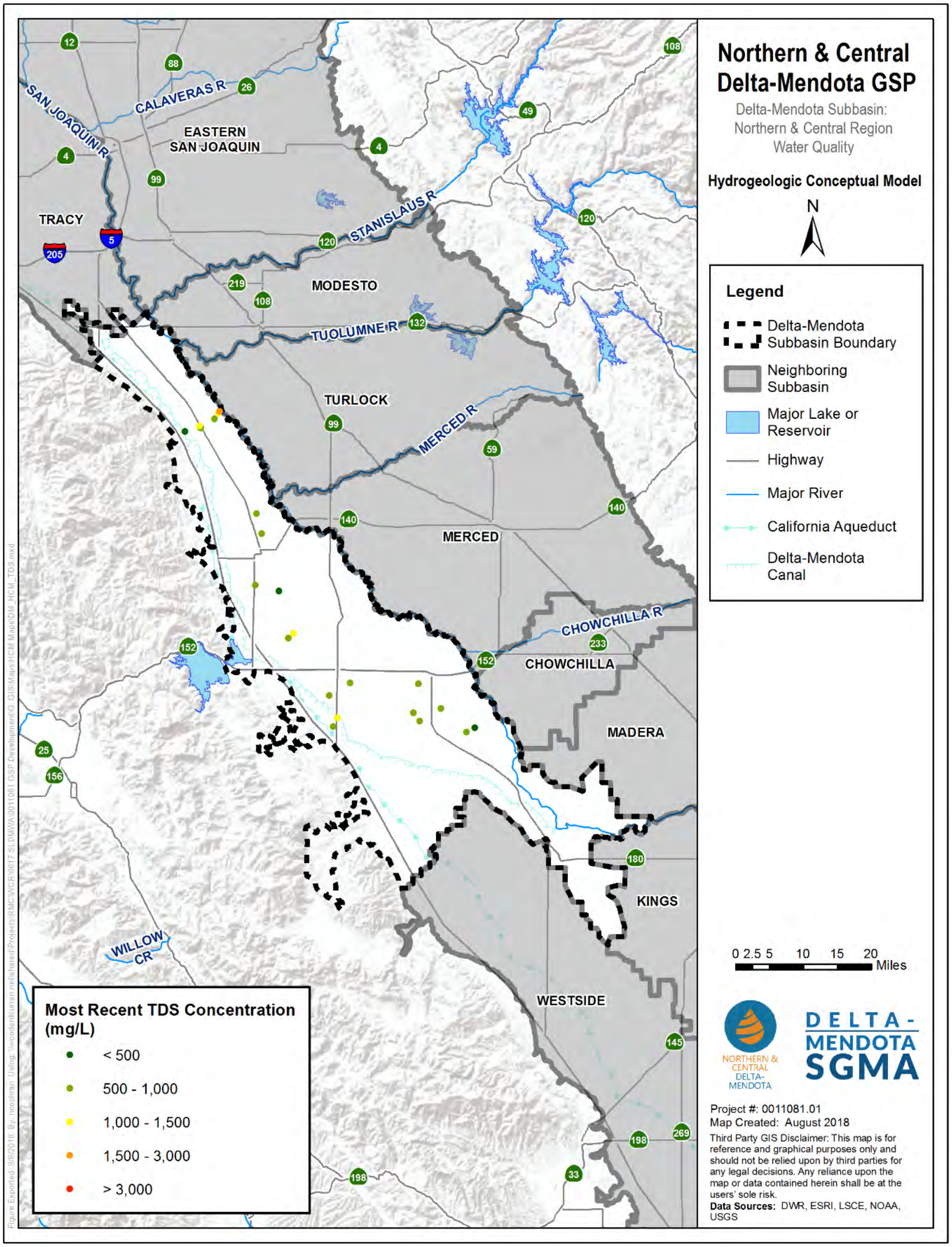
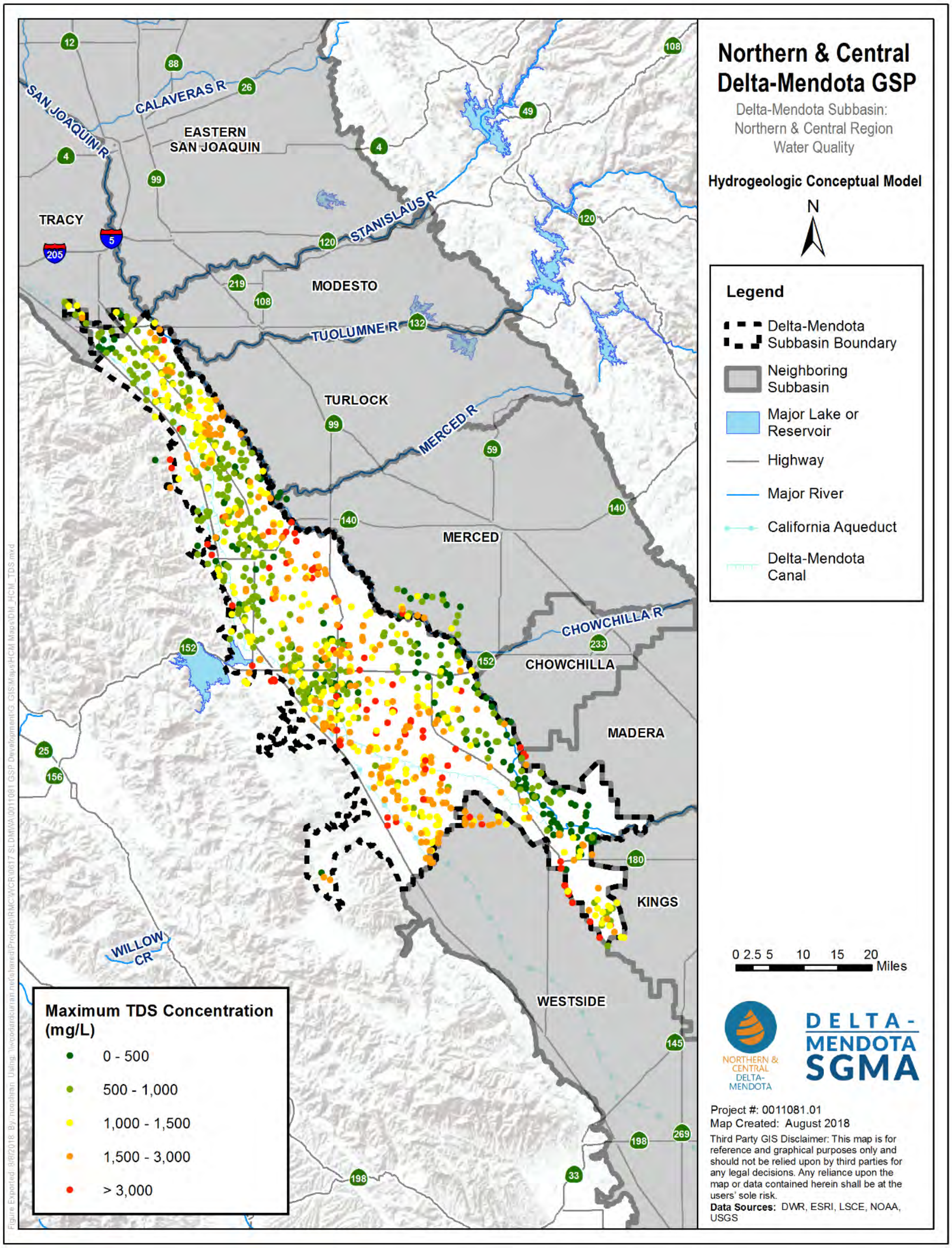


Figure 5-38. Most Recent (2000-2014) TDS Concentrations, Composite Wells



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-39. Maximum TDS Concentrations, Wells of Unknown Depth

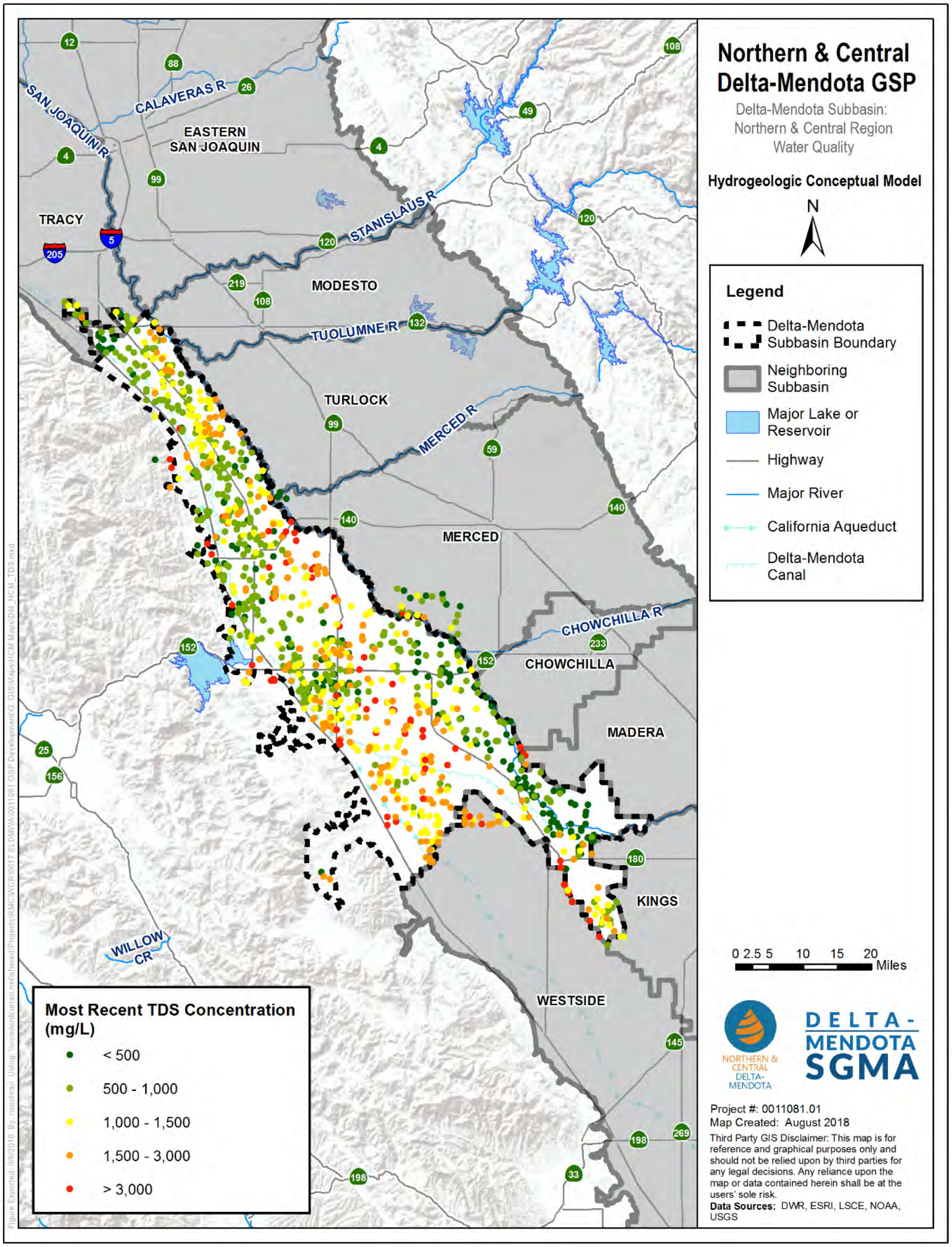


Figure 5-40. Most Recent (2000-2014) TDS Concentrations, Wells of Unknown Depth

5.2.8.2.3 Pesticides

Pesticide concentration data for the Delta-Mendota Subbasin are limited to data obtained from the California Department of Pesticide Regulation (DPR), as originally presented in Luhdorff & Scalmanini Consulting Engineers (LSCE) (2015) and LSCE (2016). Pesticide data available from DPR are for wells, but locations are only provided at the spatial resolution of the Public Land Survey System (PLSS) section in which the well is located and well depths are not reported or available for most wells. **Figure 5-41** shows the locations of sections where wells have been sampled for pesticides and where pesticide test results are reported by DPR and include sections that may only be partially within the Subbasin. Because well locations are not provided with these pesticide data, it is possible that wells in sections that are only partly within the subbasin actually fall outside of the Subbasin.

Sections with detected concentrations of pesticides exceeding levels provided in the State Water Resources Control Board (SWRCB) Water Quality Goals Online Database are symbolized red in **Figure 5-41**; sections where pesticide detections have occurred at concentrations below the identified exceedance threshold are symbolized as orange, and green sections signify areas where pesticides were not detected. **Figure 5-41** shows all available pesticide sample data from DPR within the Delta-Mendota Subbasin. **Table 5-1** summarizes pesticides that have been detected in wells that are in sections that overlap with the Subbasin completely or partially, as reported in the DPR database. The threshold values used as a basis for identifying pesticide exceedances are also included in **Table 5-1**. The thresholds used to define pesticide exceedances were based first on a California Primary MCL; otherwise, the California Notification (action) Level and U.S. Environmental Protection Agency (EPA) Health and Water Quality advisory concentrations were used for comparison, as available.

Data for a total of 475 wells (in 258 PLSS sections) tested for pesticides in the study area were available from DPR. Of the 475 wells tested, eight unique wells had detectable concentrations of a pesticide (**Table 5-1**). As shown in **Table 5-1**, 486 instances of pesticide detections were recorded within the Delta-Mendota Subbasin; however, some wells had detectable concentrations of multiple pesticides. Of the 258 sections that had wells tested, 62 sections had wells with detectable concentrations of a pesticide and 6 sections had wells with exceedances. As shown in **Figure 5-41**, a higher density of pesticide detections and exceedances has occurred in the northern part of the Delta-Mendota Subbasin, from south of Gustine to north of Patterson.

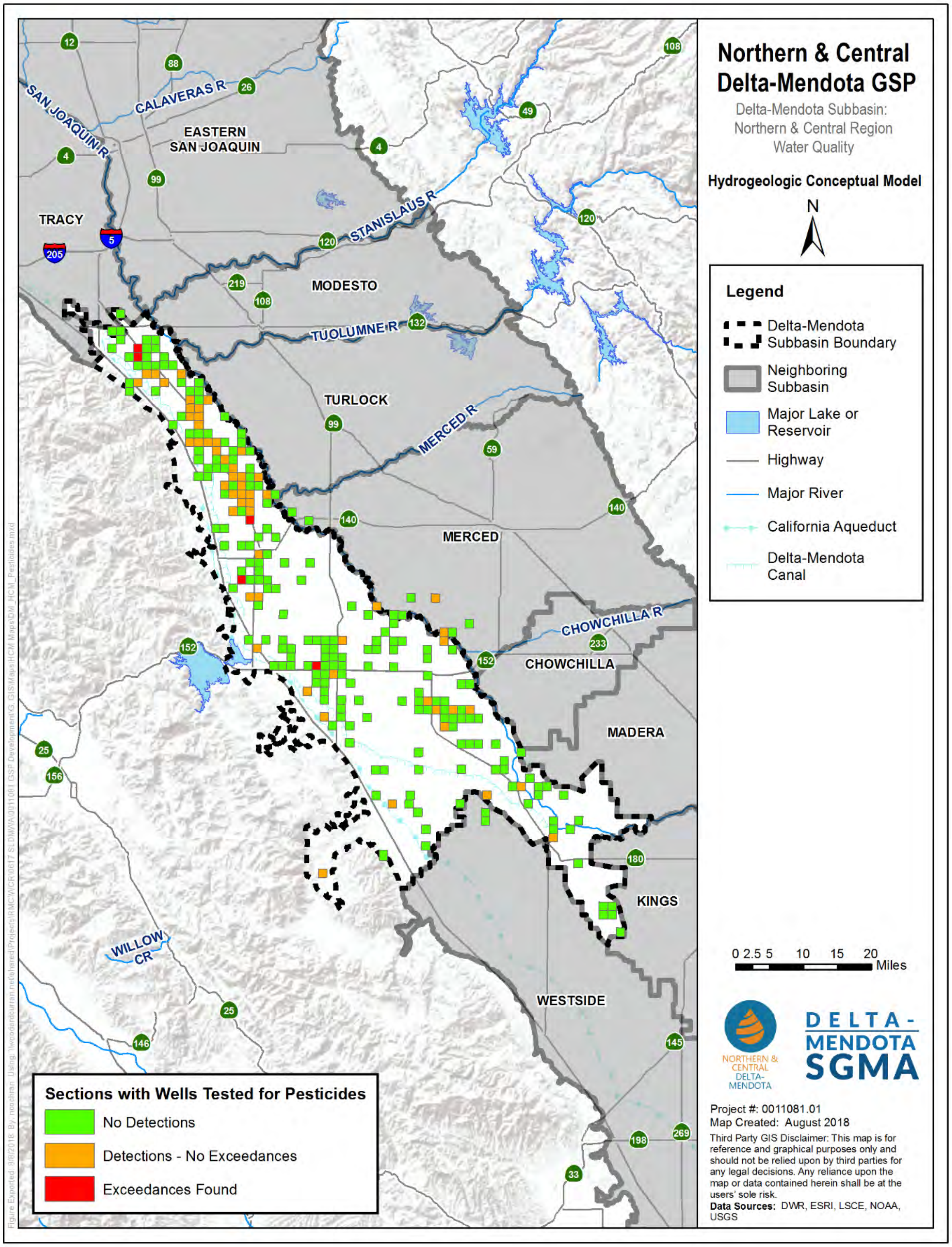


Figure 5-41. Pesticide Detections and Exceedances by Section

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Table 5-1. Summary of Pesticide Detections and Exceedances

Pesticide	Wells Sampled	Wells with Detection	Number of Sample Detections	Wells with Exceedance	Sections Sampled	Sections with Detection	Sections with Exceedance	Concentration in Samples with Detections (µg/L) Average	Minimum	Maximum	Exceedance Threshold[1] (µg/L)	Basis for Exceedance Threshold[1]
1,2-Dichloropropane (Propylene Dichloride)	204	1	1	0	129	1	0	0.039	0.039	0.039	5	
2,6-Diethylaniline	45	1	1	0	34	1	0	0.005	0.005	0.005	-	-
2-Hydroxycyclohexyl Hexazinone	8	1	1	0	6	1	0	0.126	0.126	0.126	-	-
3,4-Dichloro Aniline	45	5	5	0	34	4	0	0.048	0.004	0.215	-	-
3,5-Dichloro Aniline	40	1	1	0	30	1	0	0.004	0.004	0.004	-	-
ACET (Deisopropylatrazine)	68	1	1	0	46	1	0	0.052	0.052	0.052	-	-
Alachlor ESA	40	18	23	0	28	11	0	0.53	0.05	1.38	4	WI DNR PAL
Alachlor OXA	36	1	2	0	24	1	0	0.051	0.05	0.051	-	-
Atrazine	314	10	14	0	189	8	0	0.063	0.006	0.2	1	CA Primary MCL
Carbon Disulfide	64	3	3	0	43	3	0	0.373	0.03	1.06	160	California State Notification (Action) Level
Chlorthal-Dimethyl	52	1	1	0	40	1	0	0.004	0.004	0.004	-	-
DBCP (Dibromochloropropane)	214	15	292	2	123	10	2	0.234	0.005	10.1	0.2	CA Primary MCL
Deethyl-Atrazine (DEA)	113	11	11	0	80	9	0	0.012	0.005	0.028	-	-
Diaminochlorotriazine (DACT)	60	1	1	0	38	1	0	0.091	0.091	0.091	-	-
Diuron	165	7	17	0	104	7	0	0.204	0.07	0.73	2	U.S. EPA Health Advisory Cancer[2]
EPTC	57	5	5	0	43	5	0	0.03	0.008	0.074	40	MN HBV (Chronic)
Ethylene Dibromide	158	3	6	3	98	3	3	0.266	0.08	0.48	0.05	CA Primary MCL
Hexazinone	148	10	11	0	94	9	0	0.047	0.009	0.094	-	-

Pesticide	Wells Sampled	Wells with Detection	Number of Sample Detections	Wells with Exceedance	Sections Sampled	Sections with Detection	Sections with Exceedance	Concentration in Samples with Detections (µg/L) Average	Minimum	Maximum	Exceedance Threshold[1] (µg/L)	Basis for Exceedance Threshold[1]
Metalaxyl	47	2	2	0	36	1	0	0.035	0.015	0.054	-	-
Metolachlor	133	4	4	0	73	2	0	0.024	0.013	0.045	44	U.S. EPA Water Quality Advisory Concentration[3]
Metolachlor ESA	36	25	31	0	24	17	0	2.928	0.05	24	-	-
Metolachlor OXA	36	11	15	0	24	8	0	0.473	0.05	2.65	-	-
Molinate	114	3	3	0	59	3	0	0.01	0.007	0.01	20	CA Primary MCL
Prometon	236	8	8	0	157	8	0	4.413	0.021	13.4	-	-
Prometryn	217	2	2	0	136	2	0	0.004	0.001	0.006	-	-
Simazine	309	22	24	1	183	19	1	0.59	0.004	6.8	4	CA Primary MCL
Tebuthiuron	60	1	1	0	48	1	0	0.011	0.011	0.011	-	-

"-" No threshold established or identified

1. Source of threshold: California Environmental Protection Agency, State Water Resources Control Board, Compilation of Water Quality Goals (https://www.waterboards.ca.gov/water_issues/programs/water_quality_goals/)
2. U.S. EPA Health Advisory, Cancer Risk Level. Likely to be carcinogenic to humans.
3. National Recommended Ambient Water Quality Criteria to protect human health from consumption of water and aquatic organisms, cancer risk level

Reference: *Western San Joaquin River Watershed Groundwater Quality Assessment Report* (LSCE, 2015).and *Grassland Drainage Area Groundwater Quality Assessment Report* (LSCE, 2016)

5.2.8.2.4 Selenium and Boron

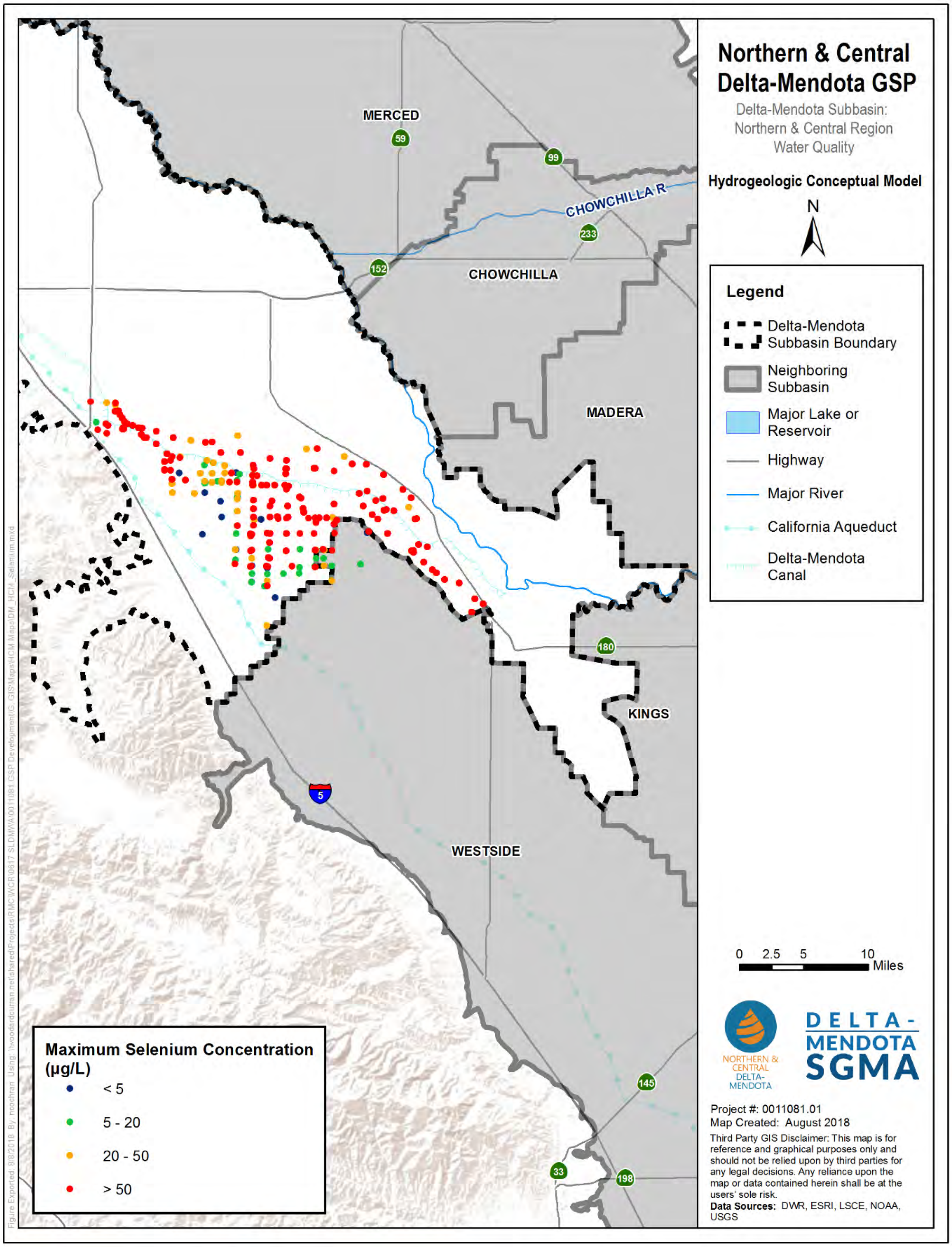
Although both selenium and boron are naturally occurring in the Delta-Mendota Subbasin and are not necessarily a product of impacts from irrigated agriculture, understanding the patterns and trends of their concentrations in groundwater within the Subbasin is helpful for the management of irrigated agriculture, particularly as it relates to sources of selenium in drainage water and boron concentrations in groundwater used for irrigation. Selenium is a natural element commonly found in soils and also occurring in groundwater. High selenium concentrations in groundwater and drainage water, especially in the southern portion of the Subbasin, have been a persistent issue. Selenium is an essential nutrient for humans; however, high concentrations can present health concerns. Selenium has a Primary MCL for drinking water of 50 micrograms per liter (µg/L) and a California Public Health Goal of 30 µg/L. Selenium can be toxic for aquatic wildlife at considerably lower levels and selenium concentrations in discharges of drainage water to surface waterways regulated under the Grassland Bypass Project Water Discharge Requirements (WDRs) have thresholds below the MCL and Public Health Goal.

Boron has no drinking water MCL, although it has a California Action Level of 1.0 mg/L and an agricultural goal of 0.7 mg/L. Many agricultural crops are sensitive to high boron concentrations and its presence in groundwater is a consideration for use of groundwater for irrigation purposes.

Figure 5-42 through **Figure 5-57** depict the historical maximum and most recent concentrations (about 2000 to 2014) for selenium and boron in the southern portion of the Delta-Mendota Subbasin, the portion of the subbasin where these constituents are of key concern. These figures are also divided by primary aquifer for each of the constituents. The units for selenium concentrations displayed on the figures are in micrograms per liter (µg/L) whereas boron concentrations are presented in milligrams per liter (mg/L).

Figure 5-42 highlights the maximum concentrations of selenium observed historically within the southern portion of the Subbasin. The majority of the datapoints show maximum historical concentrations exceeding the MCL of 50 µg/L, but an improvement is evident in the most recent concentrations of selenium in **Figure 5-43**. Although most locations exhibit concentrations above 50 µg/L, some pockets of lower selenium concentrations exist, most notably in the area to the northwest of the W. Nees Avenue and N. Russell Avenue intersection where concentrations are below 20 µg/L.

Historical maximum concentration data for boron above and below the Corcoran Clay is shown in **Figure 5-50,** and the most recent data are presented in **Figure 5-51**. Most of these data show historical boron concentrations above 2 mg/L, a level which is considerably above the agricultural goal of 0.7 mg/L.



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-42. Maximum Selenium Concentrations, All Wells

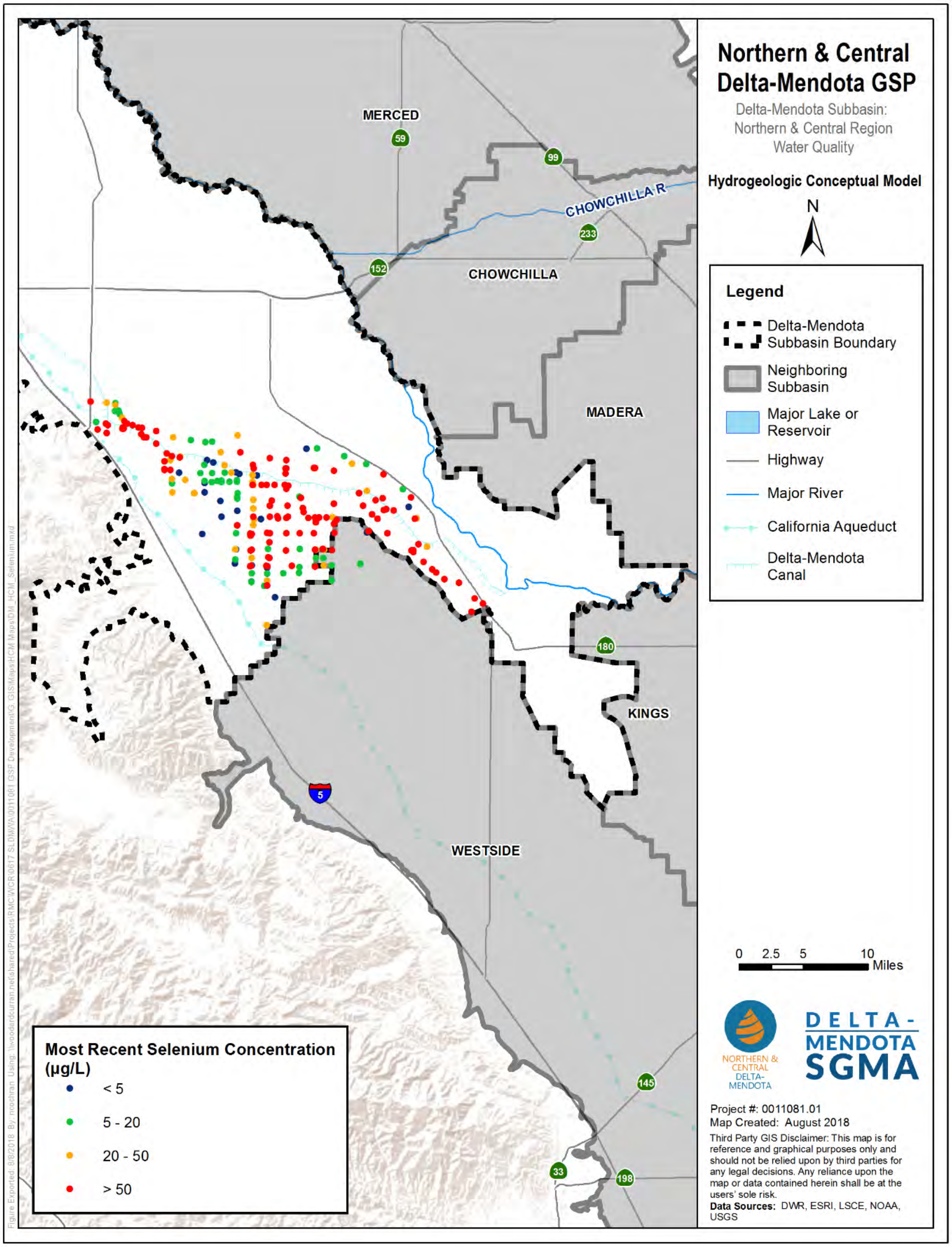
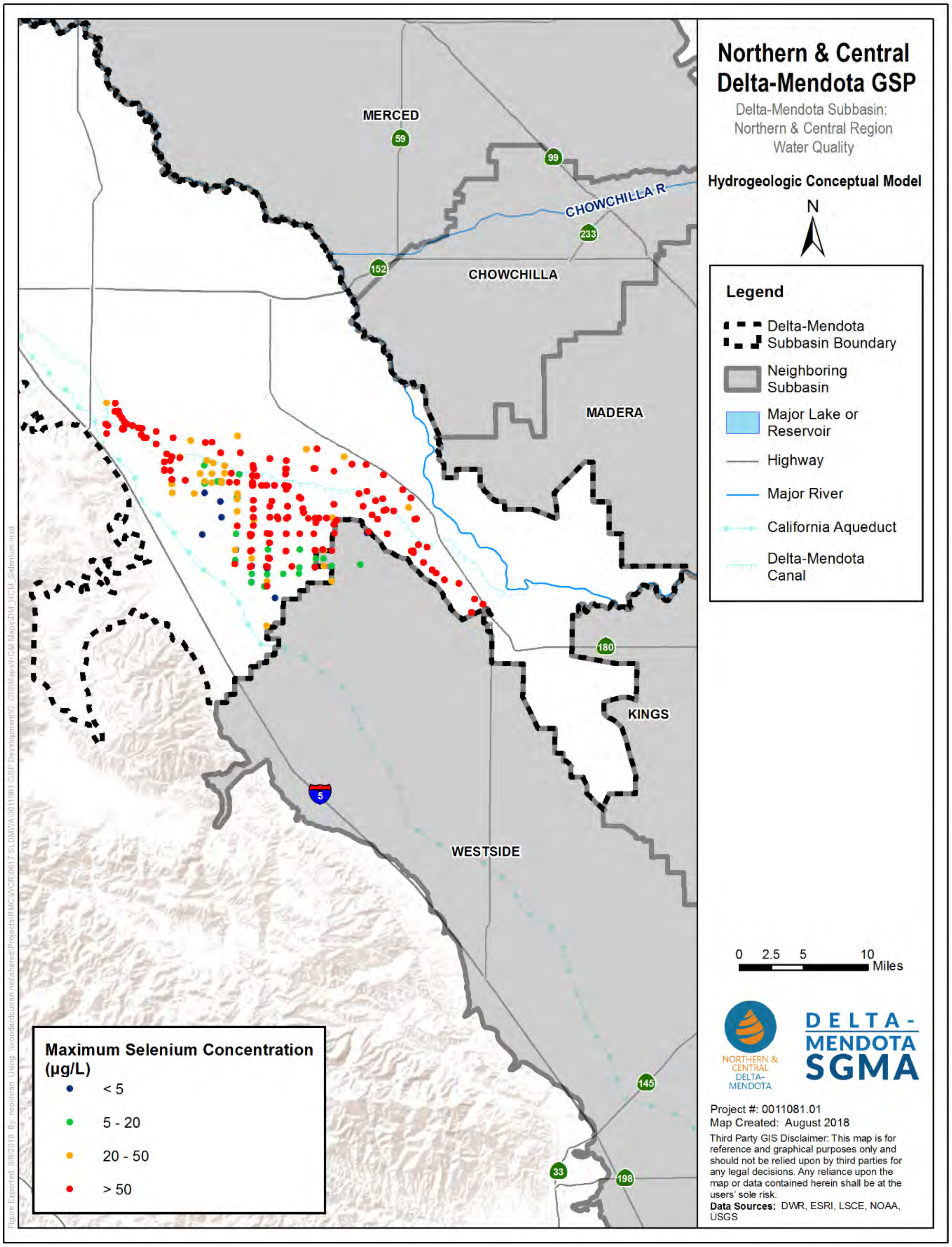


Figure 5-43. Most Recent (2000-2014) Selenium Concentrations, All Wells



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-44. Maximum Selenium Concentrations, Above Corcoran Clay

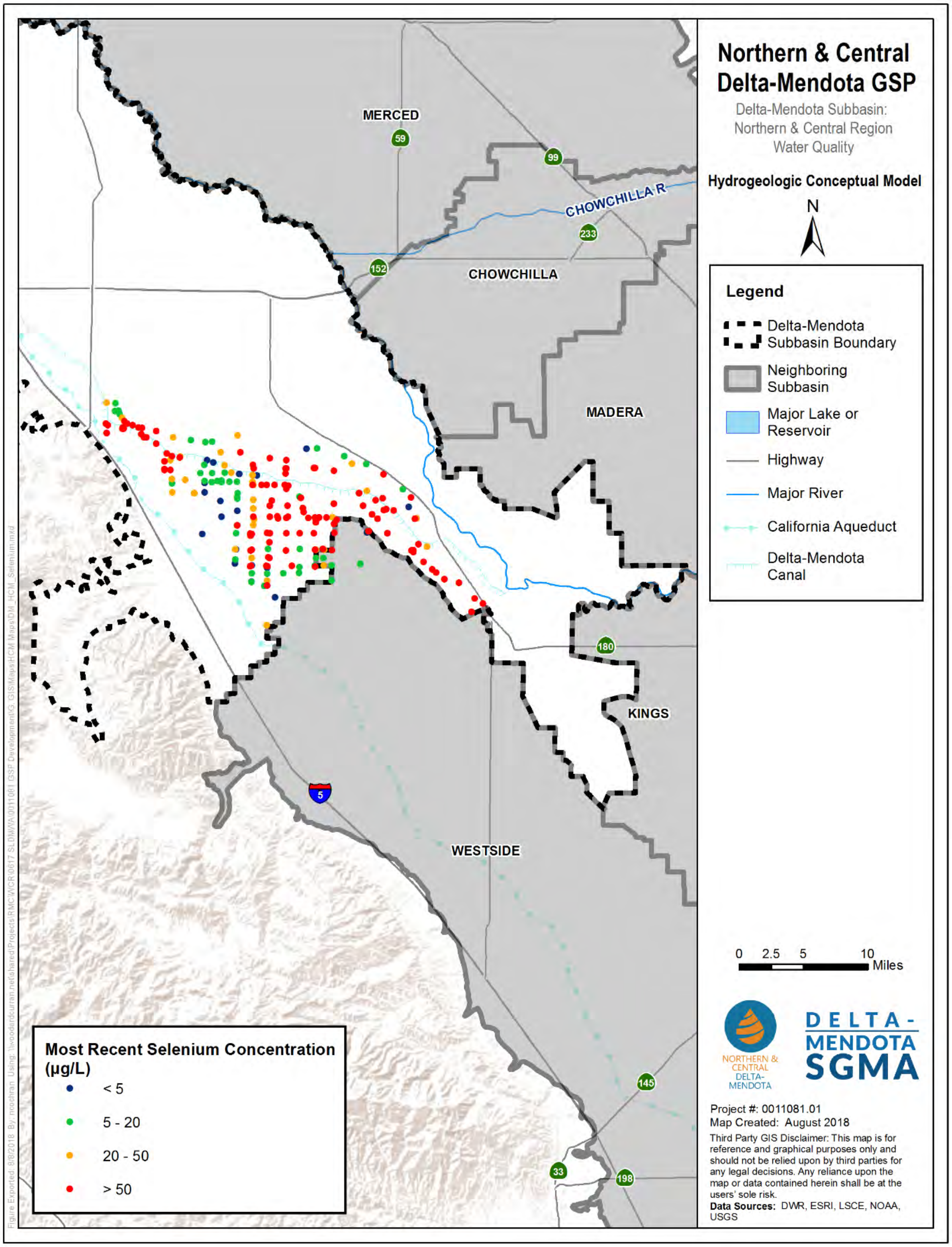
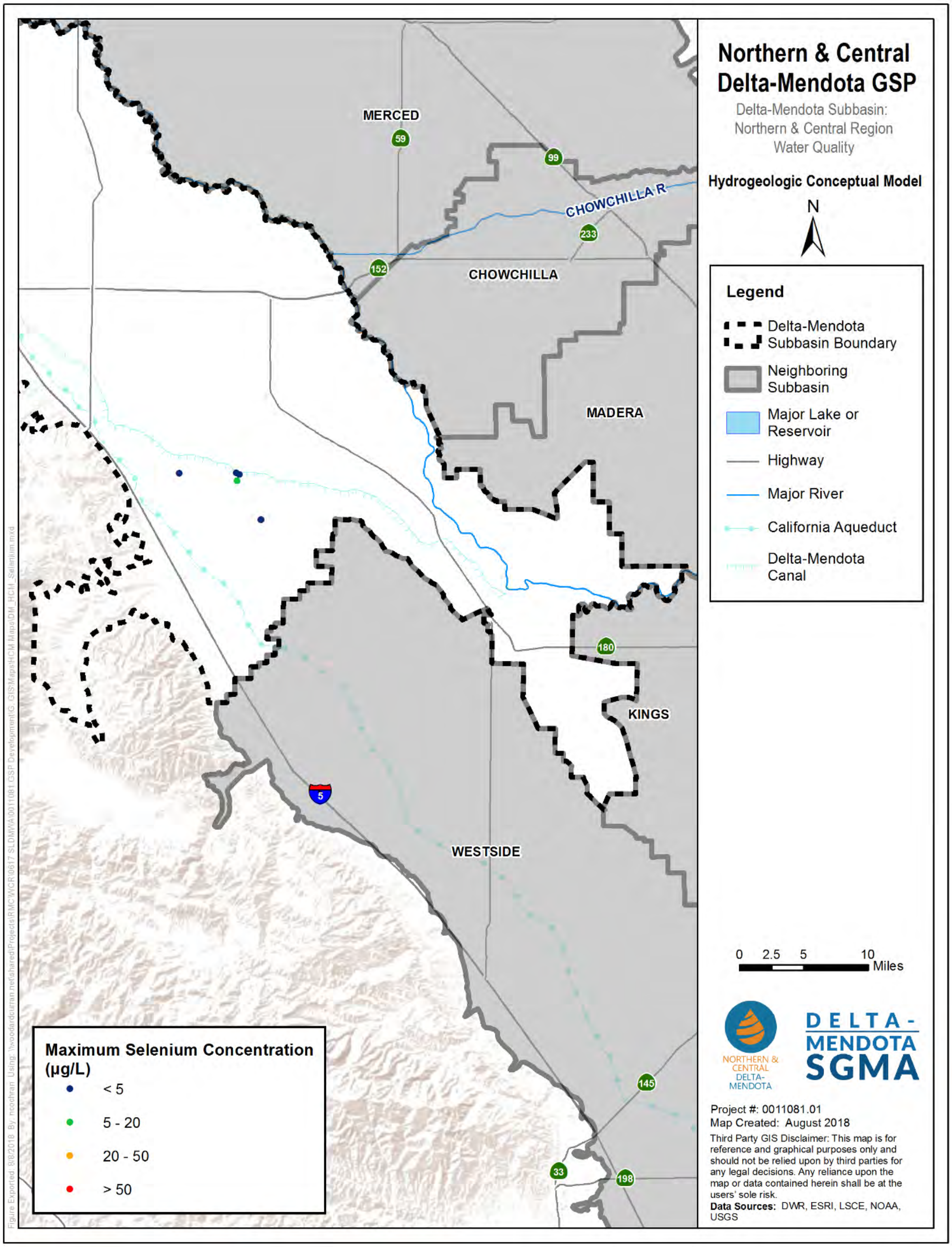


Figure 5-45. Most Recent (2000-2014) Selenium Concentrations, Above Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-46. Maximum Selenium Concentrations, Below Corcoran Clay

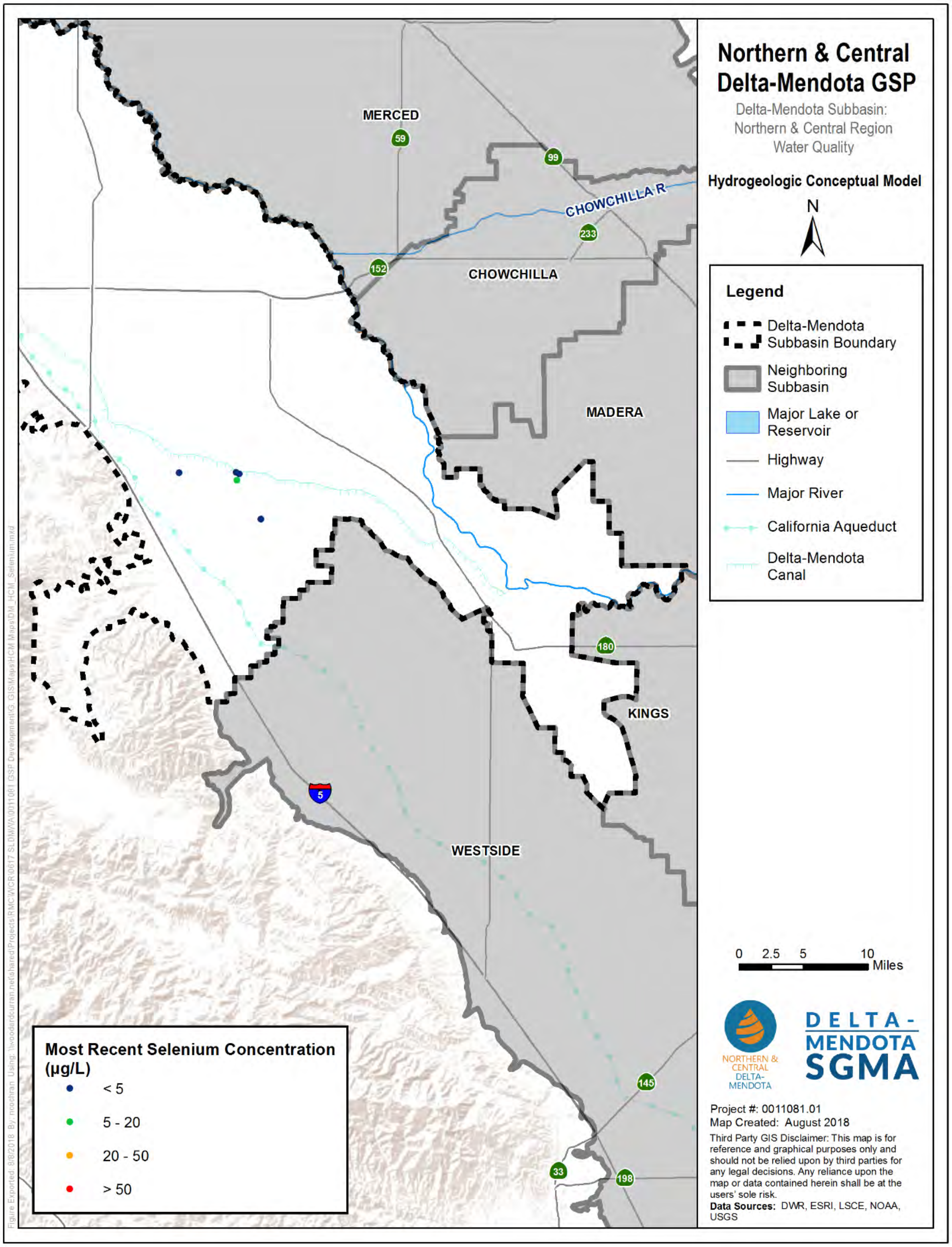
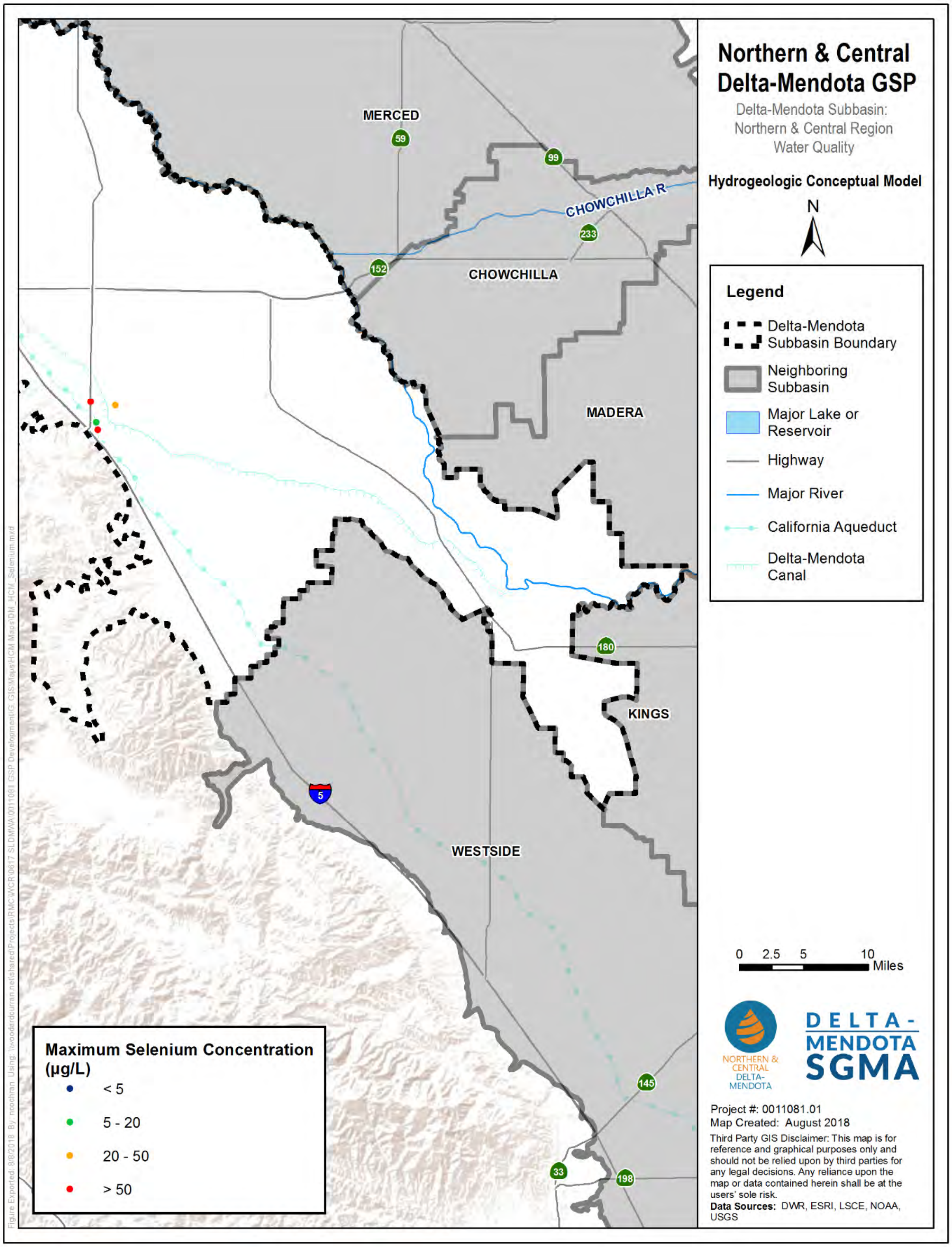


Figure 5-47. Most Recent (2000-2014) Selenium Concentrations, Below Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-48. Maximum Selenium Concentrations, Wells of Unknown Depth

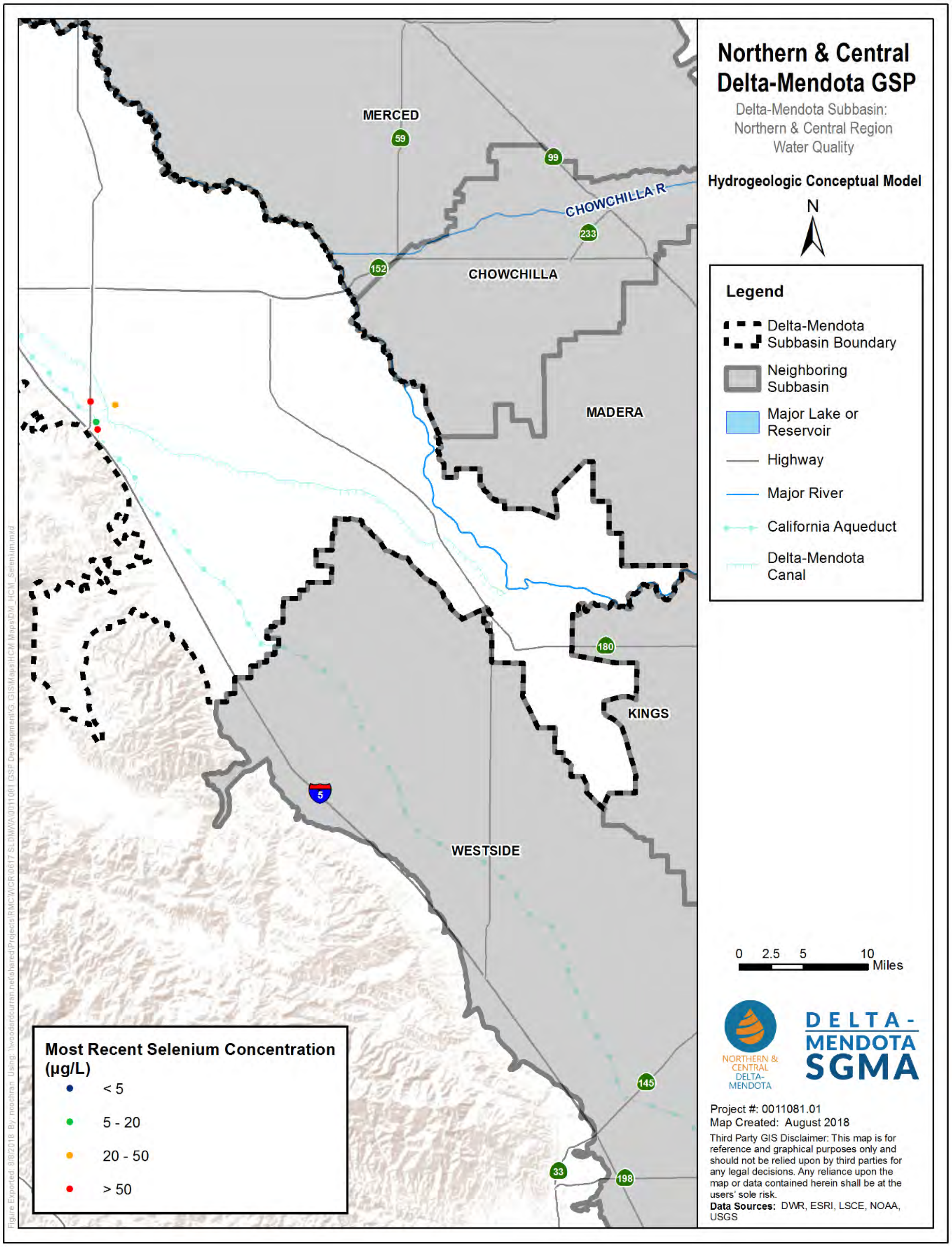
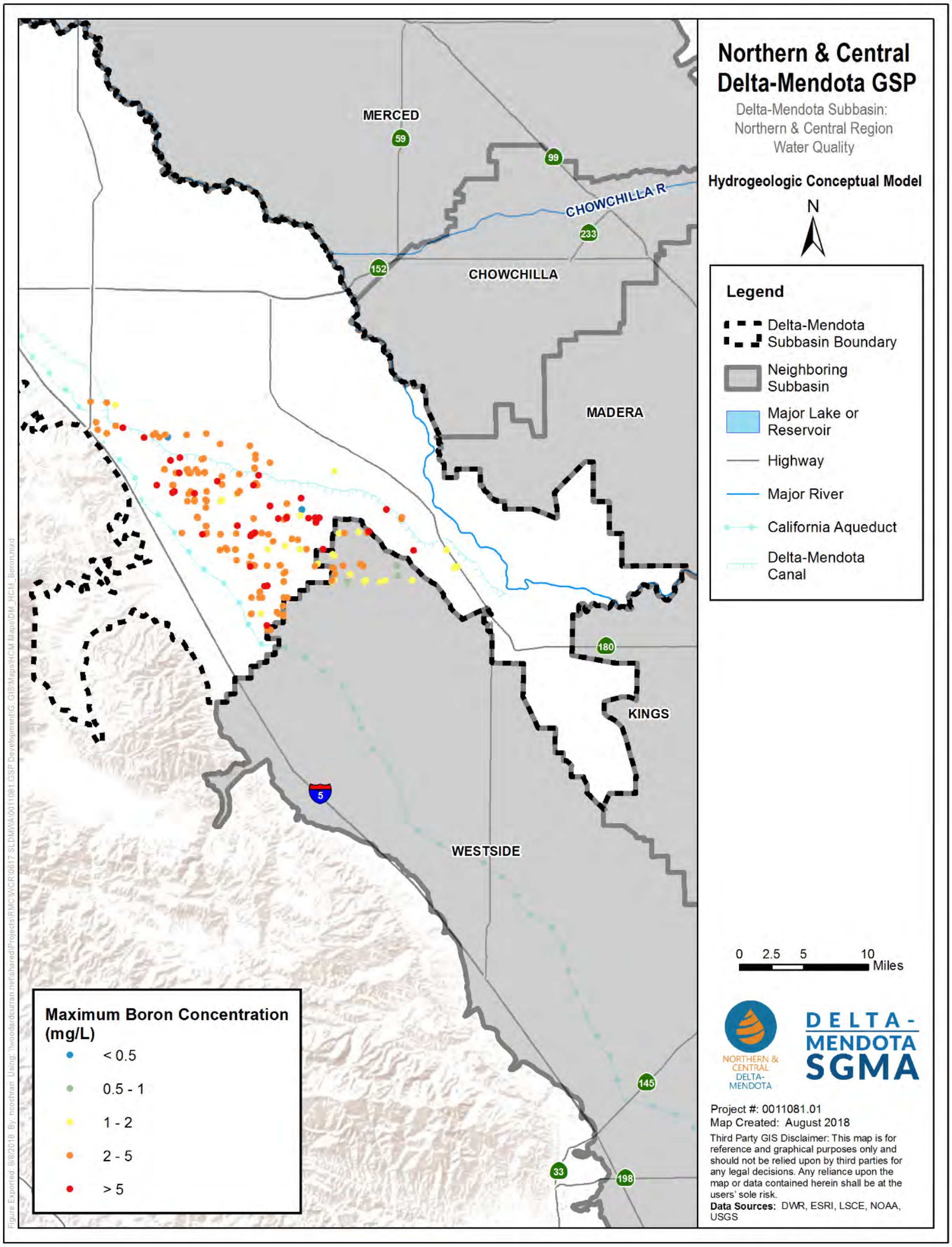


Figure 5-49. Most Recent (2000-2014) Selenium Concentrations, Wells of Unknown Depth



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-50. Maximum Boron Concentrations, All Wells

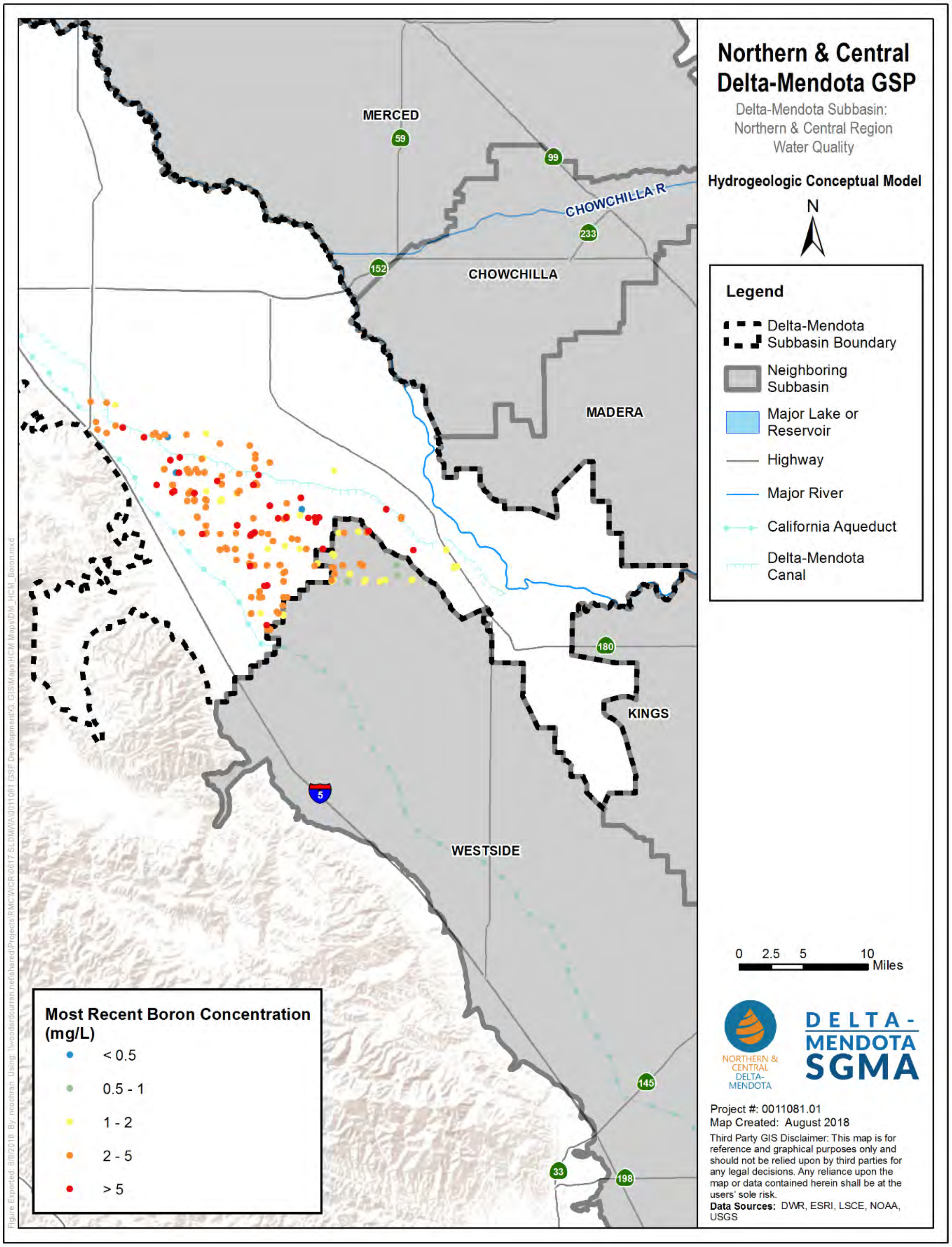
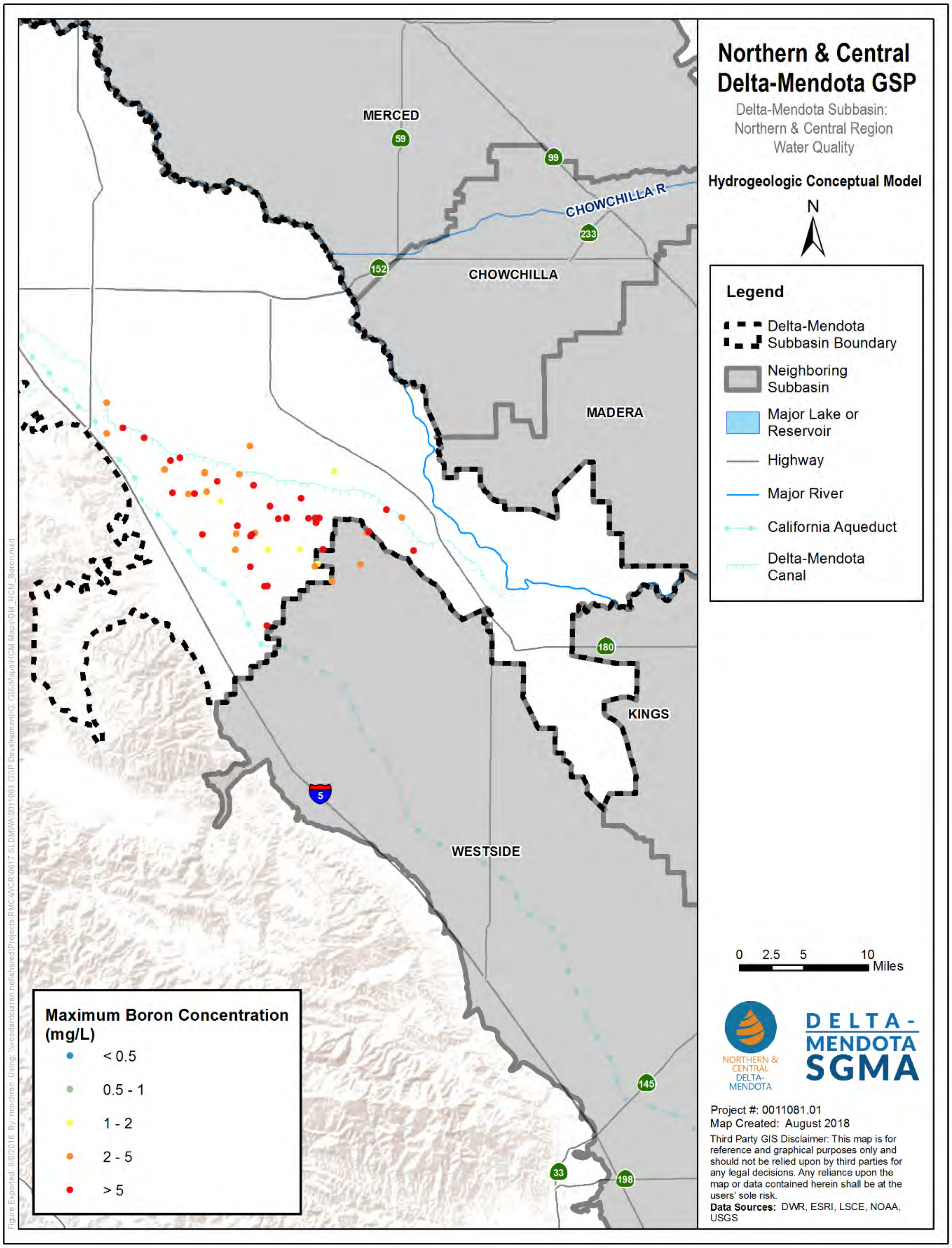


Figure 5-51. Most Recent (2000-2014) Boron Concentrations, All Wells



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-52. Maximum Boron Concentrations, Above Corcoran Clay

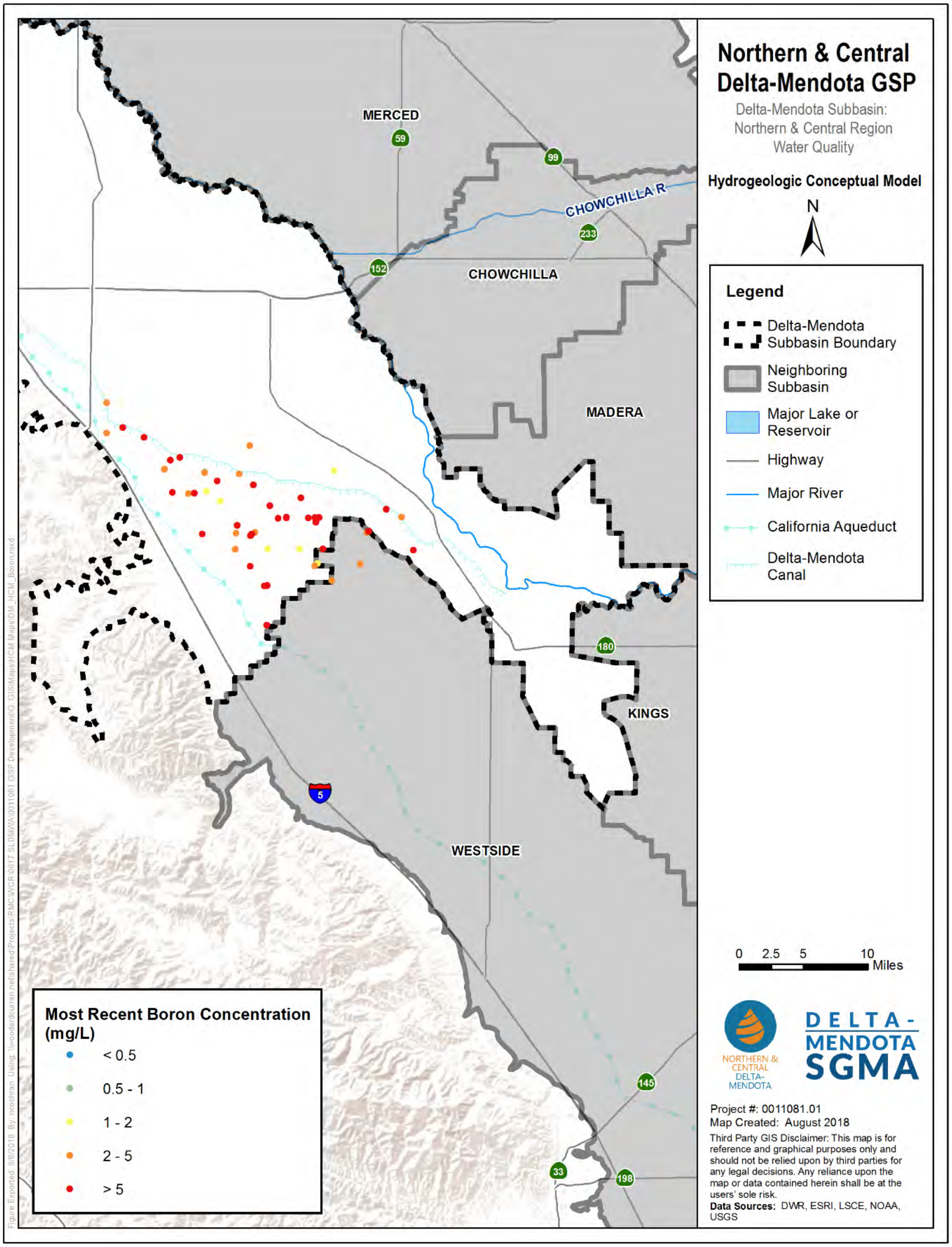
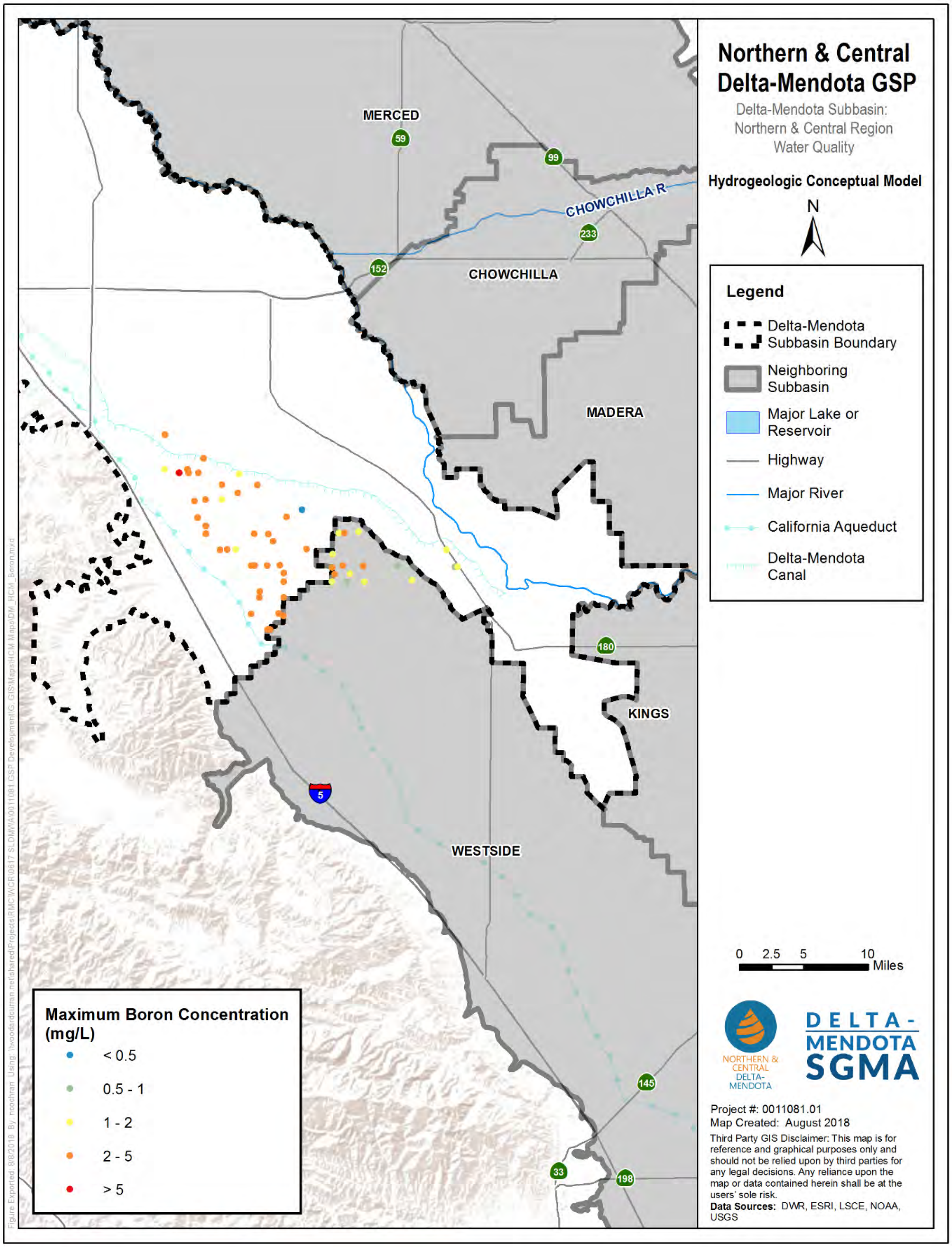


Figure 5-53. Most Recent (2000-2014) Boron Concentrations, Above Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-54. Maximum Boron Concentrations, Below Corcoran Clay

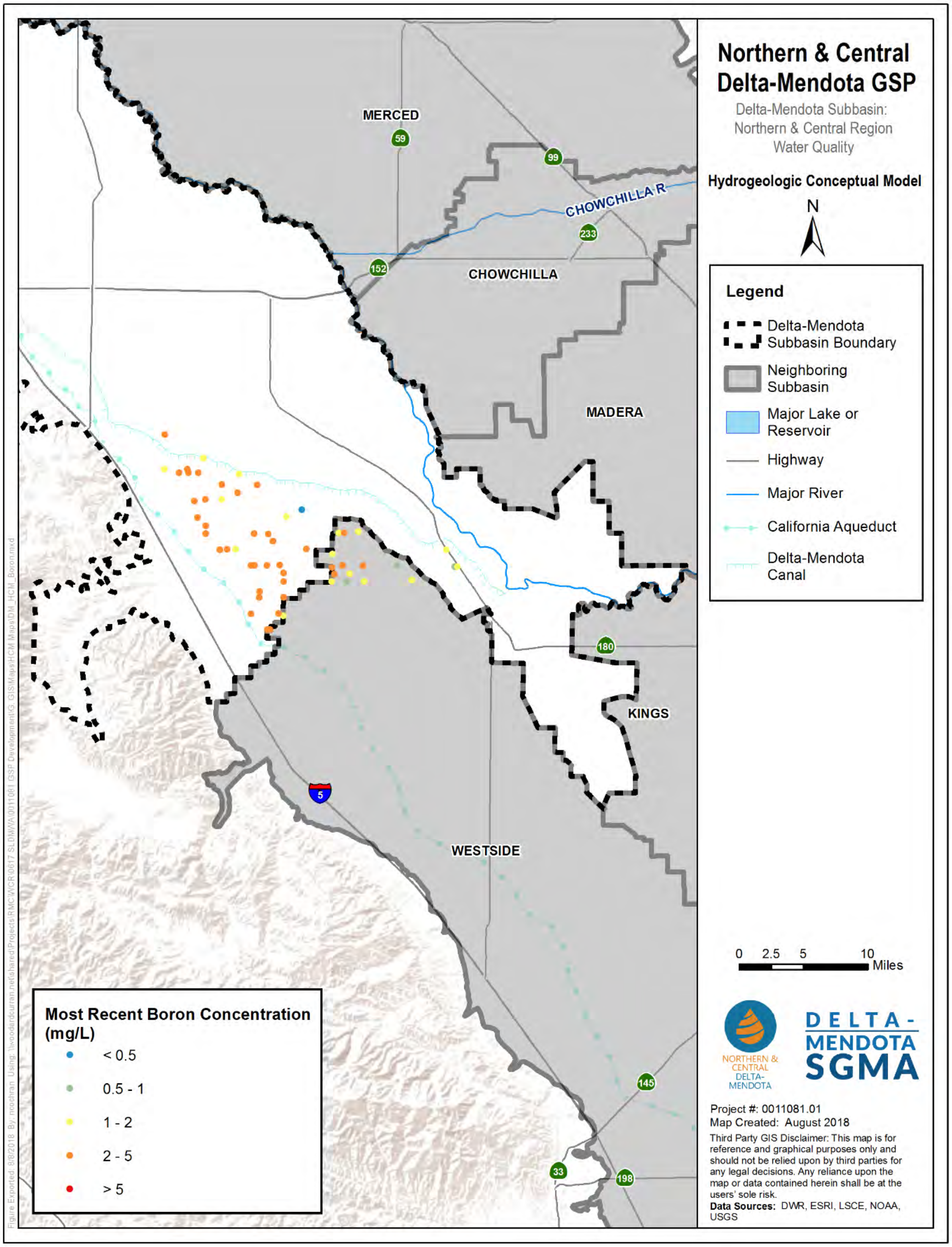
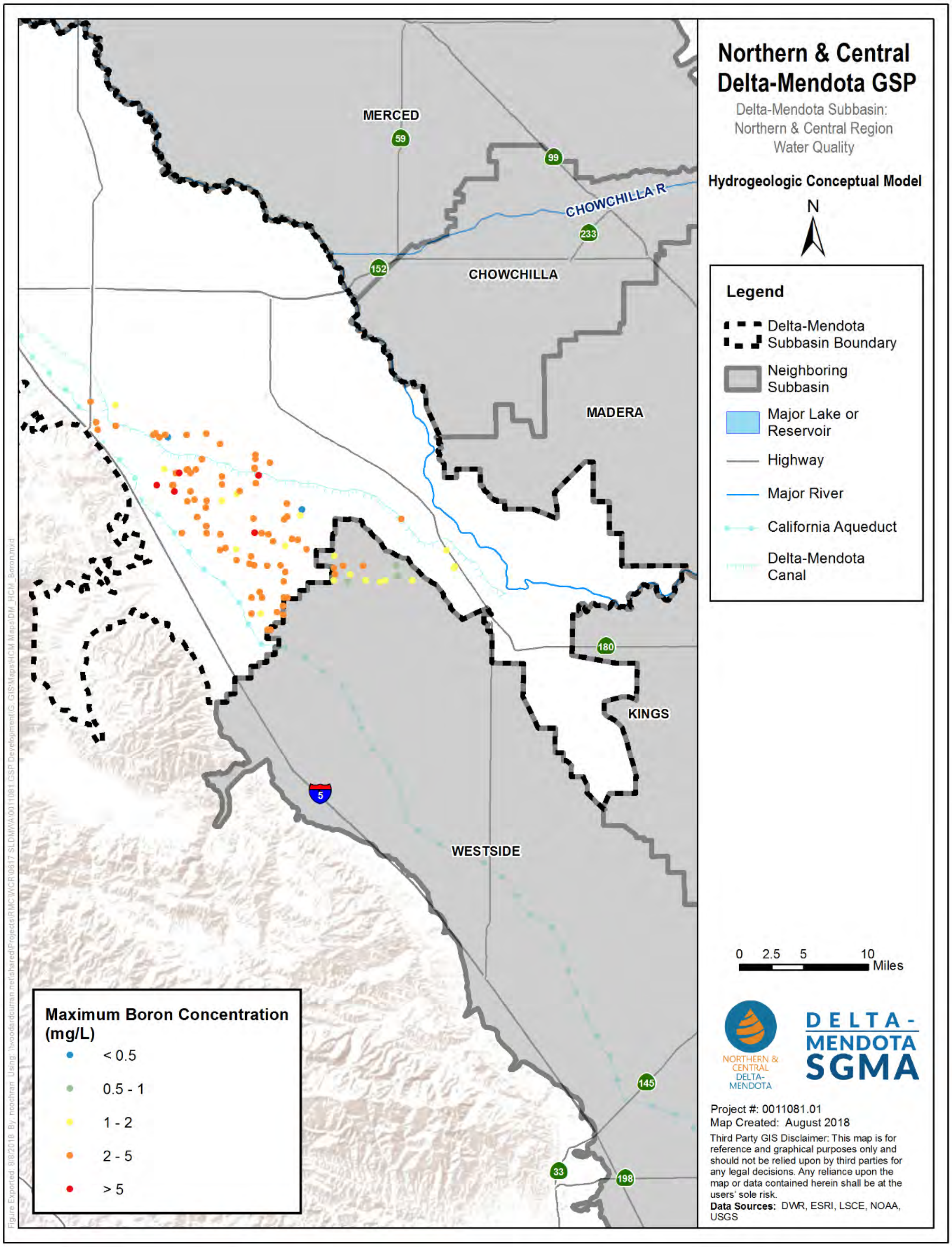


Figure 5-55. Most Recent (2000-2014) Boron Concentrations, Below Corcoran Clay



Note: Maximum concentrations are based on all data collected to date for the identified wells.

Figure 5-56. Maximum Boron Concentrations, Wells of Unknown Depth

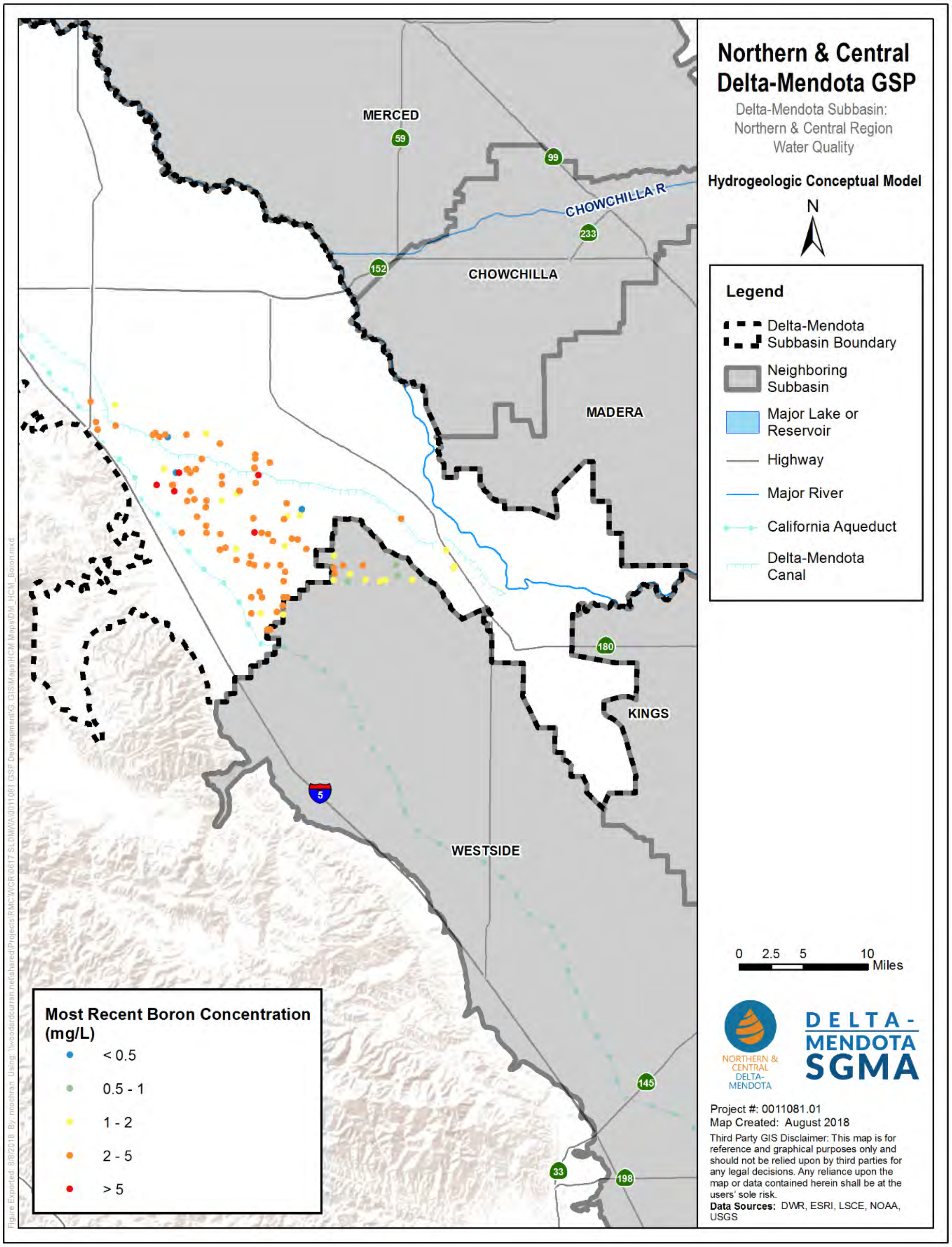


Figure 5-57. Most Recent (2000-2014) Boron Concentrations, Wells of Unknown Depth

5.2.8.3 Aquifer Use

The Delta-Mendota Subbasin is located in the San Joaquin Valley, one of the most agriculturally productive regions in California and the United States. Groundwater is one of the primary sources of water supply for agricultural uses within the Subbasin and is typically used to offset demands not met by surface water from the San Joaquin River, Central Valley Project and State Water Project. Groundwater is also the sole source of supply for many communities and cities throughout the Delta-Mendota Subbasin.

In general, most irrigation wells and many private domestic supply wells are screened in the Upper Aquifer of the Subbasin. Most municipal production wells and many larger irrigation production wells in the Northern and Central Delta-Mendota Regions are screened in the Lower Aquifer, below the Corcoran Clay.

5.2.9 Topography, Surface Water, Recharge, and Imported Supplies

This section describes the topography, surface water, soils, and groundwater recharge potential in the Delta-Mendota Subbasin.

5.2.9.1 Topography

As previously described, the Delta-Mendota Subbasin lies on the western side of the Central Valley and extends from the San Joaquin River on the east, along the axis of the Valley, to the Coast Range divide on the west side (LSCE, 2015). The Subbasin has ground surface elevations ranging from less than 100 feet above mean sea level (msl) along parts of the eastern edge to greater than 1,600 feet msl in the Coast Range mountains (**Figure 5-58**). Most of the lower elevation areas occur east of Interstate 5, in the eastern parts of the Delta-Mendota Subbasin; although some lower elevation areas also extend westward into the Coast Range, such as in Los Banos Creek Valley. Low elevation areas generally coincide with the extent of the Central Valley floor. Topography within the Delta-Mendota Subbasin consists largely of flat areas across the Central Valley floor, where slopes are generally less than 2 percent, with steepening slopes to the west. The topography outside of the Central Valley floor in the Coast Range mountains is characterized by steeper slopes, generally greater than 6 percent.

5.2.9.2 Surface Water Bodies

The San Joaquin River is the primary natural surface water feature within the Delta-Mendota Subbasin, flowing from south to north along the eastern edge of the Subbasin (LSCE, 2015). The Stanislaus, Tuolumne, Merced, and Chowchilla Rivers are tributaries to the San Joaquin River along the Subbasin boundary and generally flow east to west from the Sierra Nevada. During the 1960s, the San Joaquin River exhibited gaining flow conditions through much of the Subbasin (Hotchkiss and Balding, 1971). Numerous intermittent streams from the Coast Range enter the Delta-Mendota Subbasin from the west; however, none of these maintain perennial flow and only Orestimba Creek and Del Puerto Creek have channels that extend eastward to a junction with the San Joaquin River. Most of the flow in other notable west-side creeks, including Quinto Creek, San Luis Creek, Little Panoche Creek, and Los Banos Creek, is lost to infiltration (Hotchkiss and Balding, 1971). Flow from Los Banos and San Luis Creeks are impounded by dams on their respective systems. When flood releases are made from Los Banks Creek Reservoir, the vast majority of flows tend to be evacuated to the San Joaquin River as they tend to occur during times when demand isn't for beneficial use. The San Luis Reservoir on San Luis Creek, which is located along the western boundary of the Delta-Mendota Subbasin, is an artificial water storage facility for the Central Valley Project and California State Water Project and has no notable natural surface water inflows. Outflows from the reservoir go into the system of federal and state operated canals and aqueducts comprising the Central Valley and California State Water Projects. Surface water use within the Delta-Mendota Subbasin is derived largely from water deliveries provided by these projects, including from the California Aqueduct (sometimes referred to as San Luis Canal) and Delta-Mendota Canal, and also from the San Joaquin River (**Figure 5-59**).

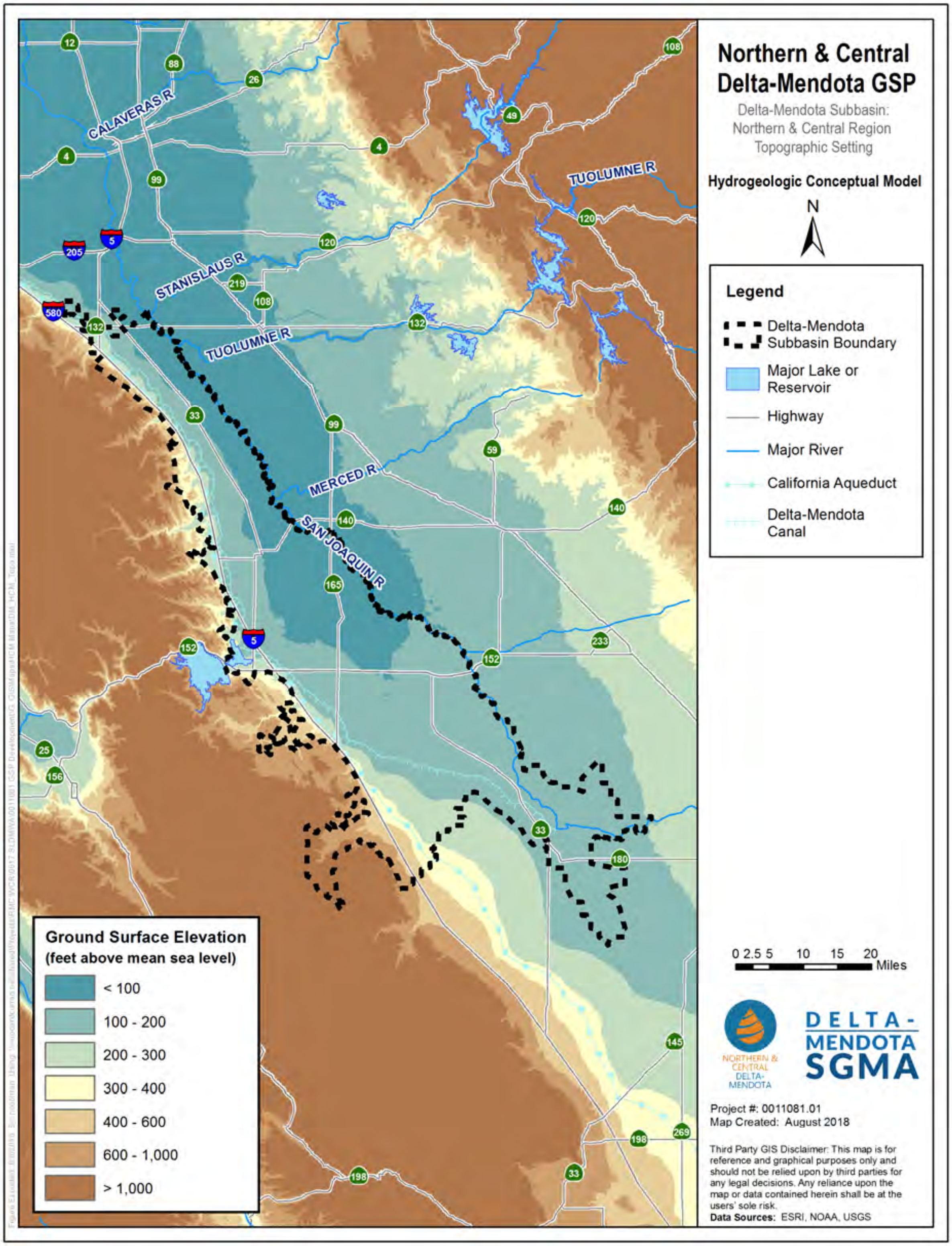


Figure 5-58. Ground Surface Elevation, Delta-Mendota Subbasin

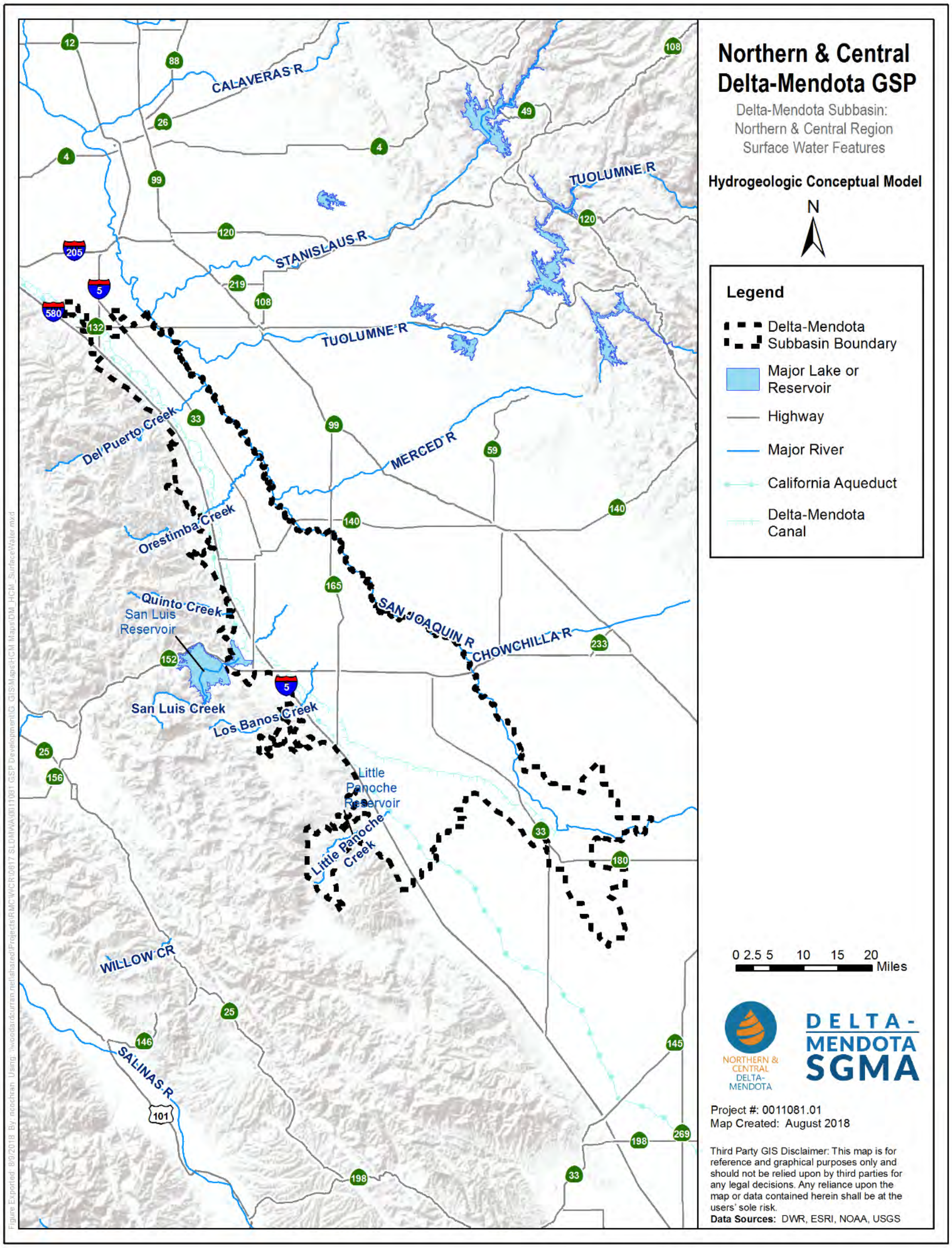


Figure 5-59. Surface Water Features, Delta-Mendota Subbasin

5.2.9.3 Soils

The predominant soil hydrologic groups within the Delta-Mendota Subbasin are soil types C and D (**Figure 5-60**). Group C soils have moderately high runoff potential when thoroughly wet (NRCS, 2009) with water transmission through the soil somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Group D soils have a high runoff potential when thoroughly wet and water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential.

Soil hydraulic conductivity groups are closely related to soil drainage characteristics and hydraulic conductivity. The fine-grained floodplain deposits present across much of the southeastern area of the Subbasin are evidenced as soils with lower hydraulic conductivity in **Figure 5-20** and accordingly, these characteristics also make these areas poorly drained. Poorly draining soil conditions are extensive within the southern and eastern areas of the Subbasin extending from the vicinity of Tranquillity to near Gustine. As early as the 1950s, farmers in parts of the western San Joaquin Valley began implementing structural and land treatment approaches to manage areas with poorly drained soils and the associated shallow water table and build-up of soil salinity (Fio, 1994; Hotchkiss and Balding, 1971). Soils in the northern and western parts of the Delta-Mendota Subbasin exhibit better drainage characteristics, although areas of poorly drained soils are also present in the north and west in proximity to surface water courses, including most notably directly adjacent to the San Joaquin River and Los Banos Creek channels. Many of the upland soils, which are of generally coarser texture and located proximal to sediment sources derived from the Coast Range hill slopes, are characterized as moderately well drained.

Groundwater recharge potential on agricultural land based on the Soil Agricultural Groundwater Banking Index (SAGBI) is shown in **Figure 5-62**. The SAGBI is based on five major factors: deep percolation, root zone residence time, topography, chemical limitations, and soil surface conditions. The predominant recharge potential classification throughout the Delta-Mendota Subbasin ranges from Moderately Poor to Very Poor (571,572 acres out of 731,820 acres of agricultural and grazing land, or about 78%). Along the eastern portion of the Subbasin, the recharge potential is generally poorer than the western portion of the Subbasin, which contains soils with higher recharge potential (Excellent, Good, and Moderately Good).

In areas with low hydraulic conductivity, corresponding to areas without adequate natural drainage, tile drains are present to remove shallow groundwater from the rooting zone. Known tile drain locations are shown in **Figure 5-61,** which are primarily located along the eastern boundary of the Delta-Mendota Subbasin as well as the southern portion of the Subbasin in the Grassland Drainage Area. The Grassland Drainage Area contains a tile drainage system as part of the Grassland Bypass Project (also known as the San Joaquin River Improvement Project) to route drainage water through the Grassland Bypass Channel, which is then used for irrigated agriculture with a high salinity tolerance.

5.2.9.4 Areas of Recharge, Potential Recharge, and Groundwater Discharge Areas

The primary process for groundwater recharge within the Central Valley floor area is from percolation of applied irrigation water, although some groundwater subbasin recharge does occur in the Delta-Mendota Subbasin along the western boundary due to mountain front recharge. Within the Northern and Central Delta-Mendota Regions, SAGBI data categorizes 103,524 acres out of 288,785 acres (36%) of agricultural and grazing land within the regions as having Excellent, Good, or Moderately Good (**Figure 5-62**) recharge properties, and 185,261 acres out of 288,785 acres (or 64%) of agricultural and grazing land as having Moderately Poor, Poor, or Very Poor recharge properties. Of the 36% of land categorized as either having Excellent, Good, or Moderately Good recharge properties, the Northern and Central Delta-Mendota Regions contain the majority of the land in the Subbasin with the highest recharge potential, with 5,106 acres out of 7,916 total acres (64%) of land classified as having Excellent recharge properties. "Modified" SAGBI data shows higher potential for recharge than unmodified SAGBI data because the modified data assumes that soils have been or will be ripped to a depth of six feet, which can break up fine grained materials at the surface to improve percolation. The modified data set was determined to more accurately represent the Delta-Mendota Subbasin due to the heavy presence of agriculture. In almost all cases, recharge from applied water on irrigated lands recharges the Upper Aquifer of the Subbasin.

The Corcoran Clay is a known barrier restricting vertical flow between the Upper and Lower Aquifers (**Figure 5-17** and **Figure 5-18**). Therefore, recharge of the Lower Aquifer is most likely restricted where the Corcoran Clay is present, including across most of the Central Valley floor. Primary recharge areas to the Lower Aquifer are most likely in western parts of the Central Valley floor, particularly in the vicinity and west of Los Banos, Orestimba, and Del Puerto Creeks, along the western margin of the Subbasin.

Groundwater discharge areas are identified as springs located within the Delta-Mendota Subbasin and the San Joaquin River. **Figure 5-62** shows the location of historic springs identified by USGS. There are only six springs/seeps identified by USGS, which are located in the southwestern corner of the Subbasin. The springs shown represent a dataset collected by USGS and are not a comprehensive map of springs in the Subbasin.

5.2.9.5 Imported Supplies

Both the California Aqueduct and Delta-Mendota Canal run the length of the Delta-Mendota Subbasin, primarily following the Interstate 5 corridor (**Figure 5-63**). The following water purveyors in the Delta-Mendota Subbasin receive water from the Central Valley Project via the Delta-Mendota Canal: Central California Irrigation District, Columbia Canal Company, Del Puerto Water District, Eagle Field Water District, Firebaugh Canal Water District, Fresno Slough Water District, Grassland Water District, Laguna Water District, Mercy Springs Water District, Oro Loma Water District, Pacheco Water District, Panoche Water District, Patterson Irrigation District, San Luis Canal Company, San Luis Water District, Tranquillity Irrigation District, Turner Island Water District, West Stanislaus Irrigation District. Oak Flat Water District is the only recipient of State Water Project (SWP) water in the Delta-Mendota Subbasin. Oak Flat Water District initially bought into the SWP in 1968 and has a contracted Table A annual volume of 5,700 acre-feet (AF).

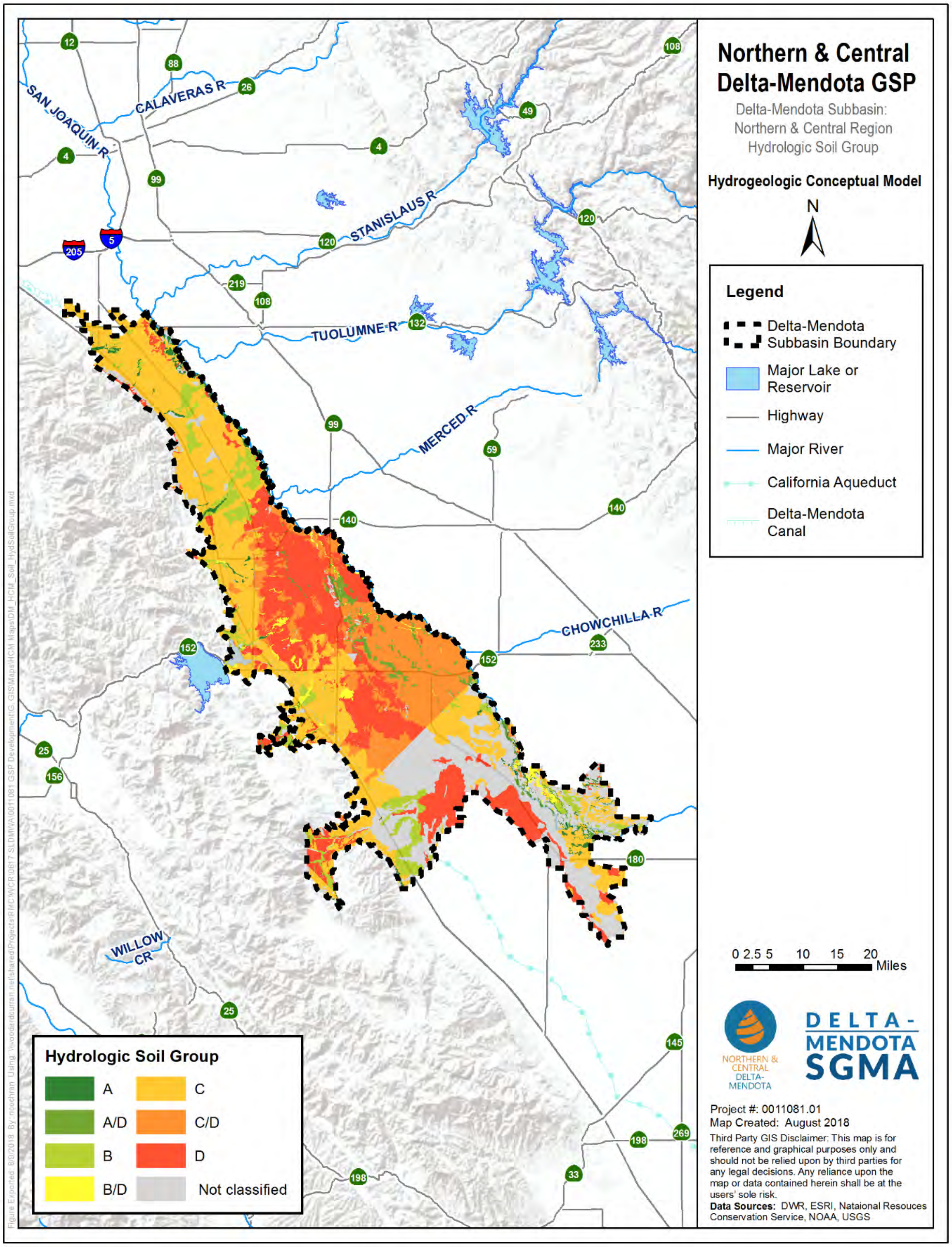


Figure 5-60. Hydrologic Soil Groups, Delta-Mendota Subbasin

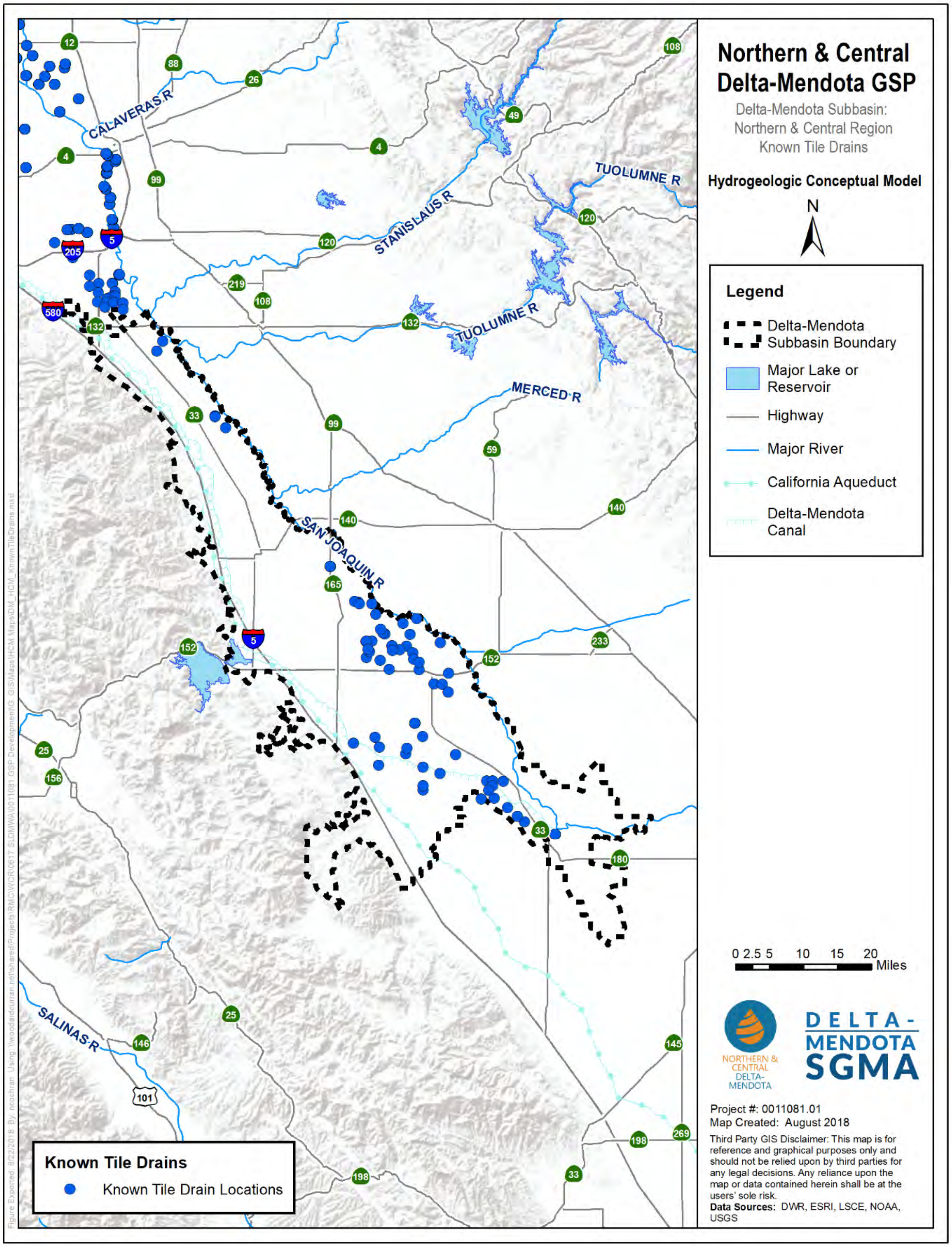


Figure 5-61. Tile Drains, Delta-Mendota Subbasin

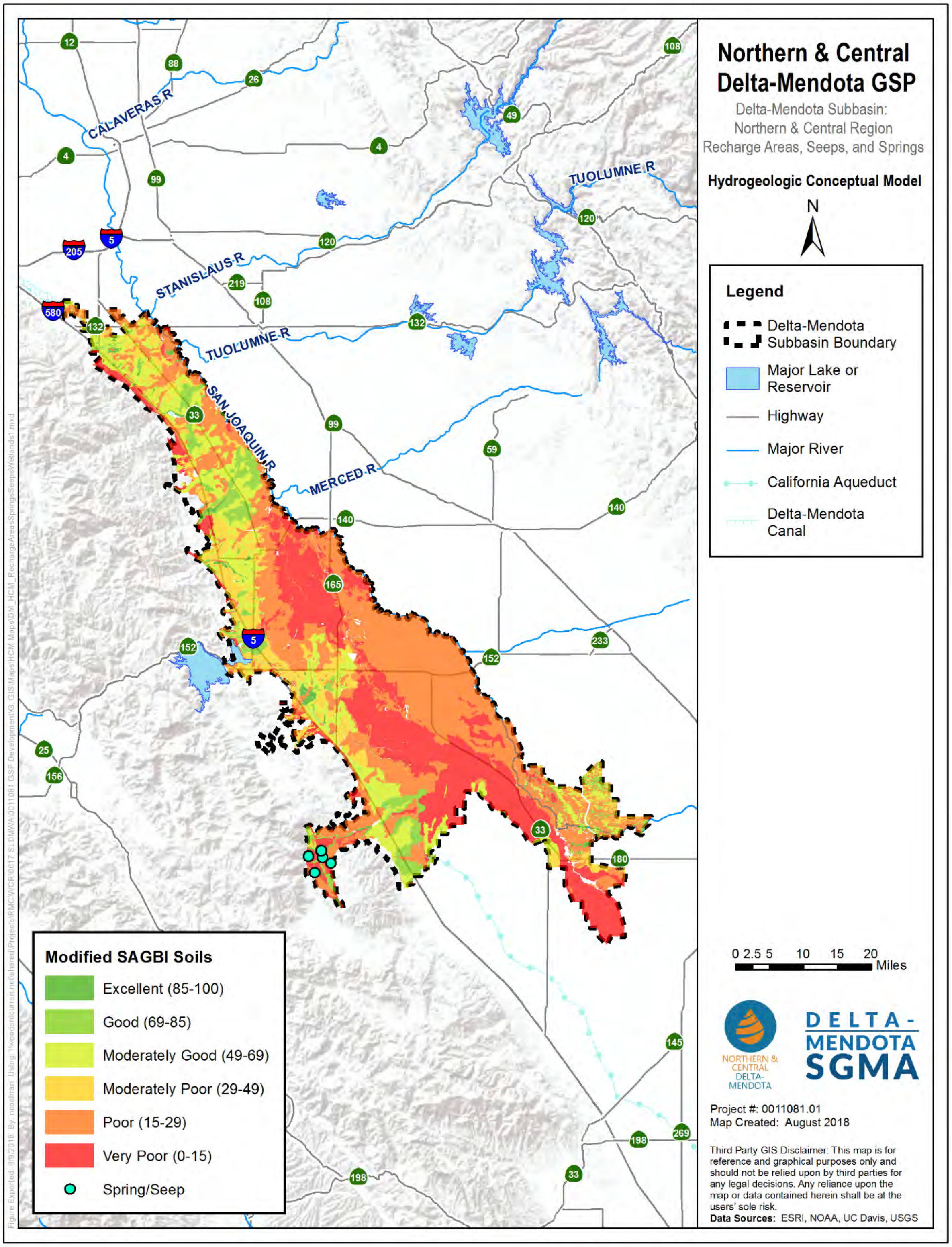


Figure 5-62. Recharge Areas, Seeps and Springs, Delta-Mendota Subbasin

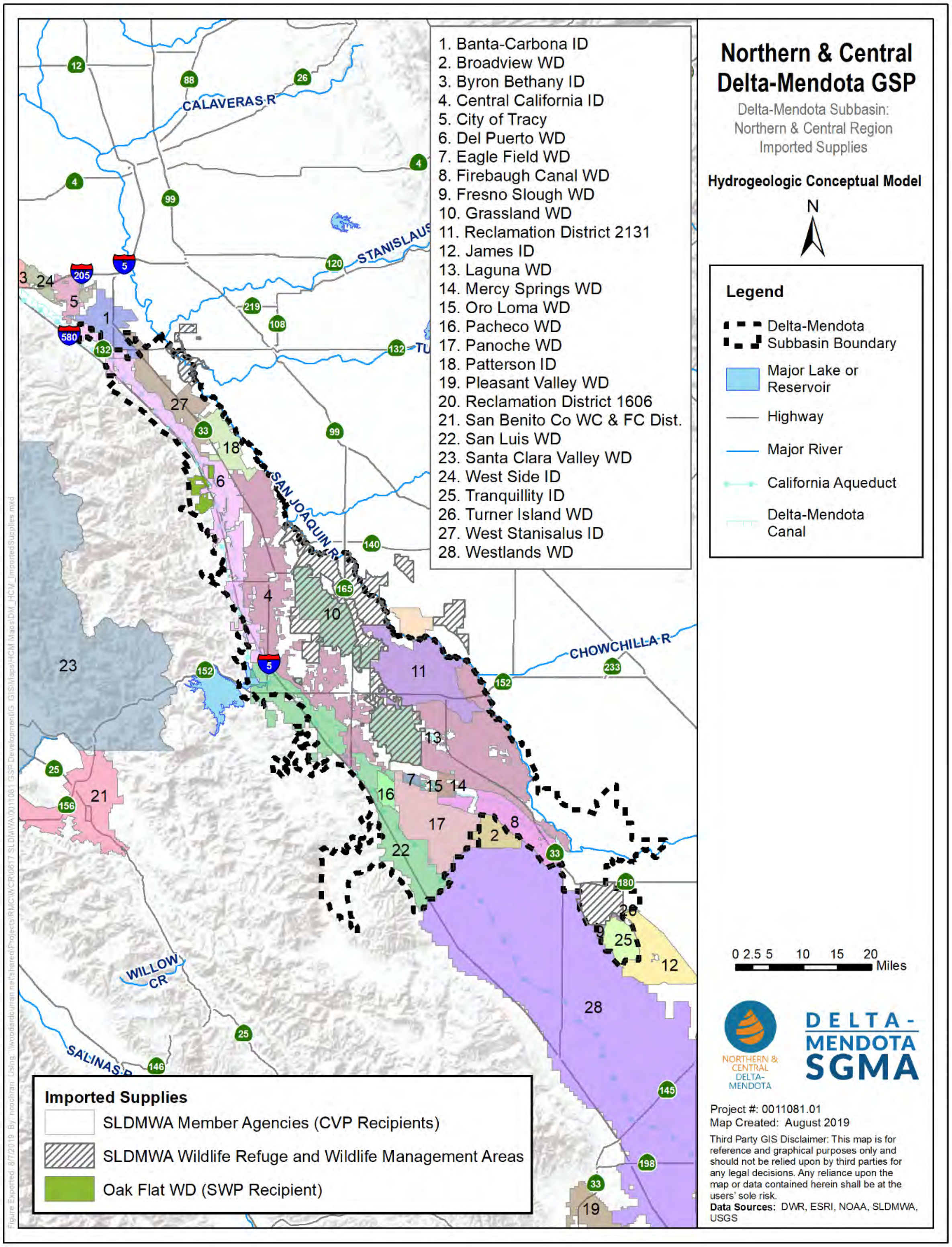


Figure 5-63. Imported Supplies, Delta-Mendota Subbasin

5.3 GROUNDWATER CONDITIONS

This section describes the current and historic groundwater conditions in the Northern and Central Regions of the Delta-Mendota Subbasin (Plan area of this Groundwater Sustainability Plan [GSP]), including data from January 1, 2015 to current conditions, for the following parameters: groundwater elevations, groundwater storage, groundwater quality, land subsidence, interconnected surface water systems, and groundwater dependent ecosystems (GDEs) (pursuant to Article 5 Plan Contents, Subarticle 2 Basin Setting, § 354.16 Groundwater Conditions of the GSP Emergency Regulations). Seawater intrusion is not discussed herein as the Delta-Mendota Subbasin is inland and is not impacted by seawater intrusion. For the purposes of this GSP, "current conditions" is represented by Water Year (WY) 2013 conditions, which is consistent with the year representing the Current Conditions Water Budget (see Section 5.4 for more information about Water Budgets). Data post-WY 2013 through present day are presented when available.

The purpose of describing groundwater conditions, as contained in this section, is to establish baseline conditions that will be used to monitor changes relative to measurable objectives and minimum thresholds. Therefore, these established baseline conditions will help support monitoring to demonstrate measurable efforts in achieving sustainability goals for the Northern and Central Regions as well as the whole Delta-Mendota Subbasin.

5.3.1 Useful Terminology

This groundwater conditions section includes descriptions of the amounts, quality, and movement of groundwater, among other related components. A list of technical terms and a description of the terms are listed below. The terms and their descriptions are identified here to guide readers through the section and are not a definitive definition of each term:

- **Depth to Groundwater –** The distance from the ground surface to first-detected non-perched groundwater, typically reported at a well.
- **Upper Aquifer –** The alluvial aquifer above the Corcoran Clay (or E-clay) layer.
- **Lower Aquifer –** The alluvial aquifer below the Corcoran Clay (or E-clay) layer.
- **Horizontal gradient –** The slope of the groundwater surface from one location to another when one location is higher or lower than the other. The gradient is shown on maps with an arrow showing the direction of groundwater flow in a horizontal direction.
- **Vertical gradient** – Describes the movement of groundwater perpendicular to the ground surface. Vertical gradient is measured by comparing the elevations of groundwater in wells that are of different depths. A downward gradient is one where groundwater is moving down into the ground towards deeper aquifers and an upward gradient is one where groundwater is upwelling towards the ground surface.
- **Contour Map** – A contour map shows changes in groundwater elevations by interpolating groundwater elevations between monitoring sites. The elevations are shown on the map with the use of a contour line, which represents groundwater being at the indicated elevation along the contour line. Contour maps can be presented in two ways:
  - Elevation of groundwater above mean sea level (msl), which can be used to identify the horizontal gradients of groundwater, and
  - Depth to water (i.e. the distance from the ground surface to groundwater), which can be used to identify areas of shallow or deep groundwater.
- **Hydrograph** – A graph that shows the changes in groundwater elevation or depth to groundwater over time at a specific location. Hydrographs show how groundwater elevations change over the years and indicate whether groundwater is rising or descending over time.
- **Maximum Contaminant Level (MCL)** – MCLs are standards that are set by the State of California and the U.S. Environmental Protection Agency for drinking water quality. MCLs are legal threshold limits on the amount of an identified constituent that is allowed in public drinking water systems. At both the State and

Federal levels, there are Primary MCLs, set to be protective of human health, and Secondary MCLs for constituents that do not pose a human health hazard but do pose a nuisance through either smell, odor, taste, and/or color. The MCL is different for different constituents and have not been established for all constituents potentially found in groundwater.

- **Assimilative Capacity** – The difference between the ambient concentration of a water quality constituent of concern and the regulatory threshold.
- **Elastic Land Subsidence** – Reversible and temporary fluctuations in the elevation of the earth's surface in response to seasonal periods of groundwater extraction and recharge.
- **Inelastic Land Subsidence** – Irreversible and permanent decline in the elevation of the earth's surface resulting from the collapse or compaction of the pore structure within the fine-grained portions of an aquifer system.
- **Gaining Stream** – A stream in which groundwater flows into a streambed and contributes to a net increase in surface water flows across an identified reach.
- **Losing Stream** – A stream in which surface water is lost through the streambed to the groundwater, resulting in a net decrease in surface water flows across an identified reach.
- **Conjunctive Use** – The combined use of surface water and groundwater supplies, typically with more surface water use in wet years and more groundwater use in dry years.

5.3.2 Groundwater Elevations

This section describes groundwater elevation data utilized and trends. Groundwater conditions vary widely across the Delta-Mendota Subbasin. Historic groundwater conditions through present day conditions, the role of imported surface water in the Subbasin, and how conjunctive use has impacted groundwater trends temporally and spatially are discussed. Groundwater elevation contour maps associated with current seasonal high and seasonal low for each principal aquifer, as well as hydrographs depicting long-term groundwater elevations, historical highs and lows, and hydraulic gradients (both horizontal and vertical), are also described.

5.3.2.1 Available Data

Groundwater elevation data, and accompanying well construction information, within the Delta-Mendota Subbasin from the following sources and associated programs were utilized in this GSP:

- California Department of Water Resources (DWR)
    - California Statewide Groundwater Elevation Monitoring Program (CASGEM)
    - Water Data Library (WDL)
- Central Valley Regional Water Quality Control Board
    - Irrigated Lands Regulatory Program (ILRP)
        - Western San Joaquin Groundwater Quality Assessment Report (GAR)
        - Grassland Drainage Area GAR
- Local Agency Data

Data provided by these sources included well information such as location, well construction, owner, ground surface elevation and other related components, as well as groundwater elevation data (including information such as date measured, depth to water, groundwater surface elevation, questionable measurement code, and comments). At the time that this analysis was performed, groundwater elevation data were available for the time period from 1930 through 2018. There are many wells with monitoring data from some time in the past, but no recent data, while a small number of wells have monitoring data recorded for periods of greater than 50 years.

Not all groundwater elevation data received were used in preparing the groundwater elevation contour maps for both principal aquifers (defined in this GSP as the Upper and Lower Aquifers which are divided by the Corcoran Clay [E-clay] layer). Some groundwater elevation data were associated with wells with unknown screened depths and/or composite well screens constructed across the Corcoran Clay. Groundwater elevation data associated with wells with composite screens and/or unknown screened depths were removed from the data set, along with any data point that appears to be an outlier when compared with surrounding data from the same period. Duplicate well measurements were also removed prior to contouring and only one observation for a given well was used for the identified season, rather than averaging all measurements at a given well during the same season.

Figure 5-64 shows the locations of wells with known screened depths within the Delta-Mendota Subbasin as well as known spatial gaps where no well information is currently available. These wells include those monitored under CASGEM, the Delta-Mendota Canal Well Pump-in Program, and local owners or agencies. Monitoring data available for these wells varies by local owner and agency. Well locations were provided by local agencies to the best of their knowledge at the time of writing and may include wells that have been destroyed or are no longer in service.

5.3.2.2 Historic Conditions

Historic groundwater trends can generally be divided by the first deliveries of imported water deliveries to the Delta-Mendota Subbasin. Construction of the Delta-Mendota Canal (DMC) and the California Aqueduct herald the introduction of significant surface water supplies into the Subbasin and reduced dependence on groundwater as the primary water supply. These conveyance systems have resulted in significant increases in the conjunctive use of surface water and groundwater throughout the Subbasin. Various drought periods also punctuate critical understandings of groundwater use patterns throughout the Subbasin, as well as what is known regarding response and recovery of groundwater levels following notable droughts.

Prior to Imported Water Deliveries (1850-1950s)

Prior to 1850, the majority of agriculture and development in the San Joaquin Valley consisted of rain-fed grain and cattle production, with irrigated development beginning sporadically during this time via river and perennial stream diversions (SWRCB, 2011). Construction of the railroad through the San Joaquin Valley from 1869 through 1875 increased demand for more extensive agriculture, making markets in larger coastal cities more accessible to valley farmers. Significant irrigation sourced from surface water and resulting production began in the western side of the San Joaquin Valley in 1872 when the San Joaquin River was diverted through the Miller and Lux canal system west of Fresno (DWR, 1965). Within the Northern Delta-Mendota Region, diversions from the San Joaquin River by West Stanislaus Irrigation District, Patterson Irrigation District, El Solyo Water District, White Lake Mutual Water Company, and other private diverters began in the early 1900s and were the primary water supply for irrigation in this Region. By the 1890s and early 1900s, sizable areas of the San Joaquin Valley were being forced out of production by salt accumulation and shallow water tables. Much of this land lay idle until the 1920s when development of reliable electric pumps and the energy to power them accelerated the expansion of irrigated agriculture with the availability of vast groundwater resources. The resultant groundwater pumping lowered the water table in many areas (SWRCB, 1977 and Ogden, 1988) and allowed the leaching of salts, particularly near the valley trough and western side of the valley. Groundwater pumping for irrigation from around 1920 to 1950 drew the water table down as much as 200 feet in areas along the westside of the San Joaquin River (Belitz and Heimes, 1990). Declining water tables were causing higher pumping costs and land subsidence, and farmers were finding poorer quality water as water tables continued to decline. These issues created a desire for new surface water supplies, which would be fulfilled by the Central Valley Project.

Post-Imported Water Deliveries (1950s-2012)

Surface water deliveries from the Central Valley Project (CVP) via the Delta-Mendota Canal began in the early 1950s, and from the State Water Project (SWP) via the California Aqueduct in the early 1970s (Sneed et al., 2013). The CVP is the primary source of imported surface water in the Northern and Central Delta-Mendota Regions, where only Oak Flat Water District receives deliveries from the SWP. Introduction of imported water supplies to the Delta-Mendota Subbasin resulted in a decrease in groundwater pumping from some parts of the Subbasin and the greater Central Valley, which was accompanied by a steady recovery of water levels. During the droughts of 1976-1977 and 1987-1992, diminished deliveries of imported surface water prompted increased pumping of groundwater to meet irrigation demands, bringing water levels to near-historic lows. Following periods of drought, recovery of pre-drought water levels has been rapid, especially in the Upper Aquifer. This trend has been observed in historic hydrographs for wells across the Northern and Central Delta-Mendota Regions.

5.3.2.3 Current Conditions

Recent Drought (2012-2016)

During the most recent drought, from 2012 through 2016, similar groundwater trends were observed as during the 1976-1977 and 1987-1992 droughts. With diminished imported surface water deliveries, groundwater pumping increased throughout the Subbasin to meet irrigation needs. This resulted in historic or near-historic low groundwater levels during the height of the drought in 2014 and 2015, when CVP and SWP allocations were 0% and post-1914 surface water rights in the San Joaquin River watershed were curtailed. In June 2015, senior water rights holders with a priority date of 1903 or later in the San Joaquin and Sacramento watersheds and the Delta were ordered by the State Water Resources Control Board to curtail diversions (State of California, 2015). This marked the first time in recent history that pre-1914 water rights holders were curtailed.

Post-Drought (2016-present)

With wetter conditions following the 2012-2016 drought, groundwater levels began to recover and reach near historic highs by 2017, comparable to 2012 pre-drought levels (**Figure 5-65** and **Figure 5-66**). This was largely a result of CVP allocations reaching 100% and full water rights supplies available from the San Joaquin River in 2017. Additionally, inelastic subsidence also drastically decreased in 2017 as imported water supplies were once again available, resulting in decreased groundwater pumping particularly from the Lower Aquifer. This pattern of increased drought-driven groundwater pumping, accompanied by declining groundwater elevations, followed by recovery is a predominant factor to be considered in the sustainable management of the Delta-Mendota Subbasin.

5.3.2.4 Groundwater Trends

Groundwater levels can fluctuate greatly throughout time due to various natural and anthropogenic factors, including long-term climatic conditions, adjacent well pumping, nearby surface water flows, and seasonal groundwater recharge or depletion (LSCE, 2015). As discussed in the Hydrogeologic Conceptual Model section of this GSP, the Delta-Mendota Subbasin is generally a two-aquifer system consisting of an Upper and Lower Aquifer that are subdivided by the Corcoran Clay layer, a regional aquitard. The Corcoran Clay layer, or E-Clay equivalent, restricts flow between the upper semi-confined aquifer and lower confined aquifer. The presence of a tile drain network along the Subbasin's eastern boundary, as well as the Grassland Drainage Area on the southern end of the Northern and Central Delta-Mendota Regions, affect the lateral and vertical water movement in the shallow groundwater zone (LSCE, 2016). The majority of production wells are perforated above the Corcoran Clay layer.

The Delta-Mendota Subbasin has a general flow direction to the east, where it loses groundwater to the adjoining San Joaquin River and its neighboring subbasins. Most recharge throughout the Subbasin is attributed to applied irrigation water, with other sources of recharge including local streams, canal seepage, and infiltration along the western margin of the Subbasin from the Coast Range.

Upper Aquifer

For very shallow groundwater (less than 50 feet depth to water), select hydrographs illustrating temporal groundwater level trends in very shallow wells across the Central Valley Floor area of the Subbasin are shown in **Figure 5-67**. Note, the hydrographs shown display different ranges of elevations on the vertical axes and all groundwater elevations are in relation to the North American Vertical Datum of 1988 (NAVD88). During the period from the 1970s through the early 2000s, wells in the western part of the Valley Floor tended to see an overall increase of around five feet in groundwater elevation during this time period, whereas in the eastern portion of the Subbasin, particularly nearer the San Joaquin River, hydrographs from very shallow wells indicate a decreased water table elevation over that same period of time.

For the Upper Aquifer, **Figure 5-68** presents select hydrographs illustrating temporal groundwater level trends in the Upper Aquifer wells within the Subbasin. Hydrographs shown on **Figure 5-68** are displayed with different ranges of elevation values on the vertical axes and all groundwater elevations are in relation to NAVD88. Wells in the Upper Aquifer exhibit decreasing trends to somewhat stable water levels until the mid-1980s, and increasing or stable water levels thereafter.

Figure 5-69 presents select hydrographs illustrating temporal groundwater level trends in the Grassland Drainage Area (including areas covered by the Central Delta-Mendota, Oro Loma Water District, and Widren Water District Groundwater Sustainability Agencies [GSAs]) at various depths. The three select hydrographs representing wells each show less than 10 years of available data, where all groundwater elevations are in relation to NAVD88. The two wells in the shallower portion of the Upper Aquifer show slight declines of about 10 feet or less from about 2003 through 2013. The one well in the deeper portion of the Upper Aquifer shows more drastic elevation changes, ranging from 100 ft msl to -20 ft msl over a 5-year period from 2010 to 2016.

Figure 5-70 through **Figure 5-75** show contours of groundwater elevations (relative to NAVD88) in the shallower (upper 50 feet) portion of the Upper Aquifer and for wells screened in the deeper portions of the Upper Aquifer for recent spring and fall time periods in the Delta-Mendota Subbasin. Recent groundwater elevations include all available data from 2000 through 2016. Spring is defined as the months of January through April, and fall is defined as September through November. All available data for each season for each well were averaged to produce a single value of groundwater elevations for each season for that well in order to develop contour maps.

Both spring and fall maps indicate a prevailing southwest to northeast flow gradient above the Corcoran Clay (or E-Clay) layer. In general, little variation is apparent in groundwater elevations in spring (**Figure 5-70**, **Figure 5-72**, **Figure 5-74**, and **Figure 5-75**) relative to fall (**Figure 5-71** and **Figure 5-73**). Spring piezometric heads were generally higher than those in the fall throughout most of the Subbasin. An area of lower groundwater elevation is observed in the vicinity of the San Joaquin River Improvement Project (SJRIP), potentially corresponding to areas of groundwater pumping (**Figure 5-75**). The effects of pumping and the resulting depression in groundwater elevations within the Upper Aquifer in the SJRIP vicinity may result in a more northernly gradient, instead of the natural northeastern flow direction (**Figure 5-75**).

<u>Lower Aquifer</u>

Figure 5-76 presents select hydrographs illustrating temporal groundwater level trends in Lower Aquifer wells, which are perforated below the Corcoran Clay layer within the Subbasin. Note, hydrographs shown on **Figure 5-76** displayed different ranges of elevation on the vertical axes and all groundwater elevations are in relation to NAVD88. In the Lower Aquifer, piezometric head typically increased or remained relatively stable during the period from the 1980s through the early 2000s.

Figure 5-69 presents select hydrographs illustrating temporal groundwater level trends in the Grassland Drainage Area (including the Central Delta-Mendota, Oro Loma Water District, and Widren Water District GSAs) at various depths. The two select hydrographs representing wells in the Lower Aquifer each show similar elevation patterns post-2010 with a total elevation change of 50 ft msl or more (relative to NAVD88). USGS1000489 shows fairly stable and increasing groundwater elevation trends from the late 1950s through the mid-1980s with a data gap from the mid-1980s through 2010, where after 2010 groundwater levels have a steep decline through 2016.

Patterns in recent spring and fall groundwater elevations (relative to NAVD88) within the Lower Aquifer are illustrated in **Figure 5-77** through **Figure 5-79**. Recent groundwater elevations include all available data from 2000 through

2016. Spring is defined as the months of January through April, and fall is defined as September through November. All available data for each season for each well were averaged to produce a single value of water level for each season for that well in order to develop contour maps.

The Lower Aquifer exhibits less seasonal difference in groundwater elevations than the Upper Aquifer. Throughout most of the Subbasin, the Lower Aquifer shows lower piezometric heads than the Upper Aquifer suggesting a downward vertical gradient where subsurface geologic conditions provide lesser hydraulic separation between these zones. **Figure 5-79** shows a distinct trough-like depression in the Lower Aquifer's groundwater elevation indicative of groundwater pumping/depletion within the Central Delta-Mendota, Oro Loma Water District, and Widren Water District GSAs, which could induce deep southwestern direction groundwater flows from the valley axis toward these GSAs as indicated by the flow direction vectors. There are also deep northeast groundwater flows within the Lower Aquifer from the Coast Ranges toward the Central Delta-Mendota, Oro Loma Water District, and Widren Water District GSAs, which could result in deep, pumping-enhanced mixing of different quality groundwater within the Lower Aquifer groundwater trough.

Vertical Gradients

Throughout most of the Delta-Mendota Subbasin, the Corcoran Clay layer acts as a regional aquitard, limiting the vertical migration of groundwater. In areas outside the Corcoran Clay layer (along the western margin of the Subbasin), localized interfingered clays minimize the downward migration of groundwater; although in areas where the clay layers are not competent or non-existent, groundwater migrates from shallower to deeper groundwater zones. Similarly, in areas where the Corcoran Clay has been compromised by the construction of composite wells, groundwater generally flows from the Upper Aquifer to the Lower Aquifer, especially in areas where the Lower Aquifer is actively used as a water supply (lowering the potentiometric head in that zone).

Groundwater Contours

Figure 5-80 and **Figure 5-81** depict groundwater surface elevation for the seasonal high (Spring 2013) and seasonal low (Fall 2013) for the Upper Aquifer relative to NAVD88. Spring is defined as groundwater surface elevation measurements from January 1 through April 8; where Fall is defined as groundwater surface elevation measurements from August 1 through October 31. For wells where multiple Spring 2013 or Fall 2013 measurements were available, the highest elevation for each season was used for contouring. In the Upper Aquifer, during Spring 2013, the general flow of groundwater in the Delta-Mendota Subbasin was from the Coastal Range along the western boundary of the Subbasin toward the San Joaquin River along the eastern boundary. In the southern-central portion of the Subbasin, groundwater flow was to the southwest toward Los Banos; while in the southern portion of the Subbasin, groundwater flow is to the southeast toward Aliso Water District and the Tranquillity area. Groundwater elevations tend to increase moving south throughout the Subbasin.

Spring groundwater elevations are the lowest within Stanislaus County, ranging between 40 and 80 feet above msl, and become increasingly higher in Merced and Fresno Counties, ranging between 80 and 140 feet above msl (**Figure 5-80**) with general Upper Aquifer groundwater flow directions to the east and north east. For Fall 2013, groundwater flows in a similar direction (west to east and northeast) with groundwater elevations in Stanislaus County still the lowest (ranging between 40 and 80 feet above msl). As with Spring 2013, groundwater elevations in Fall of 2013 (**Figure 5-81**) become increasingly higher in Merced County (ranging between 60 and 140 feet above msl) and Fresno County (ranging from 60 and 120 feet above msl).

Due to insufficient data, groundwater elevation contour maps for the Lower Aquifer for the seasonal high and low (Spring 2013 and Fall 2013, respectively) could not be accurately prepared. **Figure 5-82** and **Figure 5-83** show available groundwater elevation measurements for Spring 2013 and Fall 2013. Available Spring 2013 measurements range from -127 to 12 feet above msl in Stanislaus County, from -65 to 124 feet above msl in Merced County, and from -5 to 88 feet above msl in Fresno County (**Figure 5-82**). Available Fall 2013 measurements range from -138 to

156 feet above msl in Stanislaus County, from -94 to 19 feet above msl in Merced County, and from -72 to -4 feet above msl in Fresno County (**Figure 5-83**).

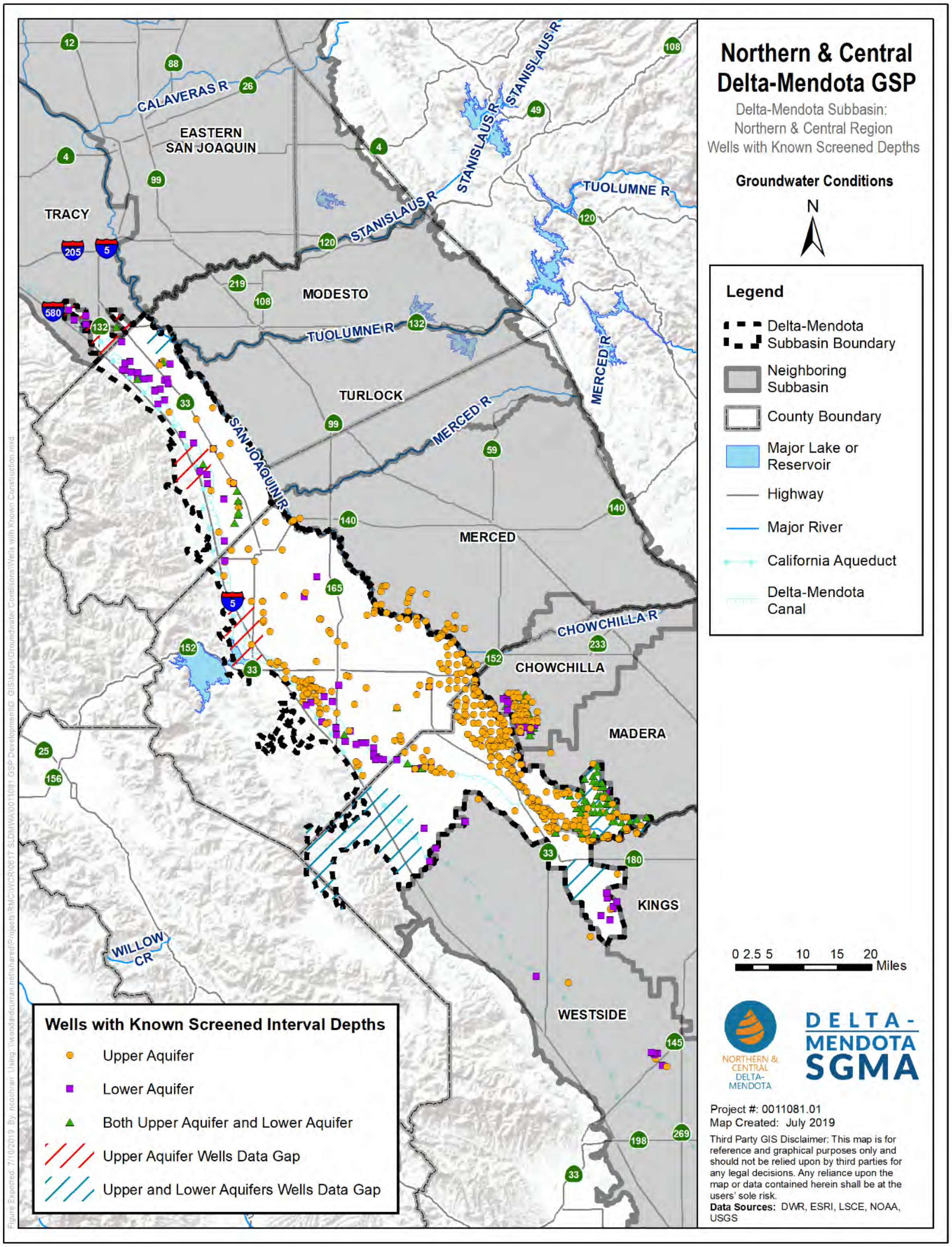


Figure 5-64. Wells with Known Screened Interval Depths, Delta-Mendota Subbasin

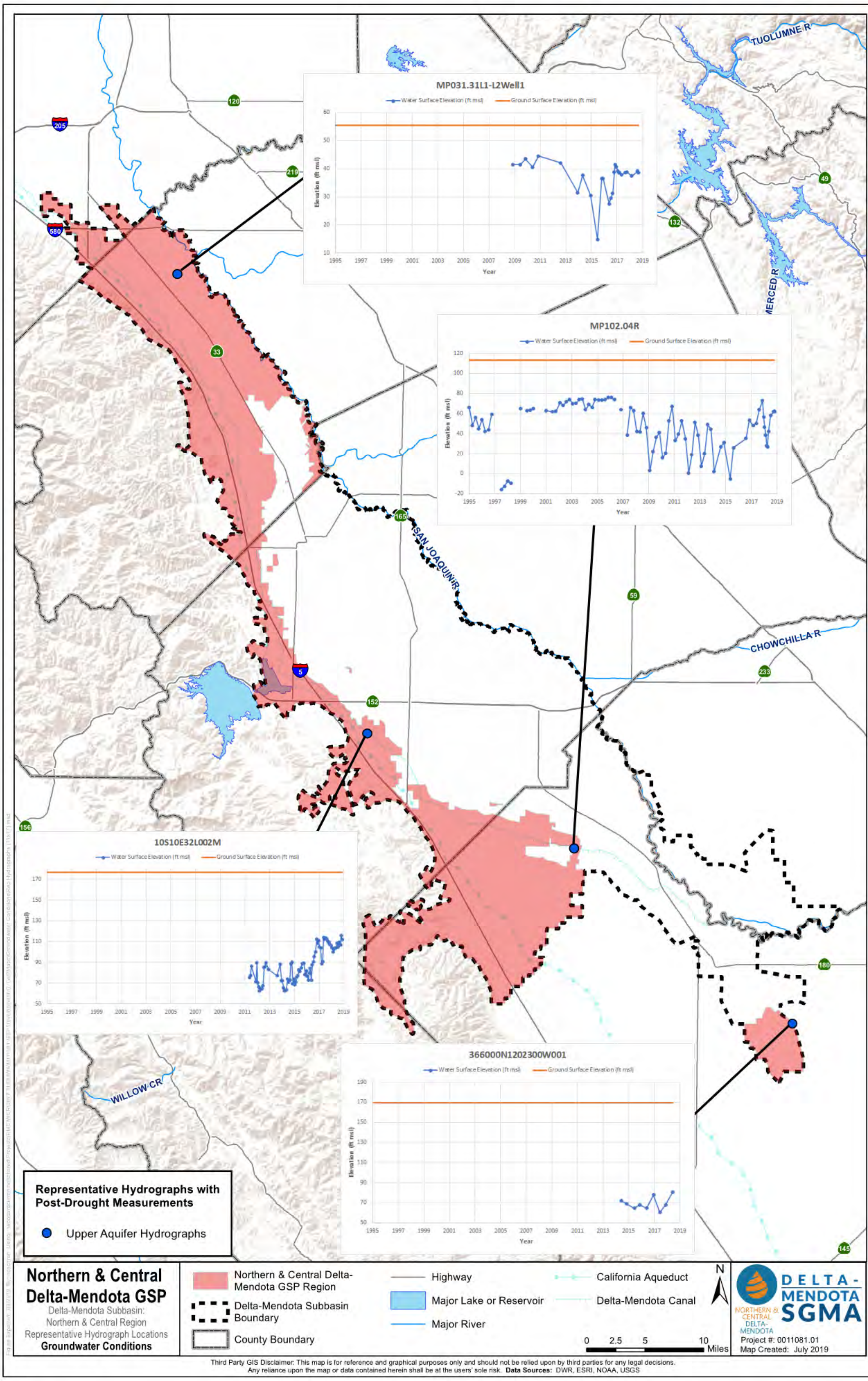


Figure 5-65. Representative Hydrographs with Post-Drought Measurements, Upper Aquifer

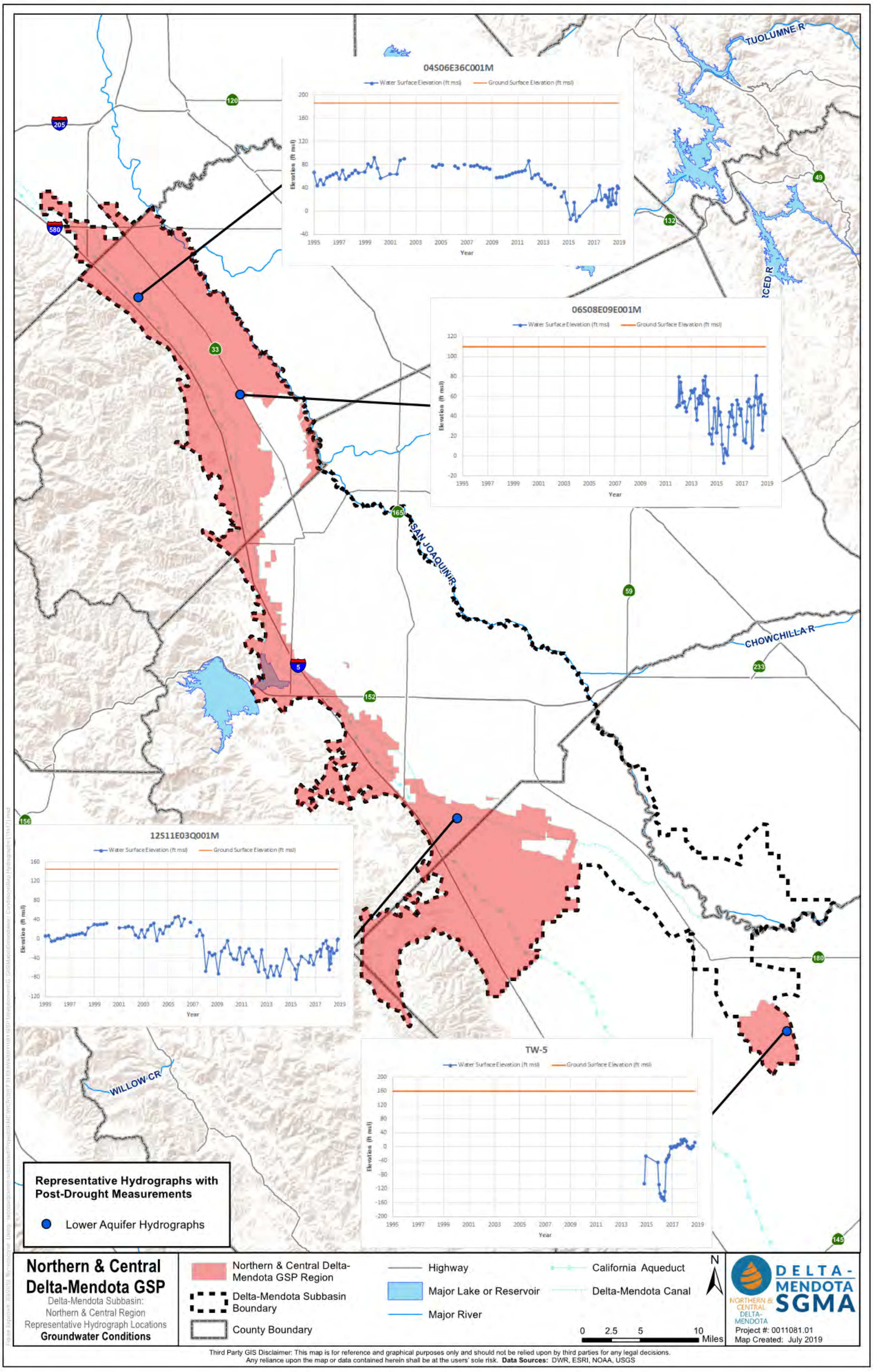
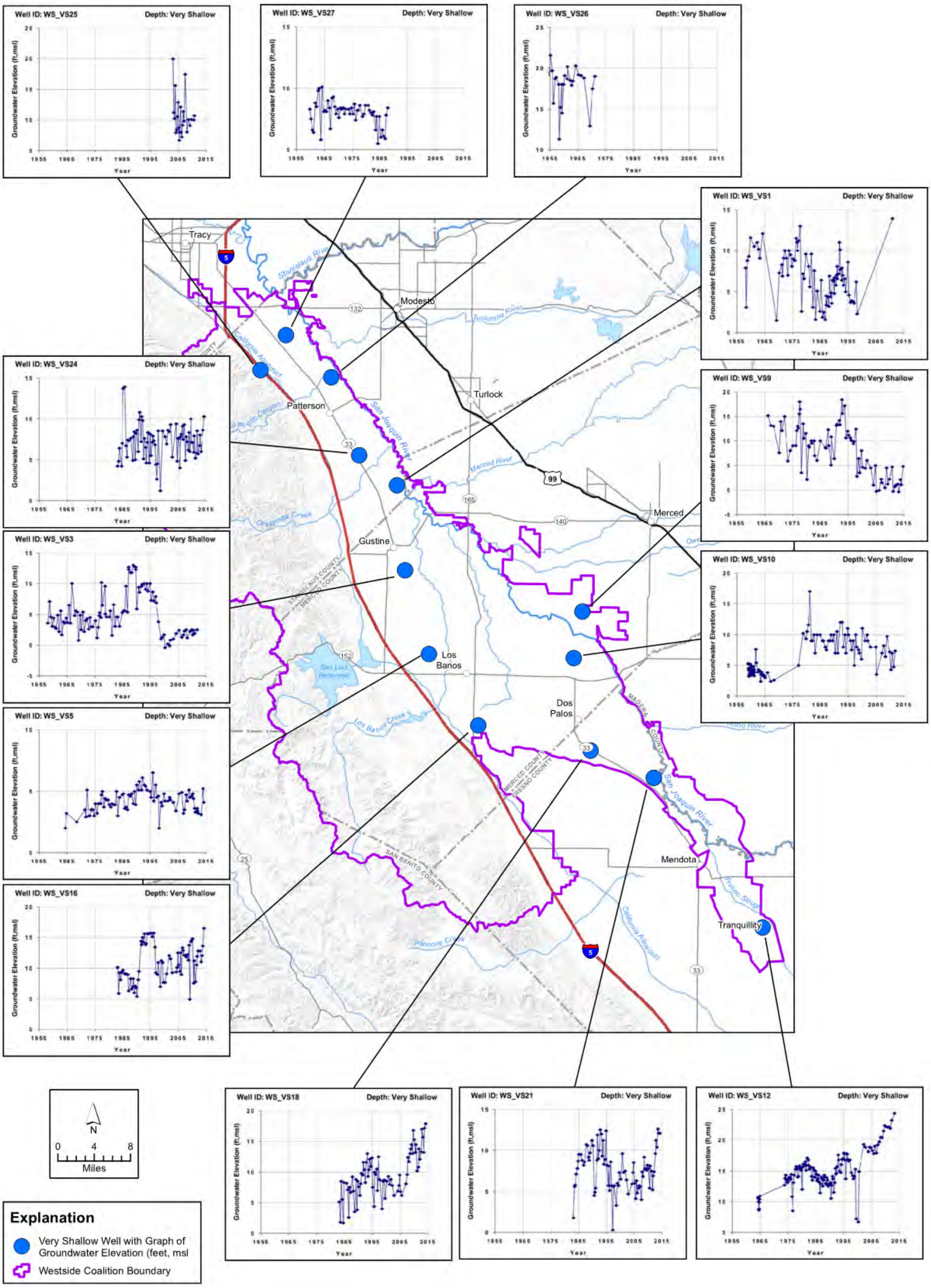


Figure 5-66. Representative Hydrographs with Post-Drought Measurements, Lower Aquifer

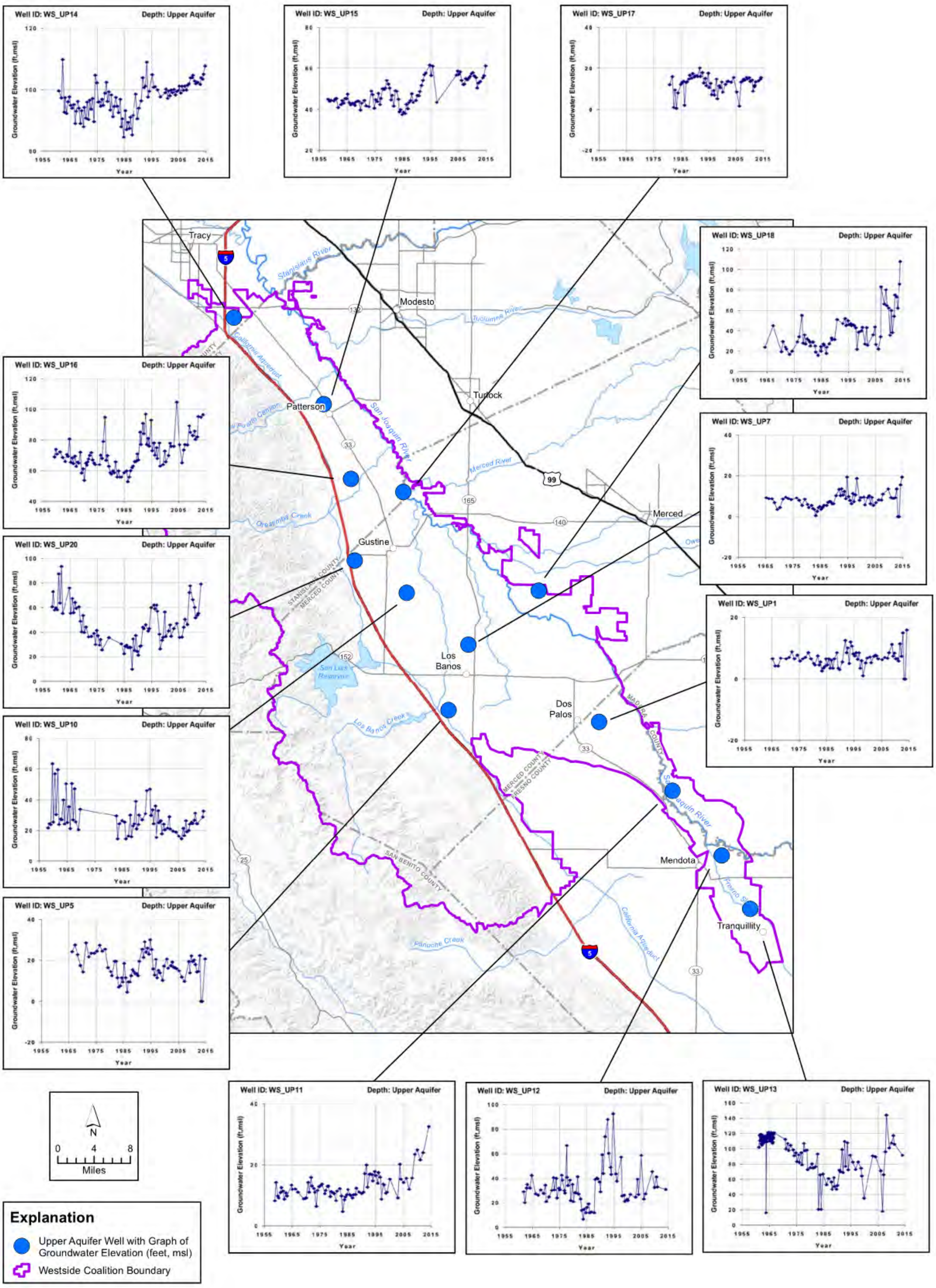


Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Notes:

1. Figure not to scale.
2. The intent of these hydrographs is to generally demonstrate groundwater trends across the Delta-Mendota Subbasin.

Figure 5-67. Select Graphs of Groundwater Elevations, Very Shallow Groundwater

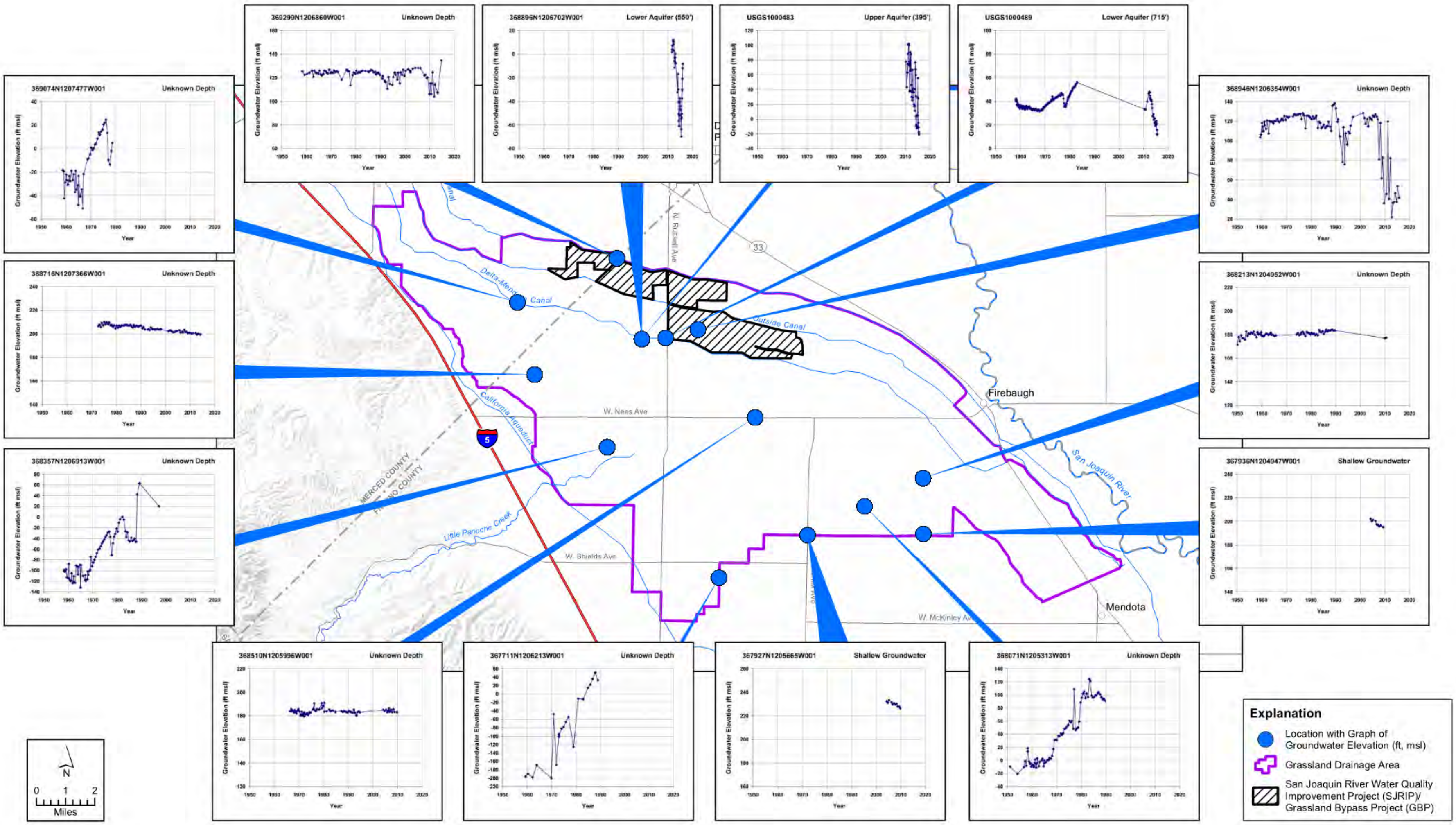


Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Notes:

1. Figure not to scale.
2. The intent of these hydrographs is to generally demonstrate groundwater trends across the Delta-Mendota Subbasin.

Figure 5-68. Select Graphs of Groundwater Elevations, Upper Aquifer



Source: *Grassland Drainage Area Groundwater Quality Assessment Report*, 2016

Notes:

1. Figure not to scale.
2. The intent of these hydrographs is to generally demonstrate groundwater trends across the Delta-Mendota Subbasin.

Figure 5-69. Select Graphs of Groundwater Elevations, Various Depths

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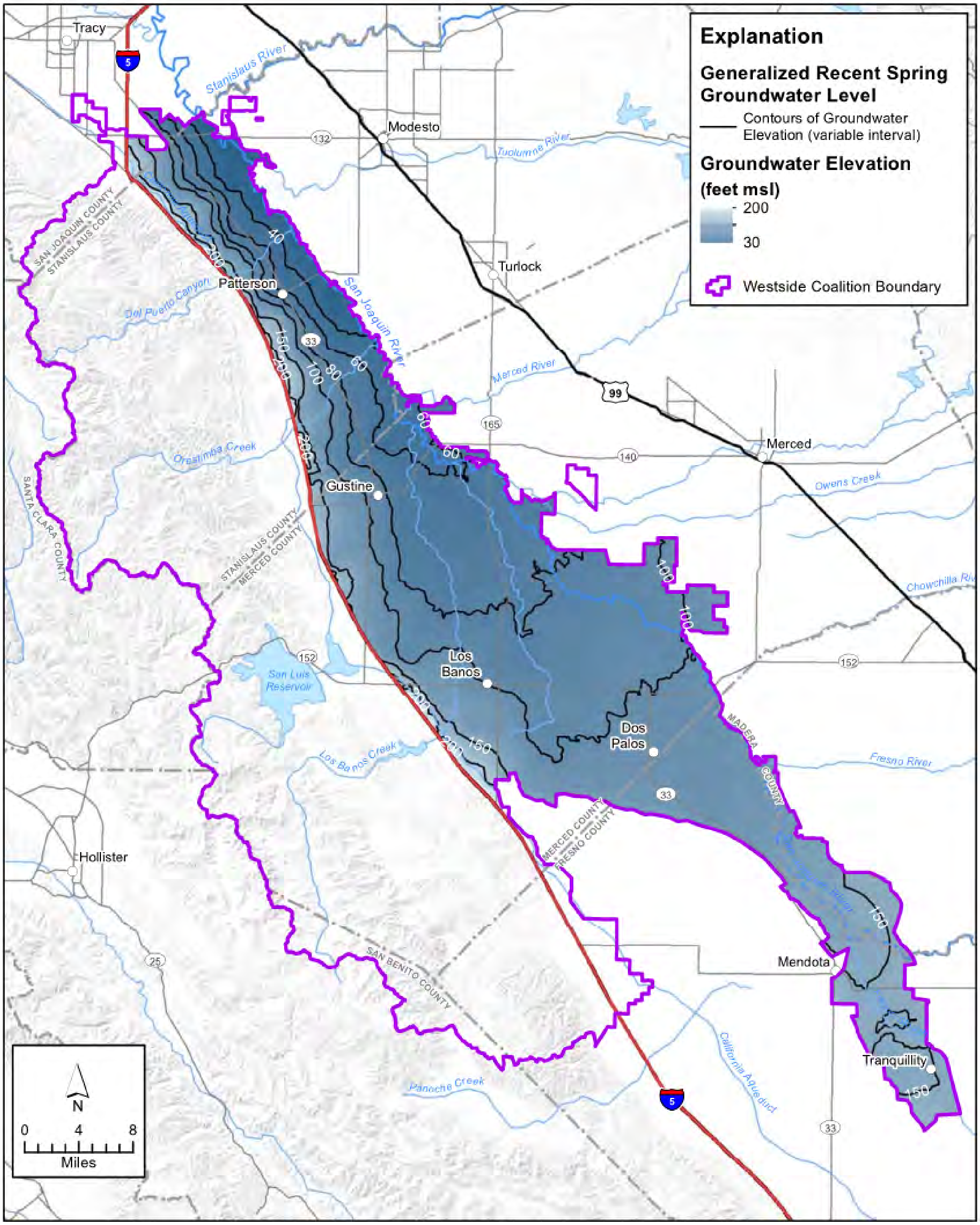
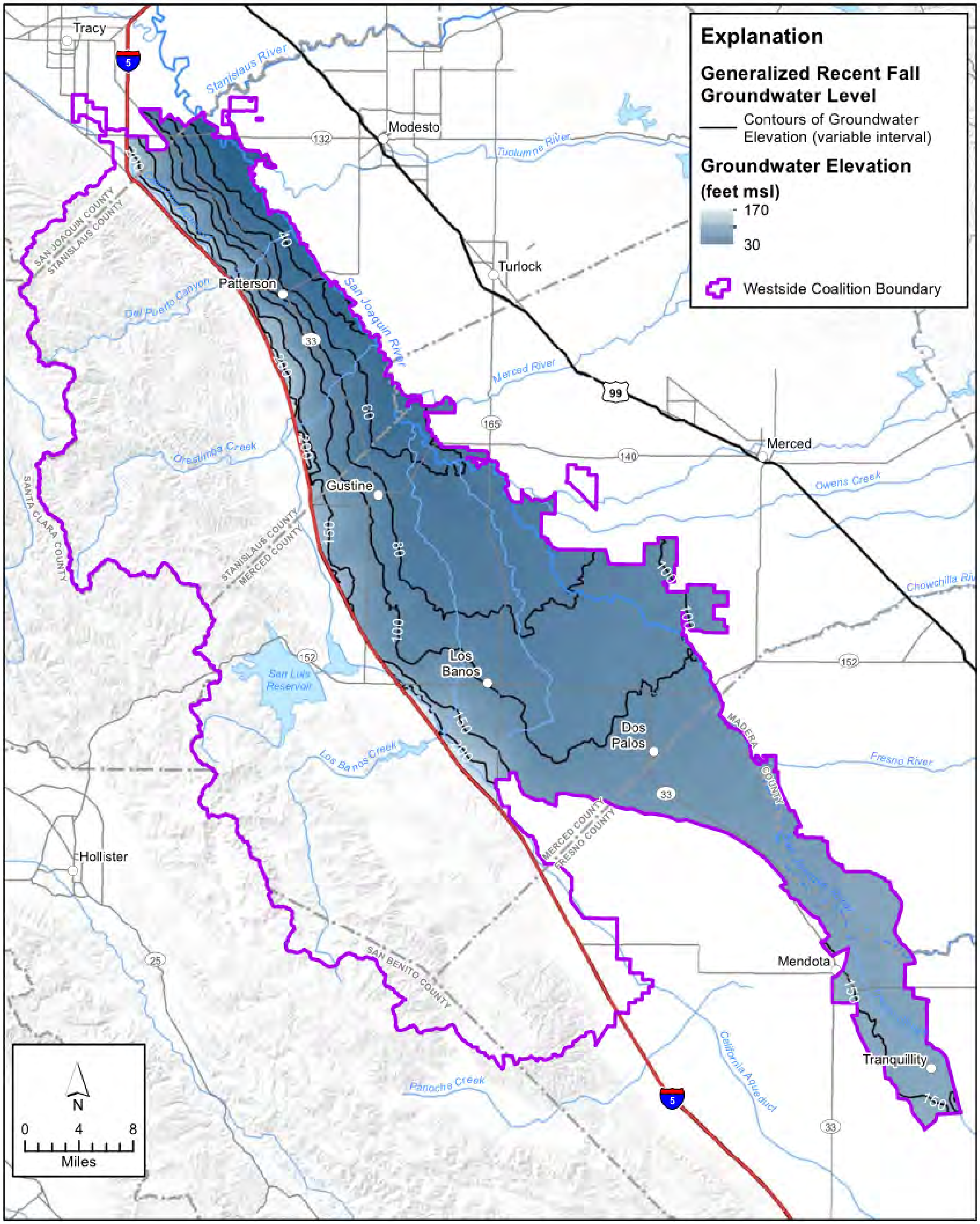


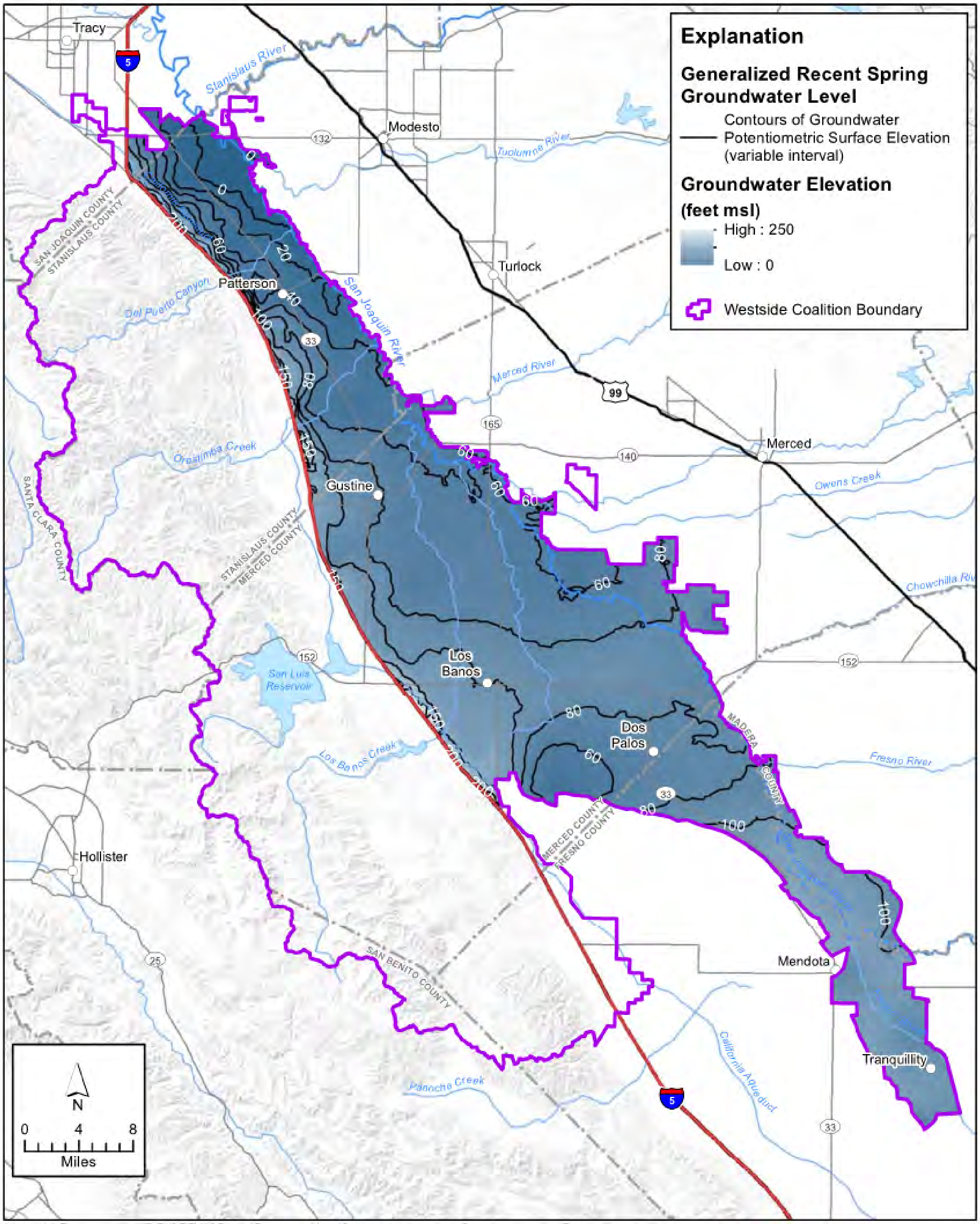
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-70. Map of Spring Groundwater Elevation (2000-2016 Average), Very Shallow Groundwater



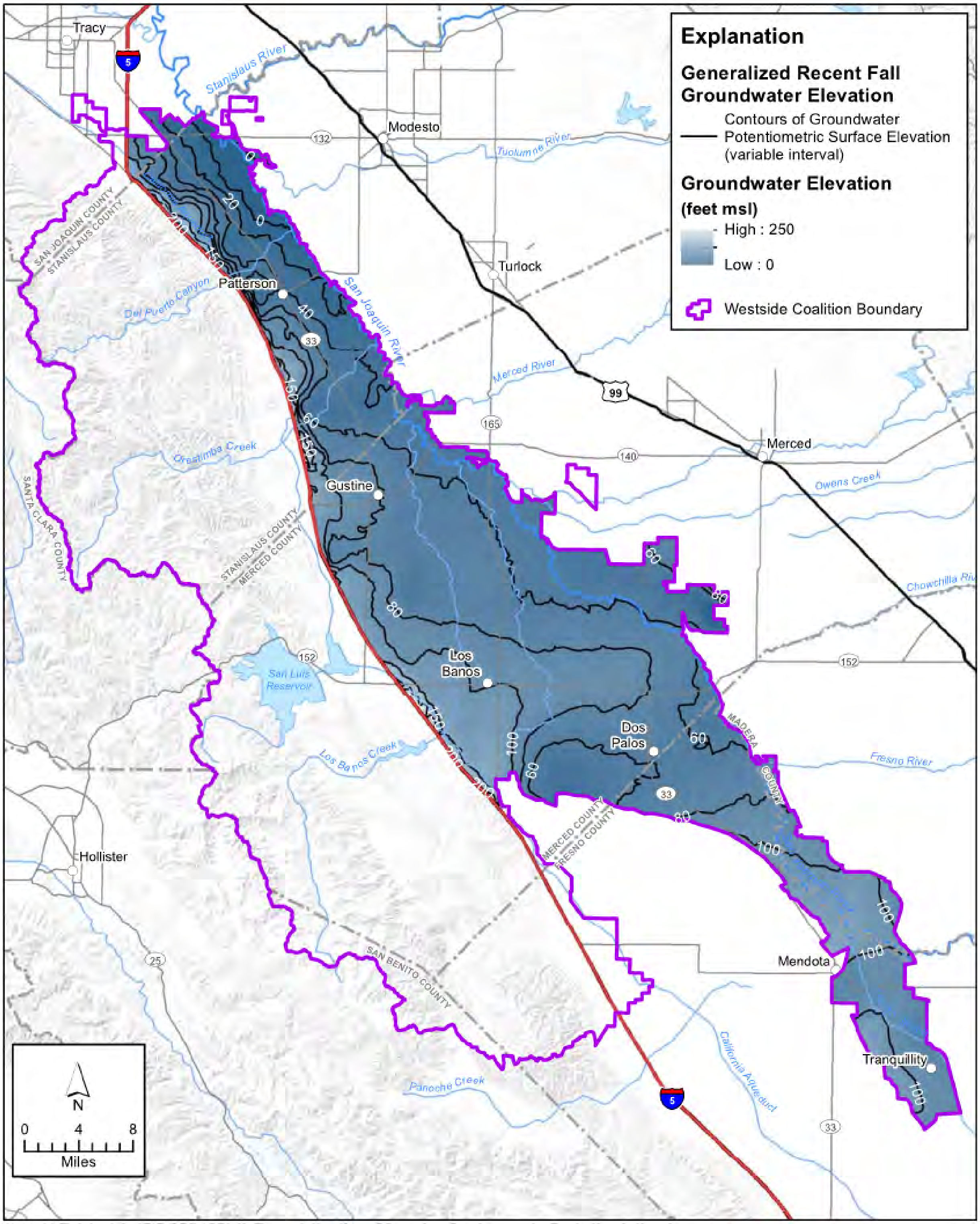
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-71. Map of Fall Groundwater Elevation (2000-2016 Average), Very Shallow Groundwater



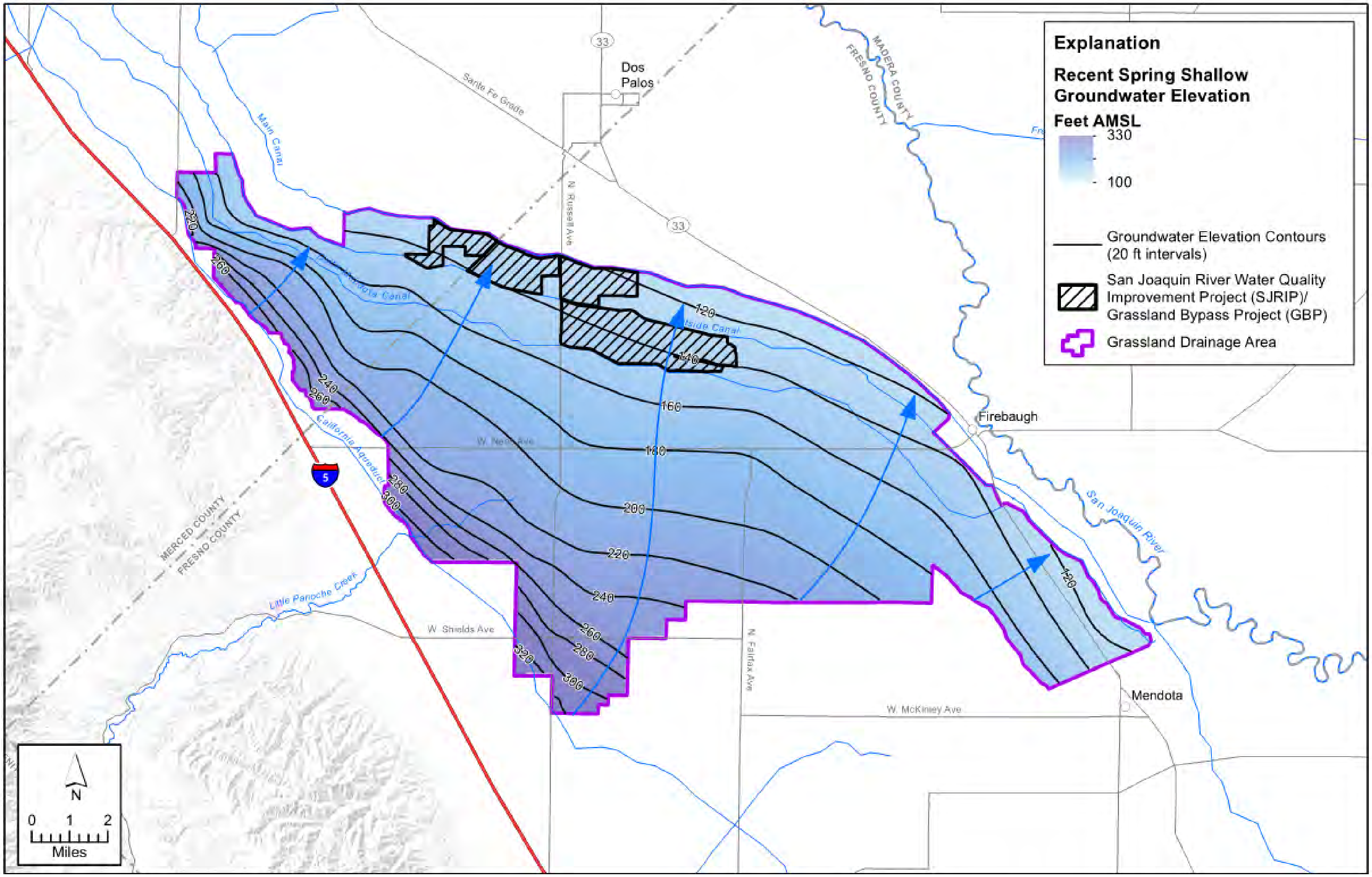
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-72. Map of Spring Groundwater Elevation (2000-2016 Average), Upper Aquifer



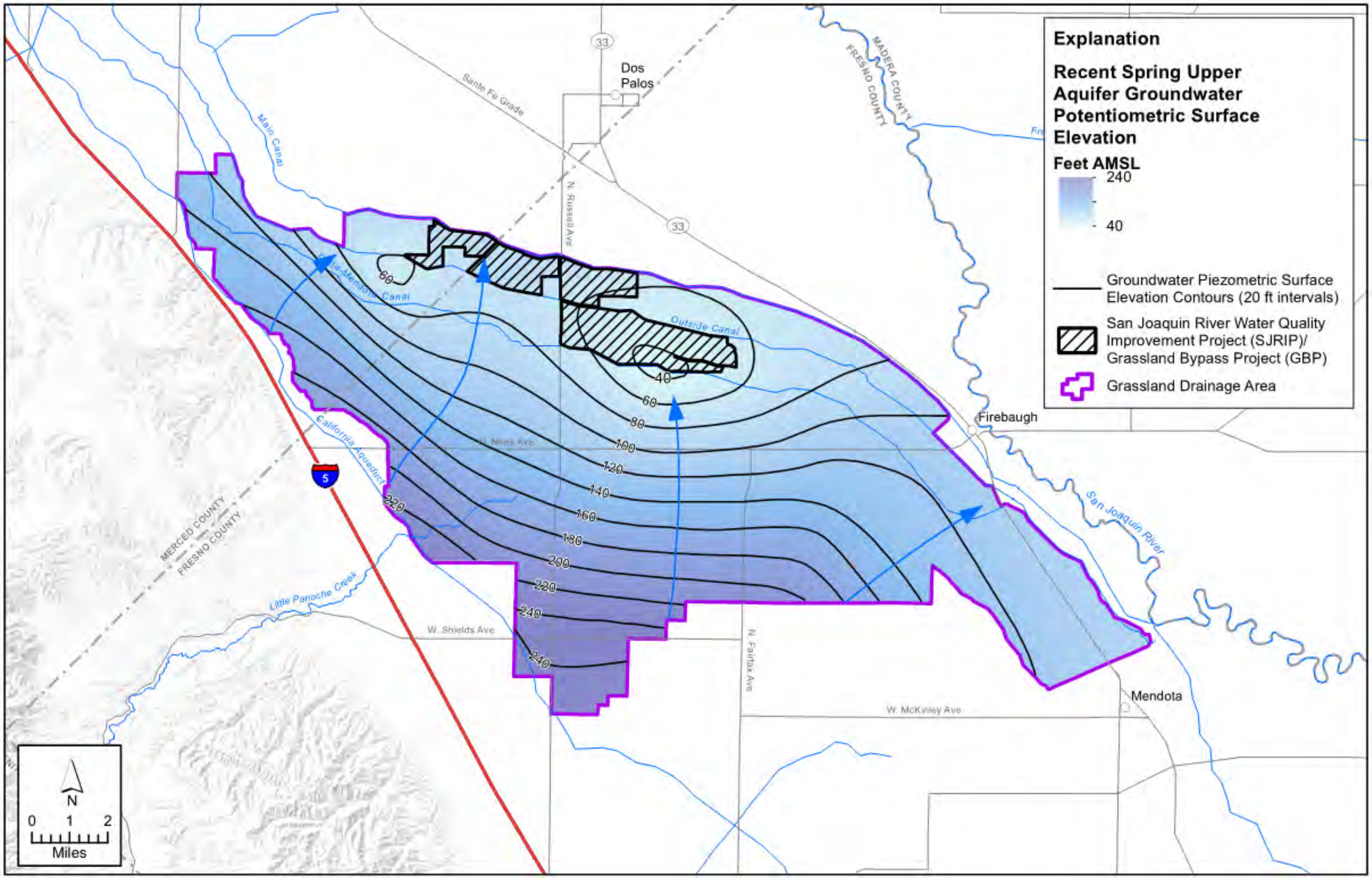
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-73. Map of Fall Groundwater Elevation (2000-2016 Average), Upper Aquifer



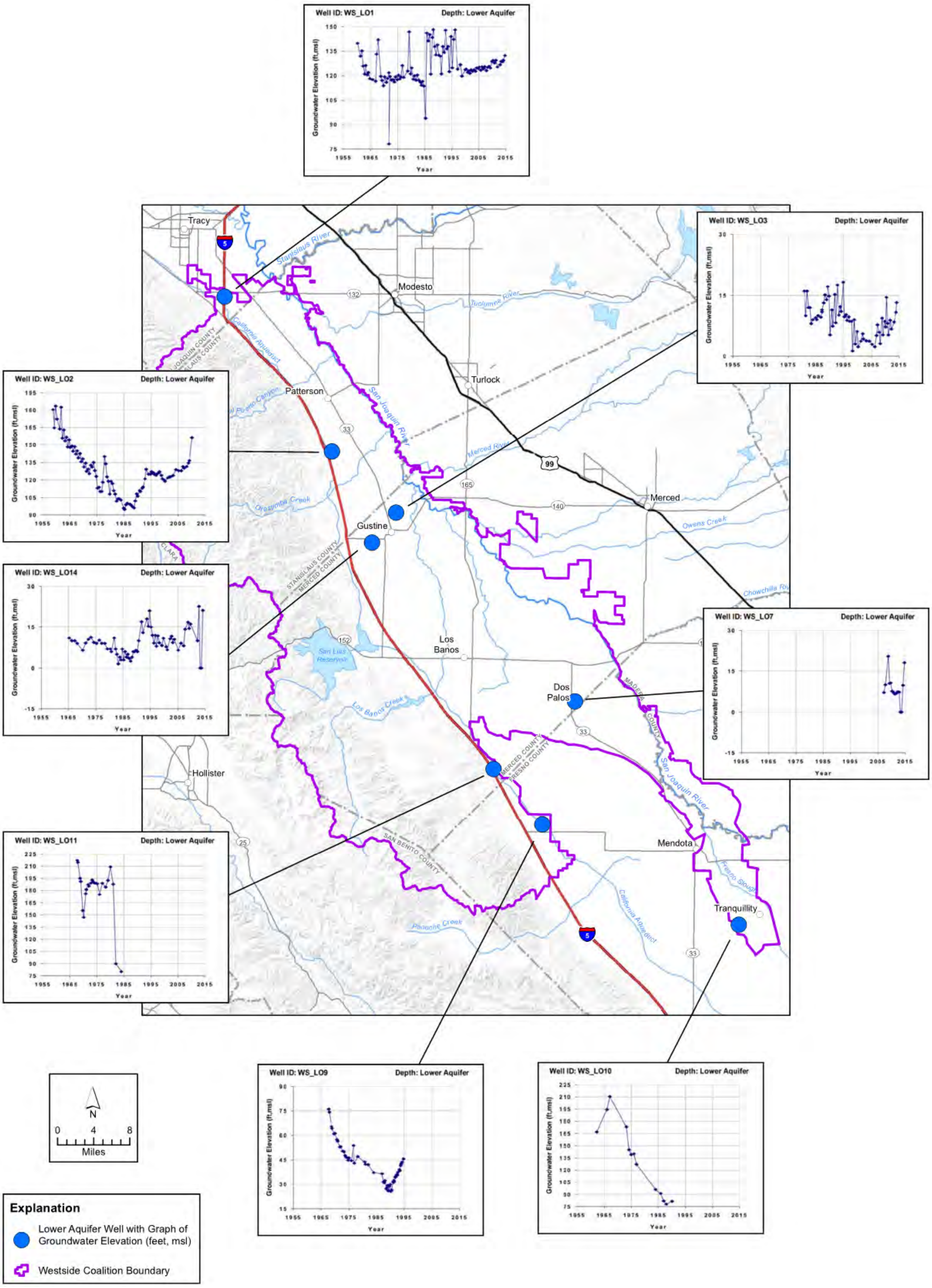
Source: *Grassland Drainage Area Groundwater Quality Assessment Report*, 2016

Figure 5-74. Map of Spring Groundwater Elevation (2000-2016 Average), Shallow Groundwater



Source: *Grassland Drainage Area Groundwater Quality Assessment Report*, 2016

Figure 5-75. Map of Spring Groundwater Elevation (2000-2016 Average), Upper Aquifer



Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015
Note: The intent of these hydrographs is to generally demonstrate groundwater trends across the Delta-Mendota Subbasin.

Figure 5-76. Select Graphs of Groundwater Elevations, Lower Aquifer

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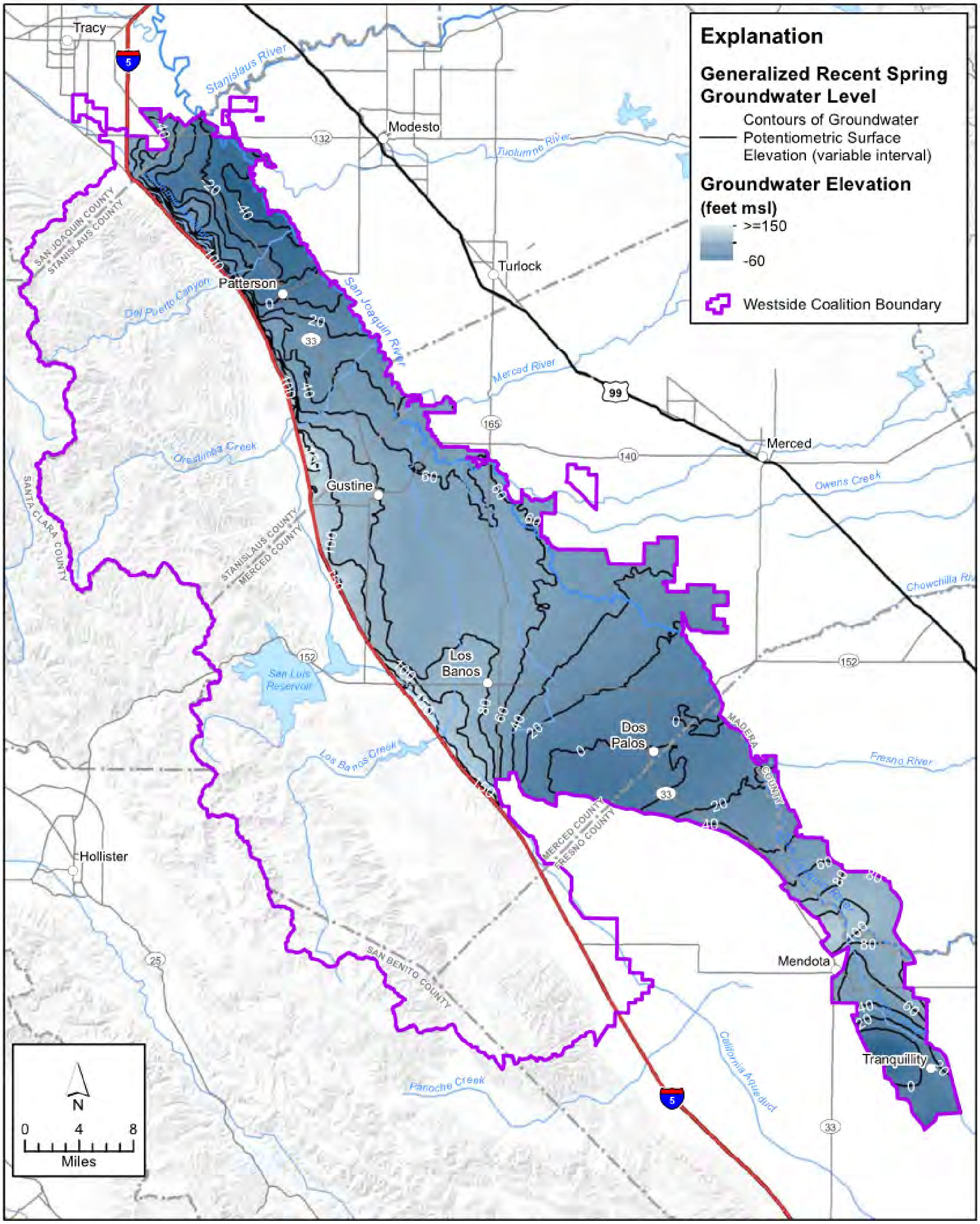
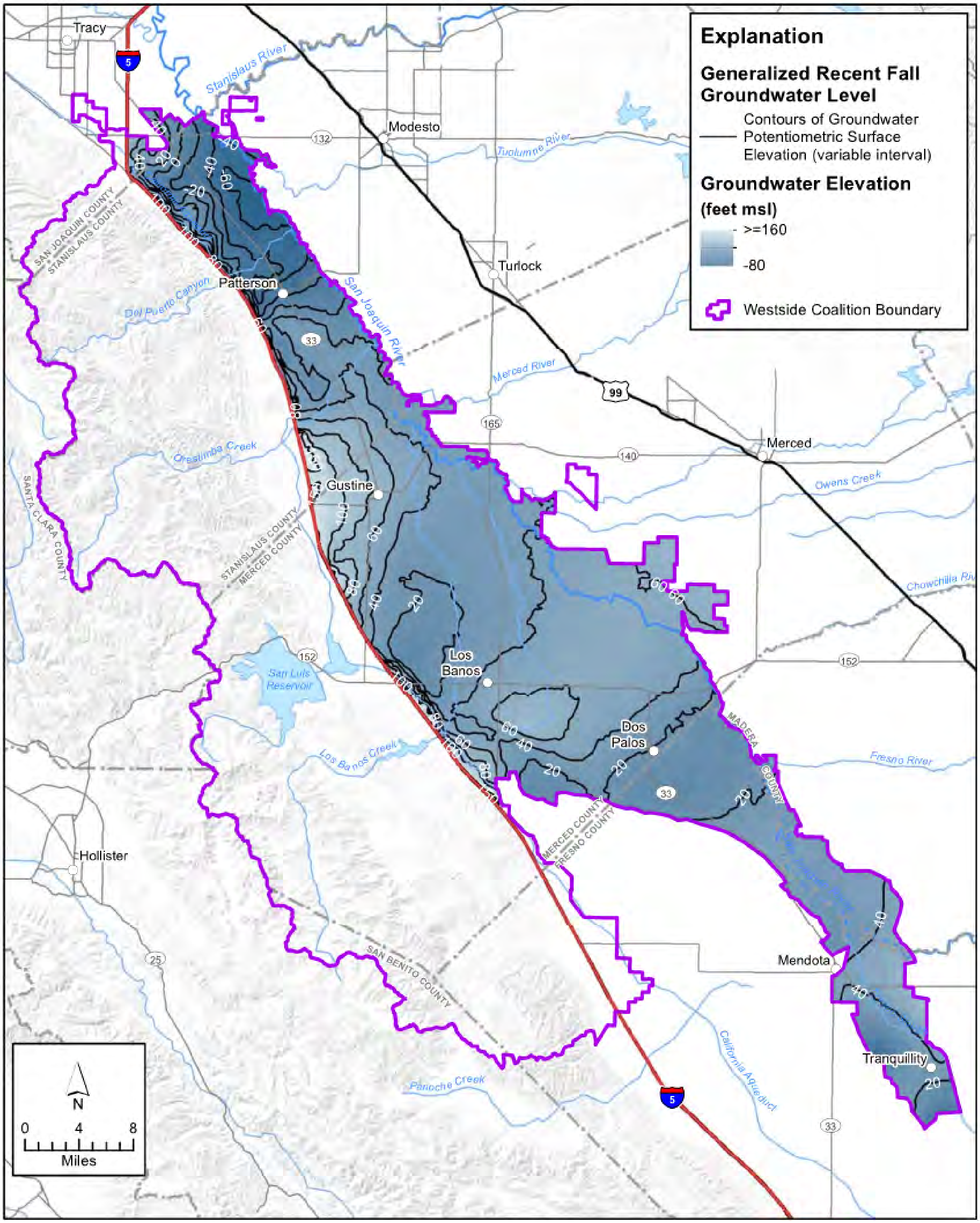


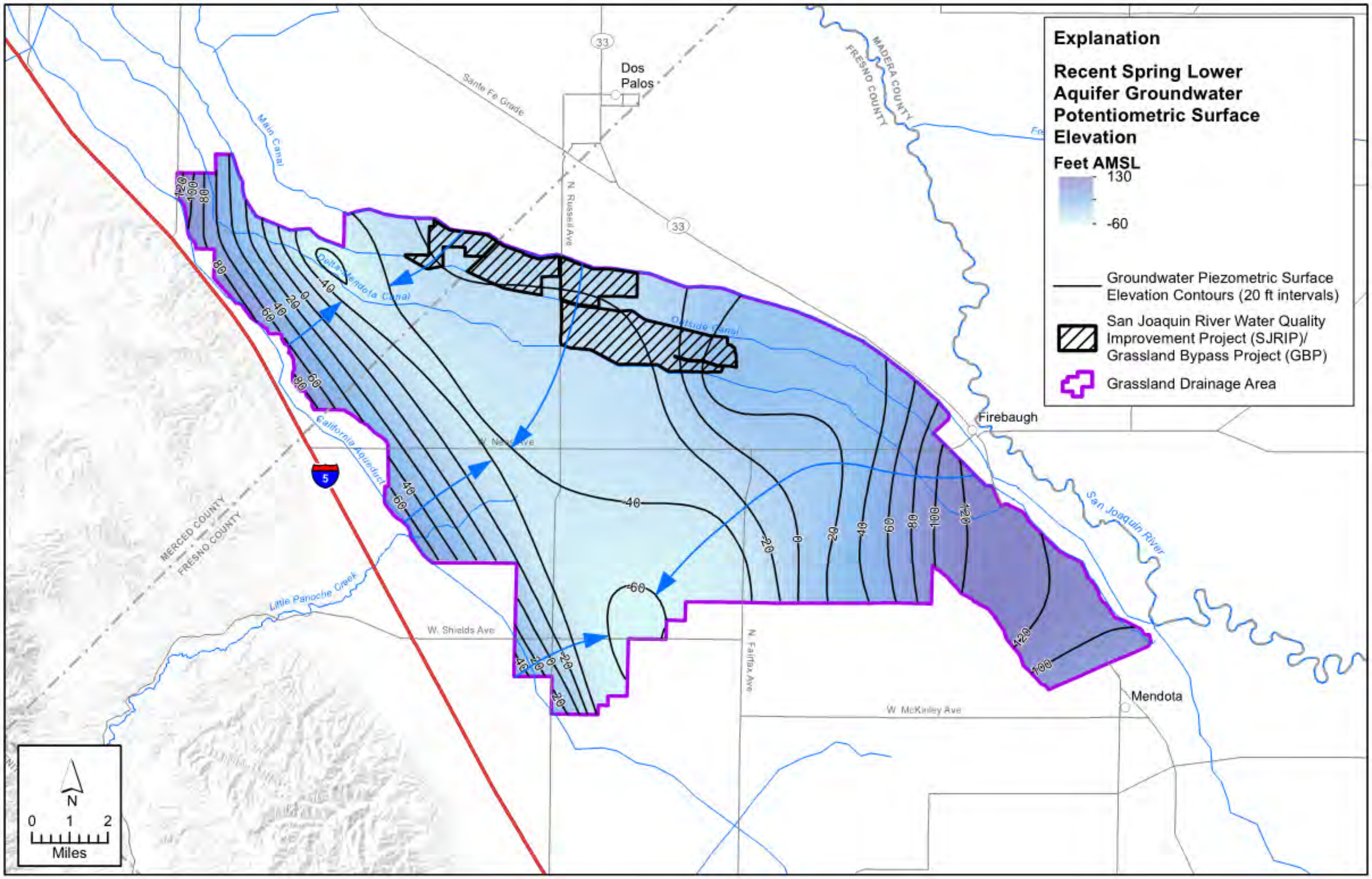
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-77. Map of Spring Groundwater Elevation (2000-2016 Average), Lower Aquifer



Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-78. Map of Fall Groundwater Elevation (2000-2016 Average), Lower Aquifer



Source: *Grassland Drainage Area Groundwater Quality Assessment Report*, 2016

Figure 5-79. Map of Spring Groundwater Elevation (2000-2016 Average), Lower Aquifer

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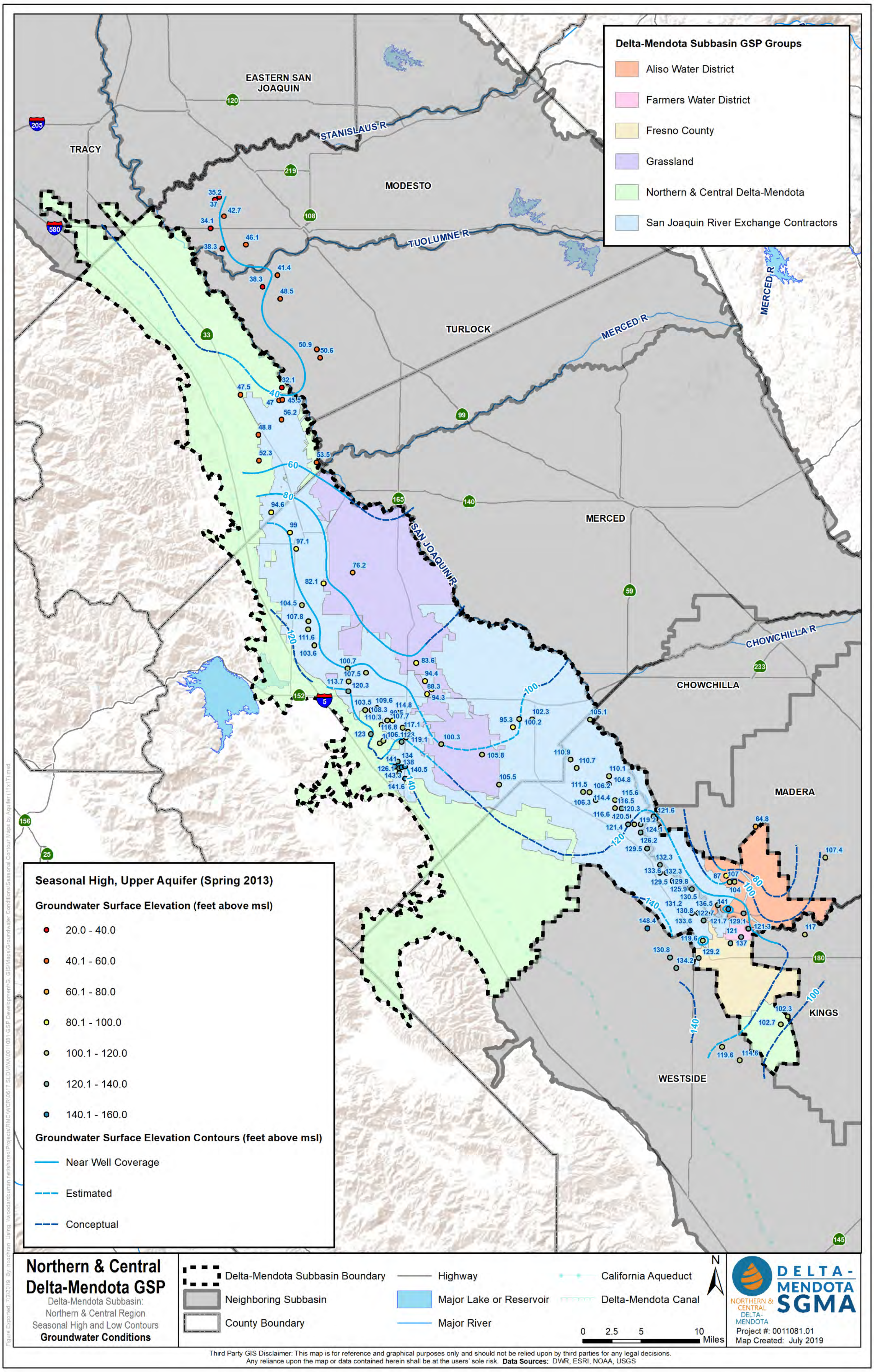

Figure 5-80. Spring 2013 Upper Aquifer Groundwater Contour Map, Delta-Mendota Subbasin

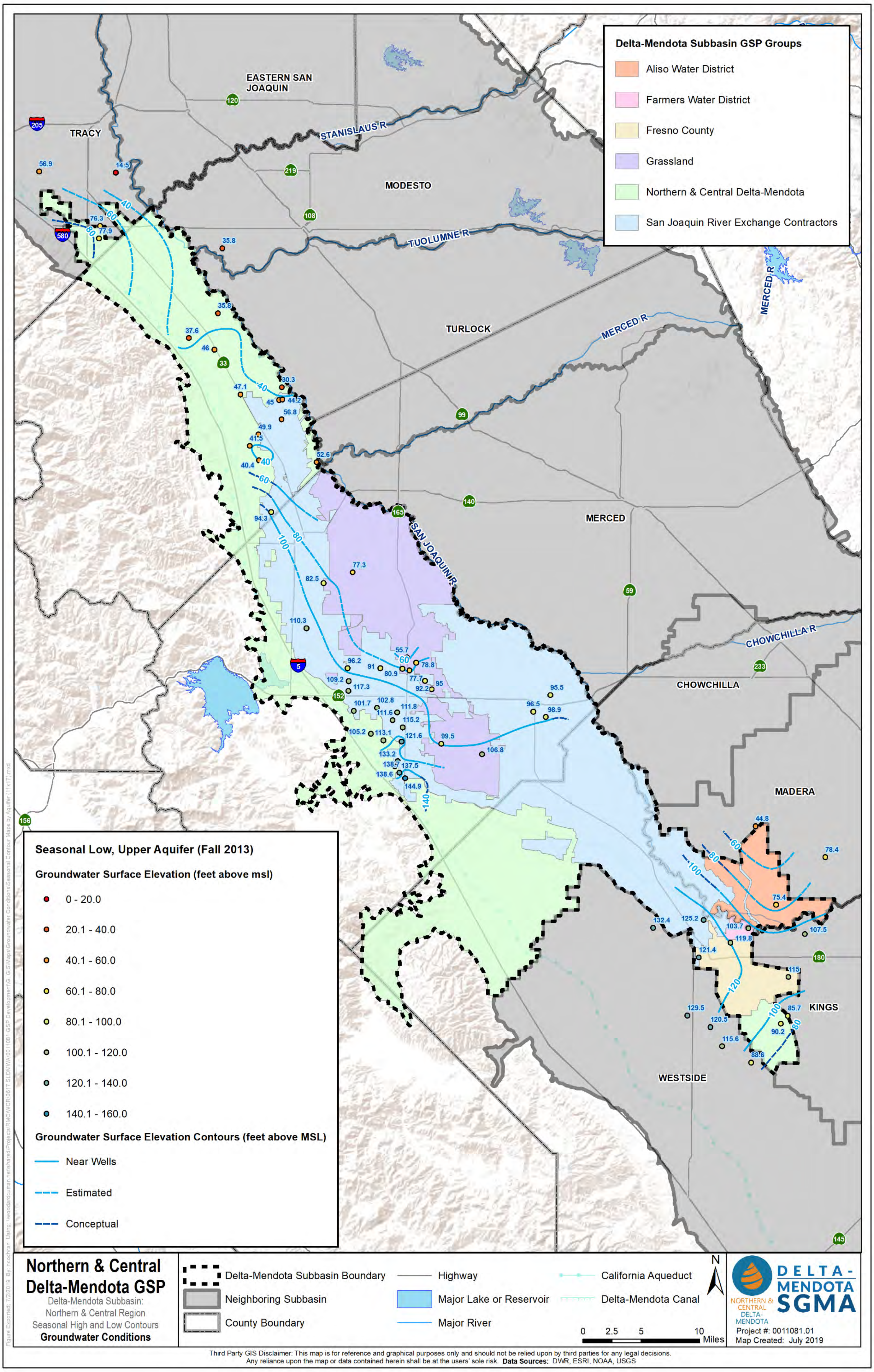

Figure 5-81. Fall 2013 Upper Aquifer Groundwater Contour Map, Delta-Mendota Subbasin

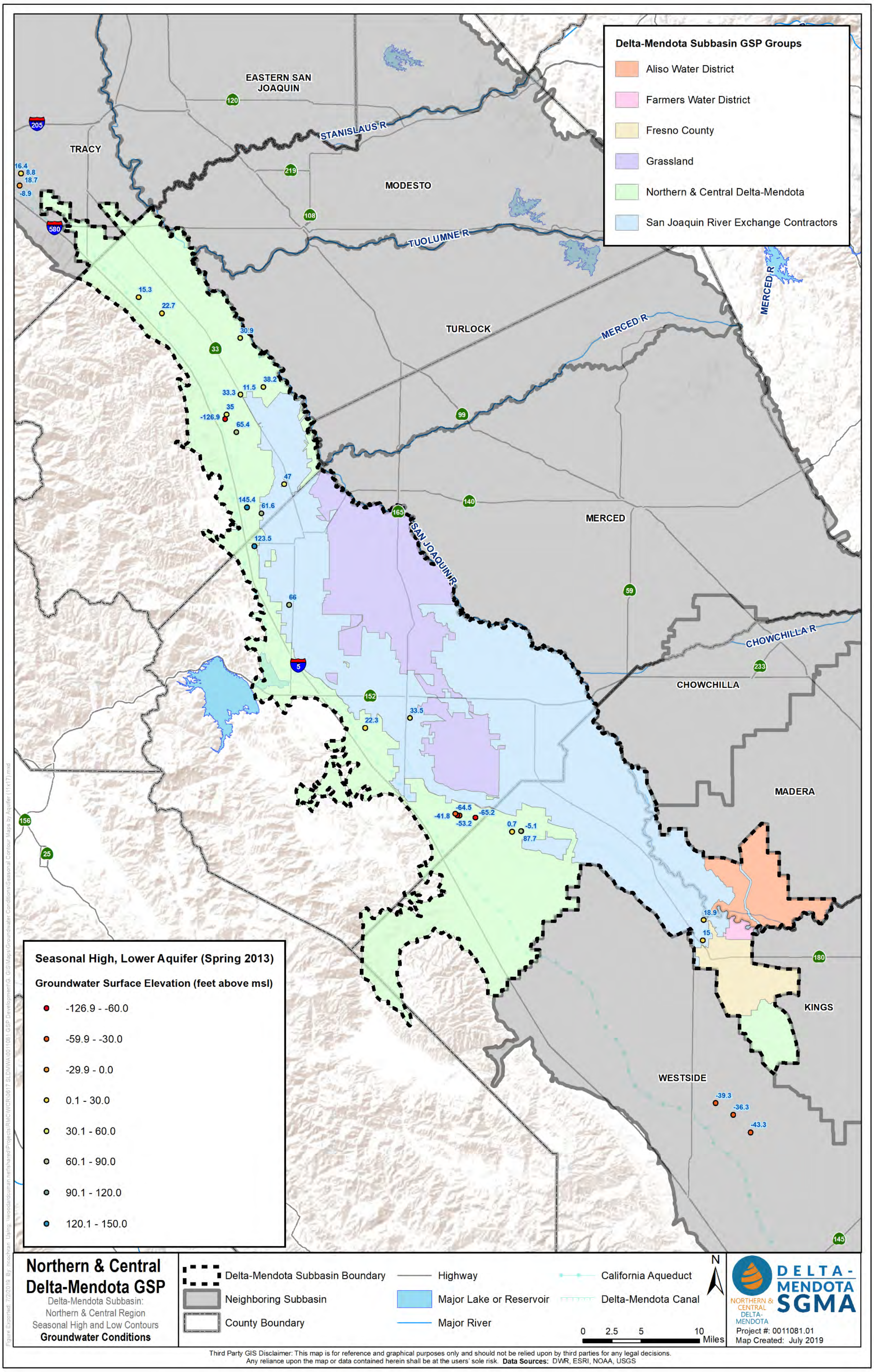

Figure 5-82. Spring 2013 Lower Aquifer Groundwater Elevation Measurements, Delta-Mendota Subbasin

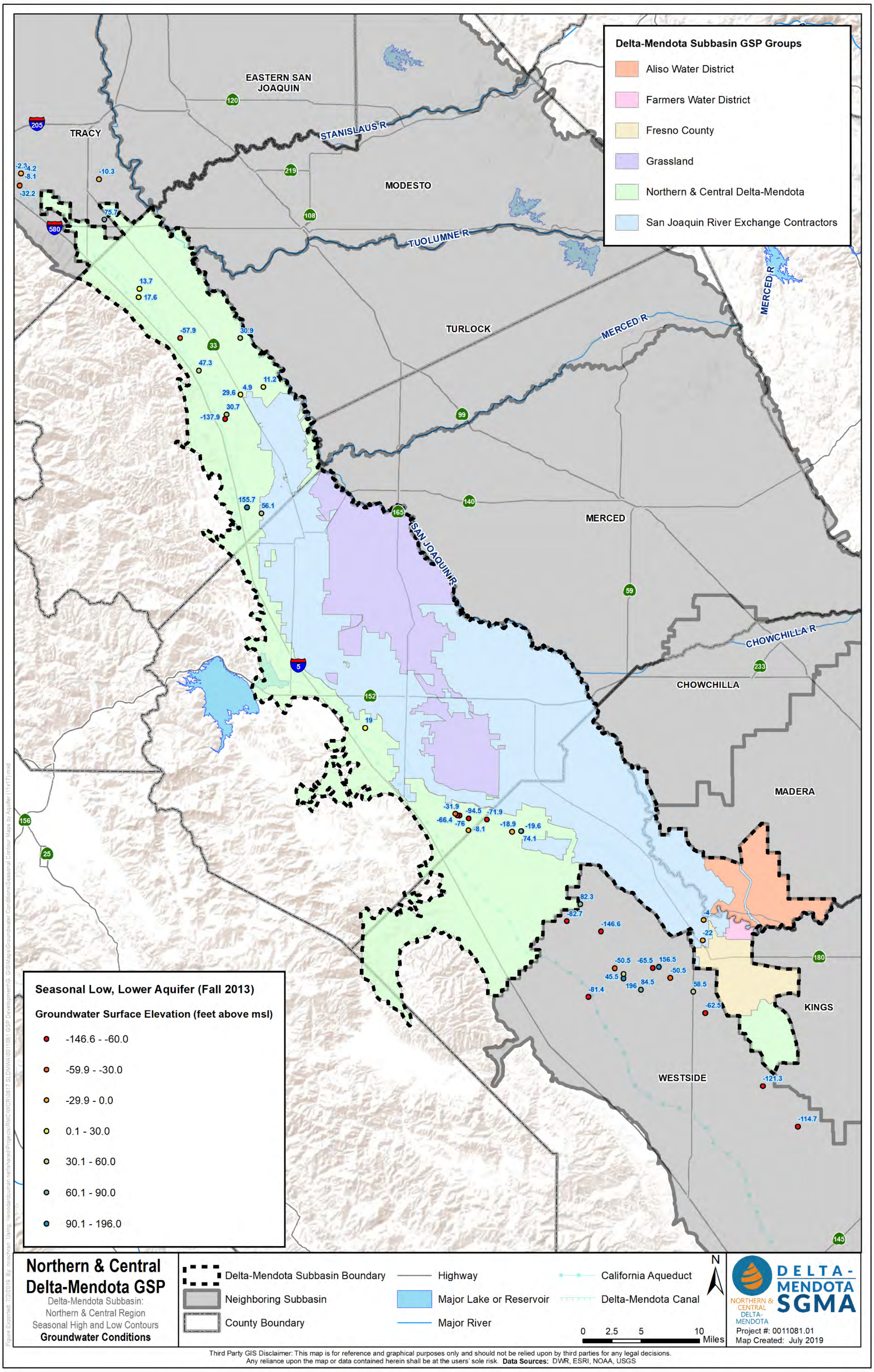

Figure 5-83. Fall 2013 Lower Aquifer Groundwater Elevation Measurements, Delta-Mendota Subbasin

5.3.3 Groundwater Storage

Annual change in groundwater storage for both the Upper and Lower Aquifers in the Northern and Central Delta-Mendota Regions was generated through the development of the historic and current water budgets (WY2003-2013). Aquifer-specific hydrographs available within the Northern and Central Delta-Mendota Regions were used to estimate annual and cumulative change in storage relative to the start of the historic water budget period in WY2003. Please refer to the Water Budget section (**Section 5.4**) and Water Budgets Model Development Technical Memorandum (**Appendix D**) for more detail regarding how change in storage was calculated.

Figure 5-84 and **Figure 5-85** show annual change in storage, cumulative change in storage, and water year type for the Upper Aquifer and Lower Aquifer, respectively, from WY2003 through WY2018 for the Northern and Central Delta-Mendota Regions. Cumulative change in storage from WY2003 through WY2013 was derived from annual change in storage based on available hydrograph data (represented as a solid line in **Figure 5-84** and **Figure 5-85**). Cumulative change in storage from WY2014 through WY2018 was estimated from annual change in storage based on the average change in storage by water year type from WY2003 to WY2013 (represented as a dashed line in **Figure 5-84** and **Figure 5-85**). For the purposes of the water budget four water year types were utilized: wet, average (corresponding to above and below normal water years from the San Joaquin River Index), dry (corresponding to dry and critical water years from the San Joaquin River Index) and Shasta critical.

Change in storage is negative for 12 out of the 16 years and negative for 4 out of the 8 Wet and Average water year types in both the Upper Aquifer and Lower Aquifer. Despite periods of wet conditions with recharge outpacing extractions, an overall declining trend in groundwater storage can be observed in both the Upper and Lower Aquifers. Cumulative change in storage declined more rapidly in the Upper Aquifer compared to the Lower Aquifer, declining by about 830,000 acre-feet (AF) in the Upper Aquifer and 160,000 AF in the Lower Aquifer between WY2003 and WY2018.

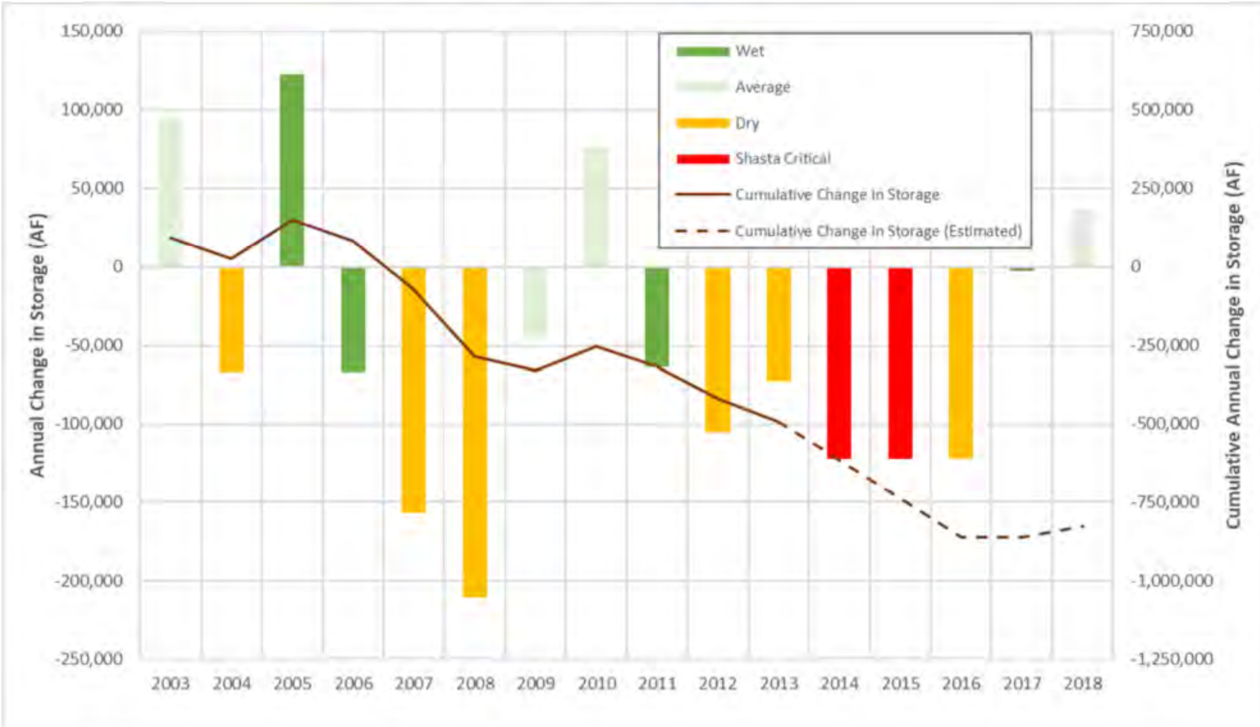

Figure 5-84. Calculated Upper Aquifer Change in Storage, Annual and Cumulative

Figure 5-85. Calculated Lower Aquifer Change in Storage, Annual and Cumulative

5.3.4 Seawater Intrusion

Seawater intrusion is not an applicable sustainability indicator for the Delta-Mendota Subbasin as a whole. The Subbasin is located inland from the Pacific Ocean; thus, groundwater conditions related to seawater intrusion are not applicable to the Delta-Mendota Subbasin.

5.3.5 Groundwater Quality

Groundwater quality is a primary factor in groundwater supply reliability. There are no known groundwater contamination sites or plumes within the Northern and Central Delta-Mendota Regions. Groundwater quality concerns within the Northern and Central Delta-Mendota Regions are largely related to non-point sources and/or naturally-occurring constituents. Constituents of concern, both natural and anthropogenic, can impact human health and agricultural production. The following subsections attempt to identify and analyze available groundwater quality data and summarize groundwater quality conditions through a literature review and evaluation of existing publicly available data sets. It should be noted that constituents of concern discussed in this GSP are not exhaustive of all constituents of concern present in groundwater in the Delta-Mendota Subbasin. The presented constituents of concern were selected based on available data, the potential to impact existing or future groundwater use, the ability to address groundwater quality impacts through projects and/or management actions, and the source of the constituent.

Primary constituents of concern within the Northern and Central Delta-Mendota Regions are nitrate, total dissolved solids (TDS), and boron, which all have anthropogenic as well as natural sources. **Table 5-1** includes the State and federal primary and secondary MCLs for drinking water in milligrams per liter (mg/L). These are also the Water Quality Objectives (WQOs) in the Central Valley Regional Water Quality Control Board's (CV-RWQCB) *Water Quality Control Plan for the Sacramento and San Joaquin River Basins* (or Basin Plan) (2009) for waters designated as having municipal (MUN) beneficial use. **Table 5-2** includes WQOs for irrigated agriculture. Agricultural WQOs identified in **Table 5-2** are derived from the *Delta-Mendota Canal Non-Project Water Pump-in Program Monitoring Plan* (2018).

While there are other constituents known to be found in localized areas throughout the Northern and Central Delta-Mendota Regions, these constituents generally characterize groundwater quality in the region of interest. It is important to note that the following discussion and analysis of ambient groundwater quality is not reflective of drinking water quality where treatment is applied to remove such constituents before public consumption.

Other known constituents of concern within the Delta-Mendota Subbasin include arsenic, selenium, and hexavalent chromium. These constituents are naturally occurring in the Delta-Mendota Subbasin and have been detected at concentrations above the WQOs at various locations throughout the Delta-Mendota Subbasin. Concentrations of these constituents do not appear to be linked to groundwater elevations, and as such, these constituents (and their associated concentrations) are considered to be existing conditions. There are no specific projects and/or management practices that can be implemented to mitigate for these constituents (other than groundwater treatment) that are not currently being implemented through other regulatory programs (such as the Irrigated Lands Regulatory Program). Therefore, these constituents are not considered manageable as part of this GSP other than through the coordination of GSP implementation with existing and anticipated future regulatory programs. Sustainability goals and indicators will therefore not be developed for these constituents. The water quality monitoring program will, however, continue to collect data relative to ongoing groundwater concentrations for these constituents for future assessment in coordination with other existing and anticipated future regulatory programs.

Table 5-1. State and Federal Primary and Secondary MCLs for Drinking Water, Constituents of Concern

Constituent	U.S. Environmental Protection Agency		State of California	
	Primary MCL (mg/L)	Secondary MCL (mg/L)	Primary MCL (mg/L)	Secondary MCL (mg/L)
Nitrate [1]	10 (as N)	-	45 (as NO_3)	-
TDS [2]	-	-	-	500 (Recommended) 1,000 (Upper) 1,500 (Short-term)
Boron [1]	N/A	N/A	N/A	N/A

[1] SWRCB, March 2018.
[2] State of California, 2006.

Table 5-2. Water Quality Objectives for Irrigation

Constituent	Water Quality Objective	Units
Nitrate (as Nitrogen) [1]	10	mg/L
TDS [2]	1,000	mg/L
Boron [3]	0.7	mg/L

[1] State of California (December 2017); Title 22. Table 64431-A Maximum Contaminant Levels, Inorganic Chemicals
[2] State of California (December 2017); Title 22. Table 64449-B Secondary Maximum Contaminant Levels "Consumer Acceptance Contaminant Level Ranges"
[3] Ayers and Westcot (1985), Table 21

5.3.5.1 Available Data

Groundwater quality data within the Delta-Mendota Subbasin are available from the following sources and associated programs:

- Central Valley Regional Water Quality Control Board
  - ILRP
    - Western San Joaquin GAR
    - Grassland Drainage Area GAR
- State Water Resources Control Board (SWRCB)
  - Central Valley Salinity Alternatives for Long-term Sustainability (CV-SALTS)
  - Geotracker Groundwater Ambient Monitoring and Assessment Program (GAMA)
- United States Bureau of Reclamation
  - Delta-Mendota Canal Warren Act Pump-in Program
- Local Agency Data

Data provided by these sources include information such as parameter sampled, sample location, sample date, sampling method, concentration, and other related information, such as questionable measurement code, well construction information, and well type. These data were synthesized to support the following discussions of constituents of concern. Data were obtained predominantly from the data sets identified above to characterize groundwater quality from 2000 to 2018. **Figure 5-86** through **Figure 5-87** show the locations of wells with available water quality monitoring data and known aquifer designation. Groundwater quality varies based on location and depth by constituent. The following discusses the primary water quality data and analyses recently completed for the Delta-Mendota Subbasin and utilized herein.

Central Valley Salt and Nutrient Management Plan (SNMP). The Central Valley SNMP, prepared under the CV-SALTs program administered under the CV-RWQCB, contains an analysis of nitrate and TDS concentrations for the entire Central Valley. For the purposes of this GSP, data from the SNMP are summarized for the Delta-Mendota Subbasin.

The SNMP examined ambient conditions and Assimilative Capacity for both TDS and nitrate using data ranging from pre-1960 through 2012. Assimilative Capacity was computed by taking the difference between the ambient concentration and the regulatory threshold (or WQO). For the purposes of this GSP, discussion focuses on data analyzed for the Upper Zone (defined generally in the SNMP as the vadose zone generally where domestic wells are perforated) and the production zone (defined generally in the SNMP as a combination of the Upper Zone and Lower Zone, which extends to the top of the Corcoran Clay where present, correlating to the Upper Aquifer defined in this GSP, as discussed in the Hydrogeologic Conceptual Model [HCM] [see Section 5.2]).

Western San Joaquin River Watershed Groundwater Quality Assessment Report. The Western San Joaquin River Watershed Coalition ("Coalition") published a GAR in March 2015 (LSCE, 2015). The GAR covers the Coalition region, which encompasses the Delta-Mendota and Merced Subbasins, as well as the Los Banos Creek Valley Groundwater Basin located in the Coast Range mountains. The intent of the GAR is to characterize groundwater quality conditions within the area. Data on nitrate, salinity (TDS and specific conductance or electrical conductivity [EC]), and pesticides were gathered from Coalition members, as well as from the California Department of Public Health's (CDPH's) Water Quality Analysis Data Files, DWR's Water Data Library, United States Geological Survey's (USGS) National Water Information System, SWRCB Geotracker GAMA, and the California Department of Pesticide Regulation (DPR) pesticide sampling database. Sampling dates for nitrate range from 1944 to 2014, while sampling dates for TDS range from 1930 to 2014. Although some data extends past 2012 (the end of the "historic" period for GSP purposes), information from the GAR is still considered to fall under historic conditions given the overall data range. Pesticide data for the GAR were limited to data obtained from the DPR. DPR well locations were not provided with pesticide data; they were associated with a Public Land Survey System (PLSS) section (one square mile) for analysis.

Grasslands Drainage Area Groundwater Quality Assessment Report. The Grassland Drainage Area published a GAR in July 2016 (LSCE, 2016). The Grassland Drainage Area GAR covers a portion of the Delta-Mendota Subbasin generally south of Dos Palos, east of Firebaugh, and north of the boundary with the Westside Subbasin (which encompasses portions of the Central Delta-Mendota, Oro Loma Water District, and Widren Water District GSAs). The GAR contains information on nitrate, salinity (TDS and EC), selenium, boron, and pesticides. Data was gathered from Coalition members, as well as CDPH's Water Quality Analysis Data Files, DWR's Water Data Library, USGS's National Water Information System, SWRCB Geotracker GAMA, and the DPR pesticide sampling database. Sampling dates for nitrate, TDS, and boron range from the 1940s through 2010s. Sampling dates for selenium range from the 1980s through 2010s. Pesticide data for the GAR were limited to data obtained from the DPR. DPR well locations were not provided with pesticide data; they were associated with a PLSS section (one square mile) for analysis.

Groundwater Quality in the Western San Joaquin Valley Study Unit, 2010: California GAMA Priority Basin Project. Water quality in groundwater resources used for public drinking-water supply in the Western San Joaquin Valley (WSJV) was investigated by the USGS in cooperation with the California SWRCB as part of its GAMA

Program Priority Basin Project (SWRCB, July 2018). The WSJV includes two study areas: the Delta–Mendota and Westside Subbasins of the San Joaquin Valley Groundwater Basin. As documented in the published study entitled *Groundwater Quality in the Western San Joaquin Valley Study Unit, 2010: California GAMA Priority Basin Project* (Scientific Investigations Report 2017-5032 by Miranda Fram), the study objectives included two assessment types: (1) a status assessment yielding quantitative estimates of the current (2010) status of groundwater quality in the groundwater resources used for public drinking water, and (2) an evaluation of natural and anthropogenic factors that could be affecting the groundwater quality. The assessments characterized the quality of untreated groundwater based on data collected from 43 wells sampled by the USGS for the GAMA Priority Basin Project (USGS-GAMA) in 2010 and data compiled in the SWRCB Division of Drinking Water (DDW) database for 74 additional public-supply wells sampled for regulatory compliance purposes between 2007 and 2010. To provide context, concentrations of constituents measured in groundwater were compared to U.S. Environmental Protection Agency (EPA) and DDW regulatory and non-regulatory benchmarks for drinking-water quality.

In general, the study found that groundwater resources used for public drinking water in the WSJV study unit are among the most saline and most affected by high concentrations of inorganic constituents of all groundwater resources used for public drinking water that have been assessed by the GAMA Priority Basin Project statewide. Among the 82 GAMA Priority Basin Project study areas statewide, the Delta–Mendota Subbasin ranked above the 90th percentile for aquifer-scale proportions of groundwater resources having concentrations of TDS, sulfate, chloride, manganese, boron, hexavalent chromium, selenium, and strontium above benchmarks. The study also found that recharge of water used for irrigation has direct and indirect effects on groundwater quality. Elevated nitrate concentrations and detections of herbicides and fumigants in the Delta-Mendota Subbasin generally were associated with greater agricultural land use near wells and with water recharged during the last 60 years.

5.3.5.2 Historic and Current Conditions and Trends

As previously noted, arsenic, hexavalent chromium, and selenium are naturally-occurring constituents in the Delta-Mendota Subbasin whose ambient concentrations sometimes exceed the WQO from the Basin Plan. However, these constituents are ubiquitous, and concentrations cannot be directly correlated to groundwater elevations or other groundwater management practices. As such, these constituents are considered to be ‘unmanageable’ by the GSAs and therefore sustainability indicators have not been developed. Constituents for which sustainability indicators have been developed include nitrate, TDS, and boron.

Nitrate

Using data from the Central Valley SNMP for the period ranging from 2000 through 2016, concentrations of nitrate (as N) in excess of 10 mg/L were found to exist north of Patterson, south of Dos Palos, and southwest of Patterson extending southwest past Los Banos. The ambient concentrations of nitrate in the upper zone are elevated north of Patterson, on the western side of the Subbasin (roughly from Patterson to Los Banos), and south of Dos Palos, with similar patterns seen in the production zone (**Figure 5-88**). **Figure 5-89** displays nitrate (as N) concentration in the production zone for the entire Delta-Mendota Subbasin. Lower nitrate (as N) concentrations (<2.5 mg/L) were found to exist in the areas east of Los Banos and south of Firebaugh.

Throughout the Delta-Mendota Subbasin, nitrate concentrations were below 5 mg/L (nitrate as N) in the majority of wells, as described in the Western San Joaquin GAR (LSCE, 2015). However, there are several areas where higher concentrations occur, including locations where the MCL of 10 mg/L is exceeded. In the Upper Aquifer, notable areas of elevated nitrate concentrations occur immediately south of Los Banos and northwest, along Highway 33, toward Patterson. Geologic formations with naturally-occurring elevated levels of nitrate have been identified in Origalita Creek alluvium in the southern portion of the Subbasin. In the Lower Aquifer, fewer data are available, but most wells have a maximum nitrate concentration above 5 mg/L. In the most recent available data, some Lower Aquifer wells have concentrations greater than 10 mg/L. In general, higher nitrate concentrations in the Lower Aquifer occur in areas where the Corcoran Clay is thin or non-existent (particularly to the west and northwest of Gustine) (LSCE, 2015). In the Grassland Drainage Area, only six wells in the Upper Aquifer had nitrate data available. Of these, only one had a nitrate concentration above 10 mg/L; other wells were below 2.5 mg/L. Data for the Lower Aquifer were also limited, including only 14 wells. The majority of observed nitrate concentrations were below 2.5 mg/L, with none exceeding 10 mg/L (LSCE, 2016).

Nitrate (as N) concentrations in the Upper Aquifer (above the Corcoran Clay) have been mostly low and stable over time since 1985 (**Figure 5-90** and **Figure 5-91**). Overall, in the northern portion of the Subbasin, nitrate (as N) concentrations in the Upper Aquifer were generally below the MCL of 10 mg/L, with concentrations generally increasing further south in the Subbasin and reaching and stabilizing at a maximum of 15 mg/L south of Dos Palos since 2007. Similar to the Upper Aquifer, nitrate concentrations in the Lower Aquifer (below the Corcoran Clay) have been low and stable since 1985 with no recorded exceedances above the MCL (**Figure 5-92**). Generally, timeseries data for nitrate concentrations south of Dos Palos within Fresno County was largely unavailable with sufficient temporal range to warrant evaluation and presentation through timeseries graphs, with most data only available for a short timeframe from the late 1980s to the early 1990s.

The Western San Joaquin and Grassland Drainage Area GARs also assessed the present temporal trends in nitrate for all available historical data through 2016 (wells with a minimum of three sampling events) using a linear regression trend analysis with a p-value of 0.05 and 0.1 indicating significance, respectively from each GAR. **Table 5-3** indicates the degree of trends for nitrate as presented in the GARs. **Figure 5-93** illustrates statistically-significant temporal trends in nitrate concentration in the Upper Aquifer. Significant trends in the increasing and decreasing directions are observed in the Upper Aquifer. Wells near Patterson, Gustine, and Los Banos largely show Mildly Increasing trends with a cluster of wells near the San Joaquin River in central Merced County, and two wells south of Dos Palos showing Mildly Decreasing and Decreasing trends. Wells with very small changes in nitrate concentration are scattered throughout the Subbasin.

Figure 5-94 illustrates statistically significant temporal trends in nitrate concentration in the Lower Aquifer. Wells with sufficient data to demonstrate a statistically significant trend are limited to the Stanislaus County portion of the Delta-Mendota Subbasin and south of Dos Palos. Trends show largely Mildly Increasing and Increasing nitrate concentrations with a few wells showing Mildly Decreasing and Decreasing trends northwest of Gustine. South of Dos Palos, one well shows a very small change in nitrate concentration and another shows a Mildly Increasing trend. **Figure 5-95** illustrates statistically significant temporal trends in nitrate concentration in composite wells screened in both the Upper Aquifer and Lower Aquifer. Only two composite wells with statistically significant trends in nitrate concentration are present in the Delta-Mendota Subbasin. One well located near Dos Palos has a Mildly Increasing trend, with the other well located south of Gustine has a Mildly Decreasing trend.

Table 5-3. Nitrate (as N) Trend Significance

from Western San Joaquin and Grassland GARs

Trend	Nitrate (mg/L/year)
Increasing	> 1.0
Mildly Increasing	0.1 - 1.0
Very Small Change	-0.1 - 0.1
Mildly Decreasing	-1.0 - -0.1
Decreasing	< -1.0

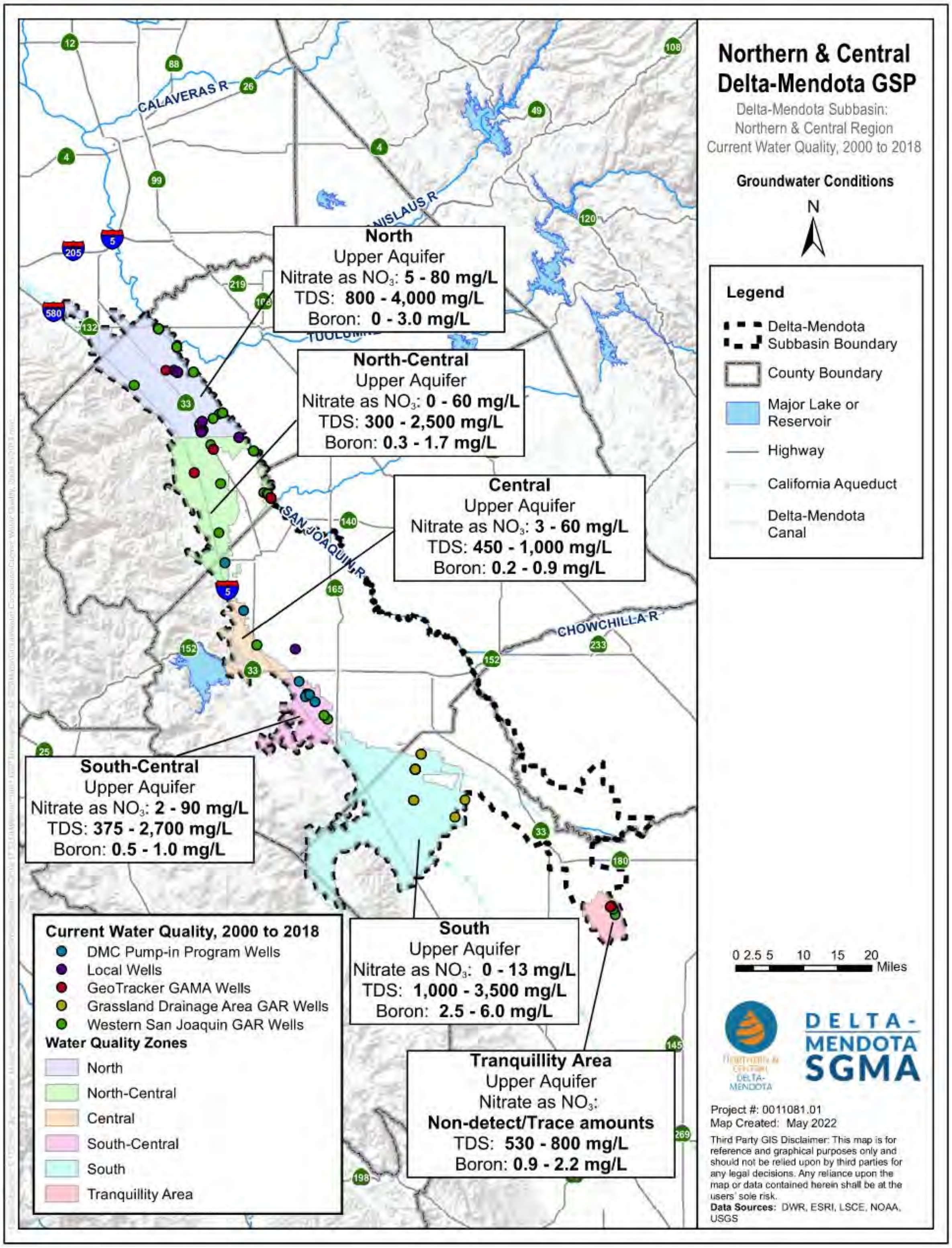

Figure 5-86. Upper Aquifer, Current Groundwater Quality (2000-2018)

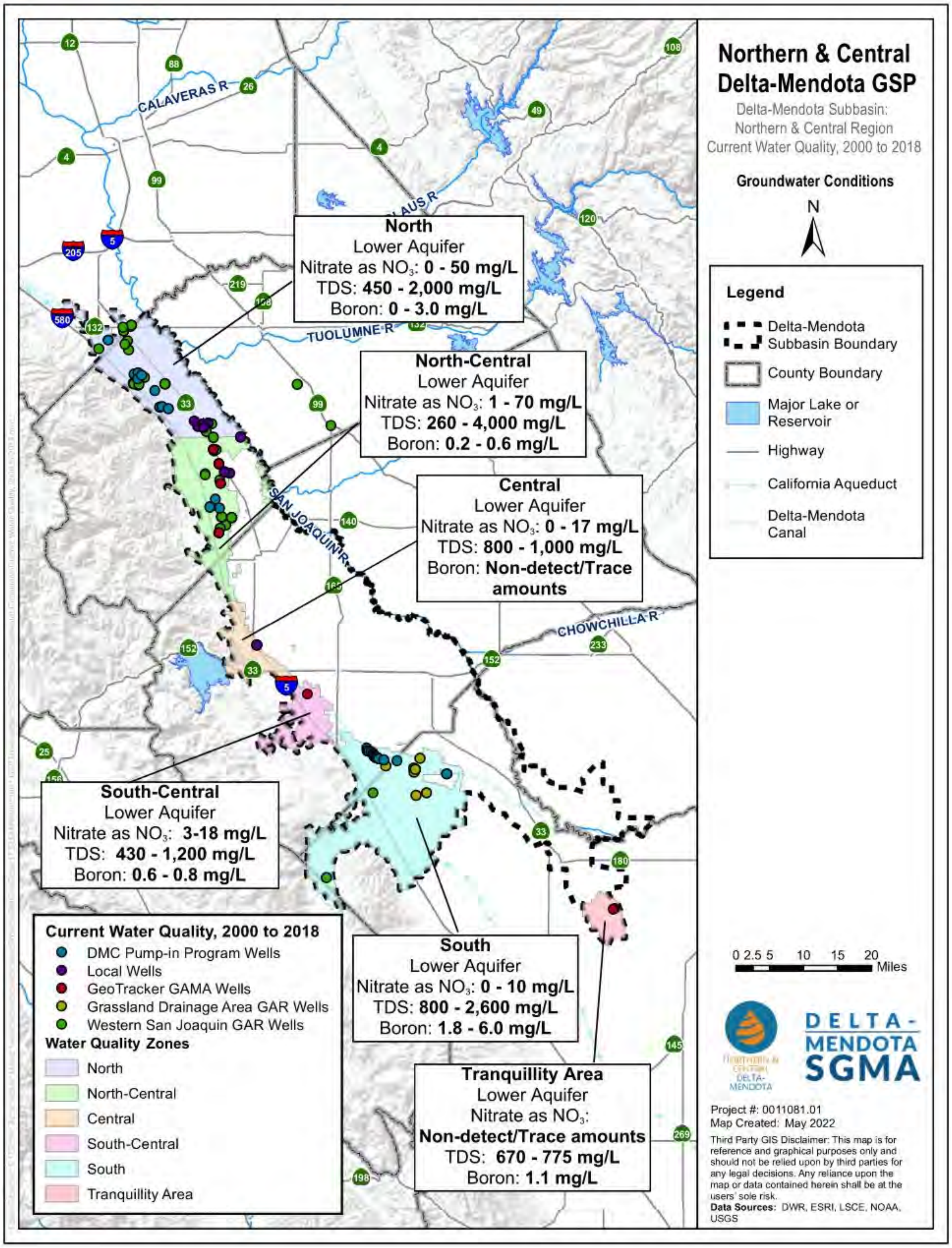

Figure 5-87. Lower Aquifer, Current Groundwater Quality (2000-2018)

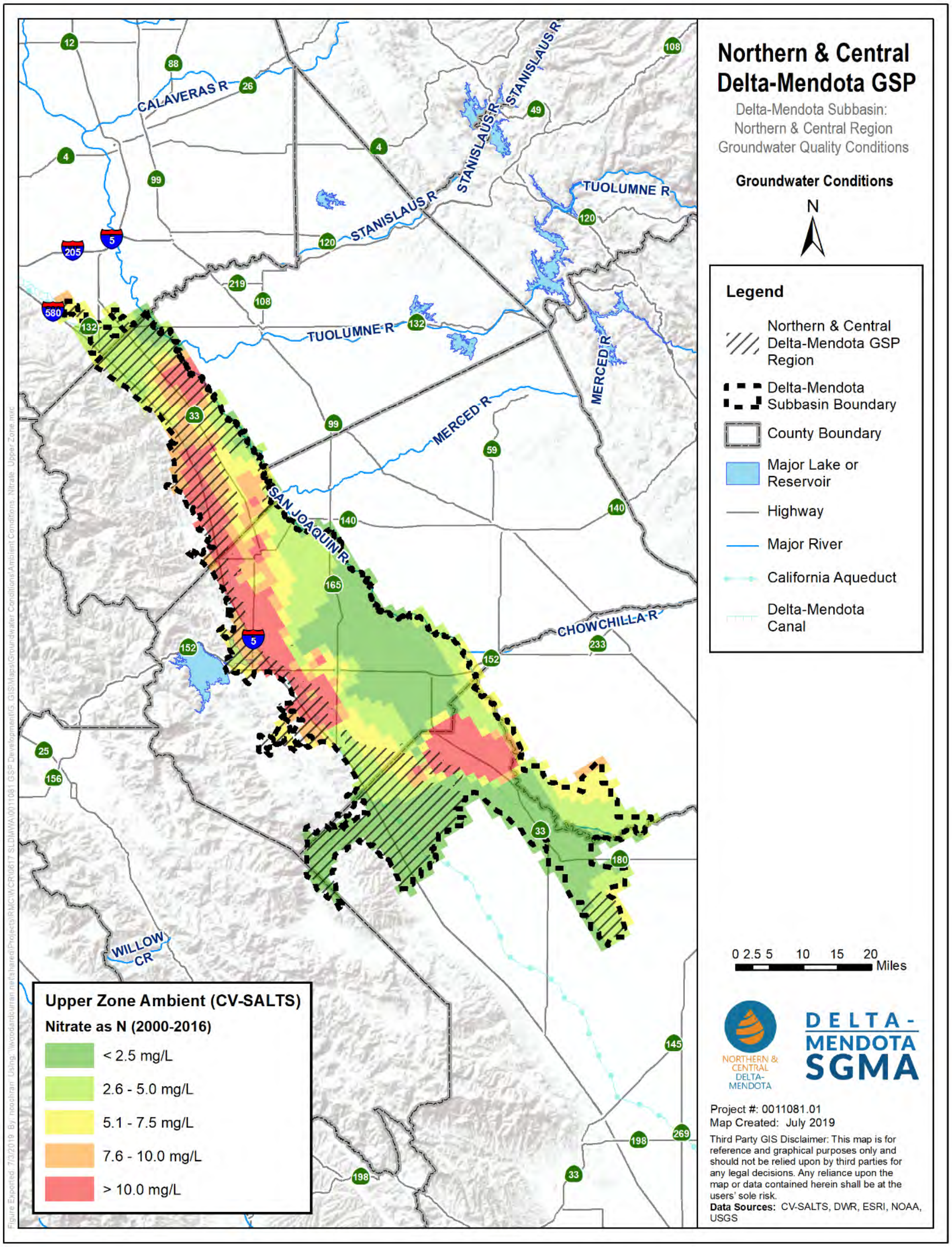

Figure 5-88. Upper Zone Ambient Nitrate as N, Delta-Mendota Subbasin

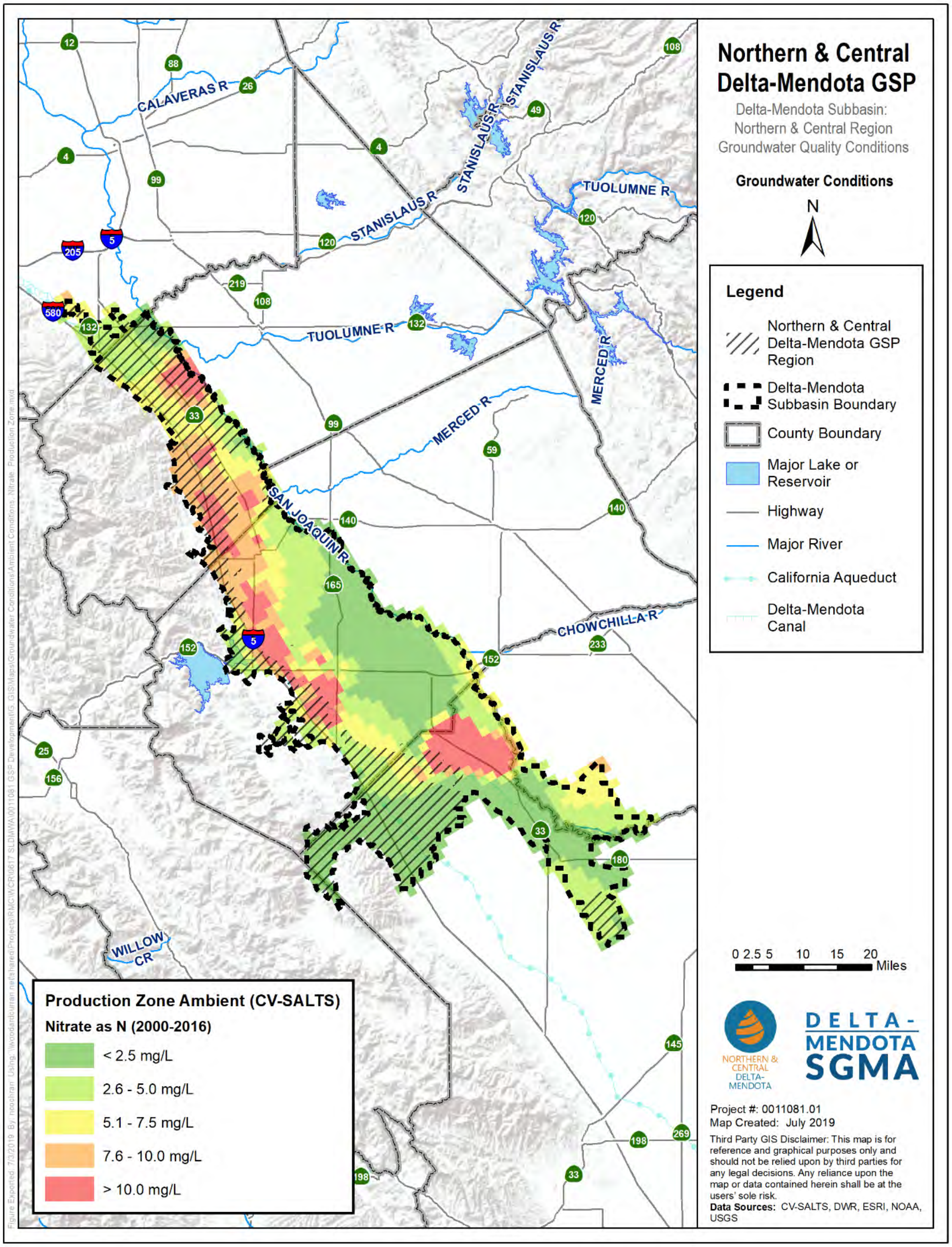

Figure 5-89. Production Zone Ambient Nitrate as N, Delta-Mendota Subbasin

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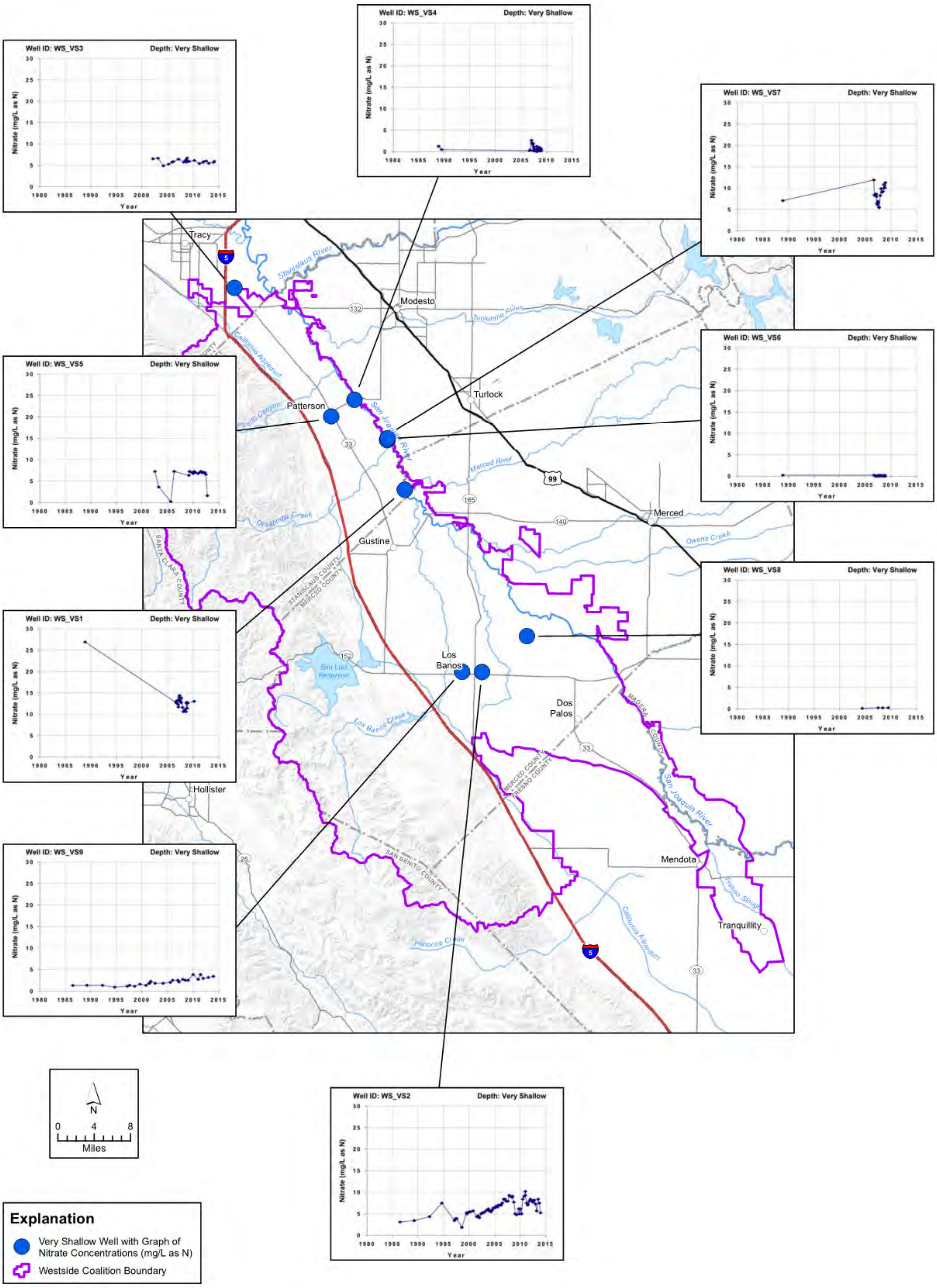
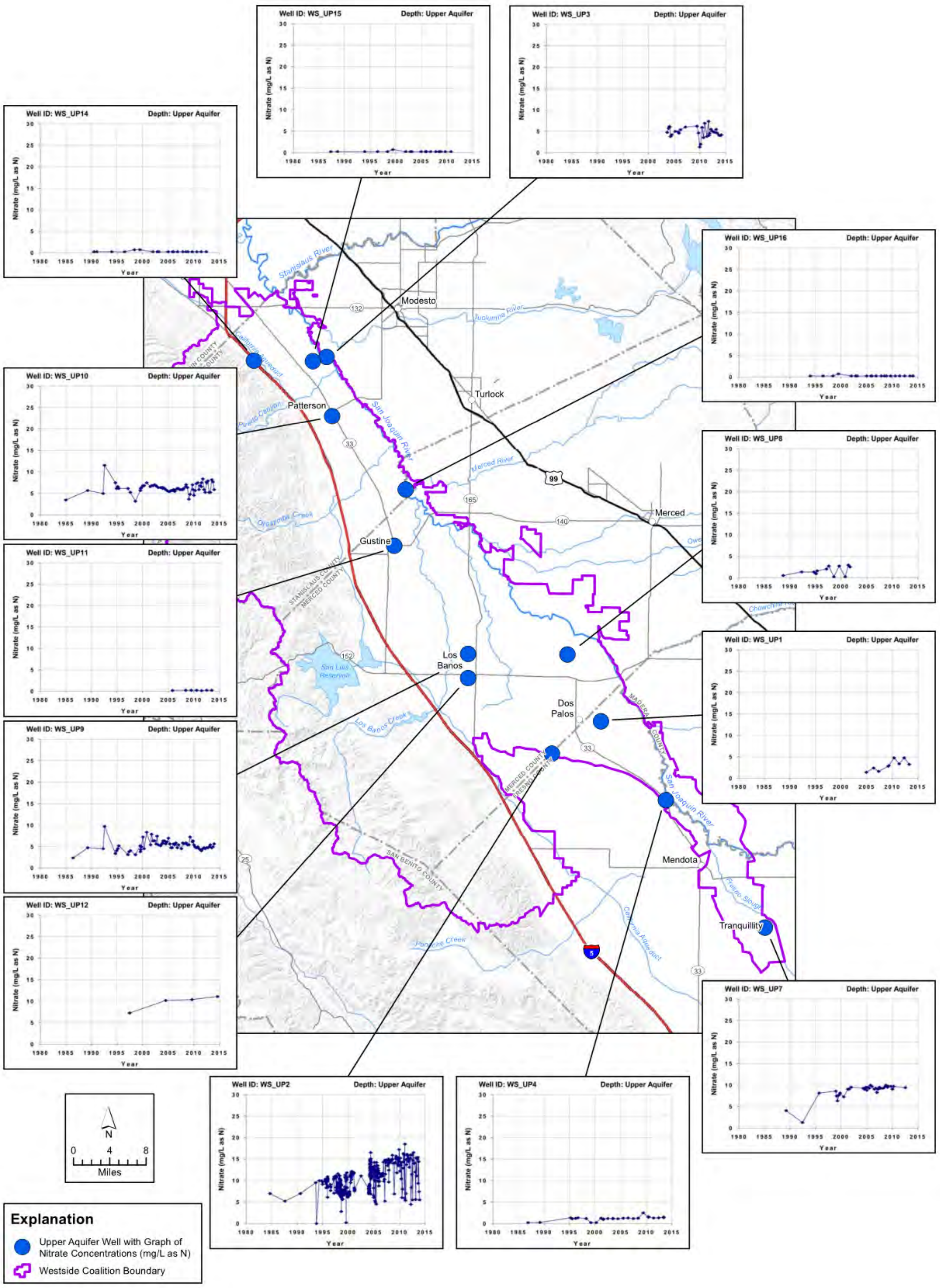


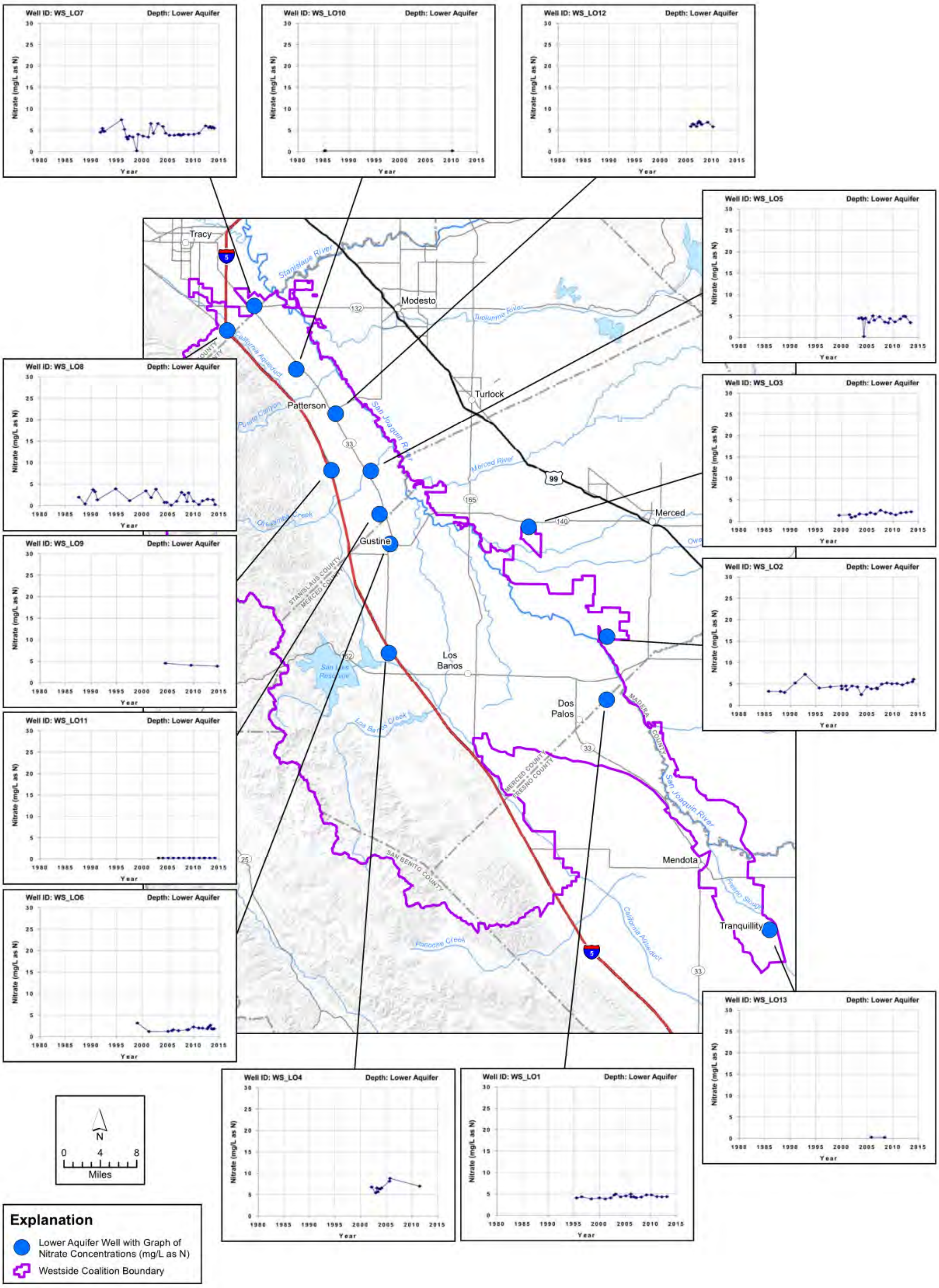
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-90. Select Graphs of Nitrate Concentrations, Shallow Groundwater



Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-91. Select Graphs of Nitrate Concentrations, Upper Aquifer



Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-92. Select Graphs of Nitrate Concentrations, Lower Aquifer

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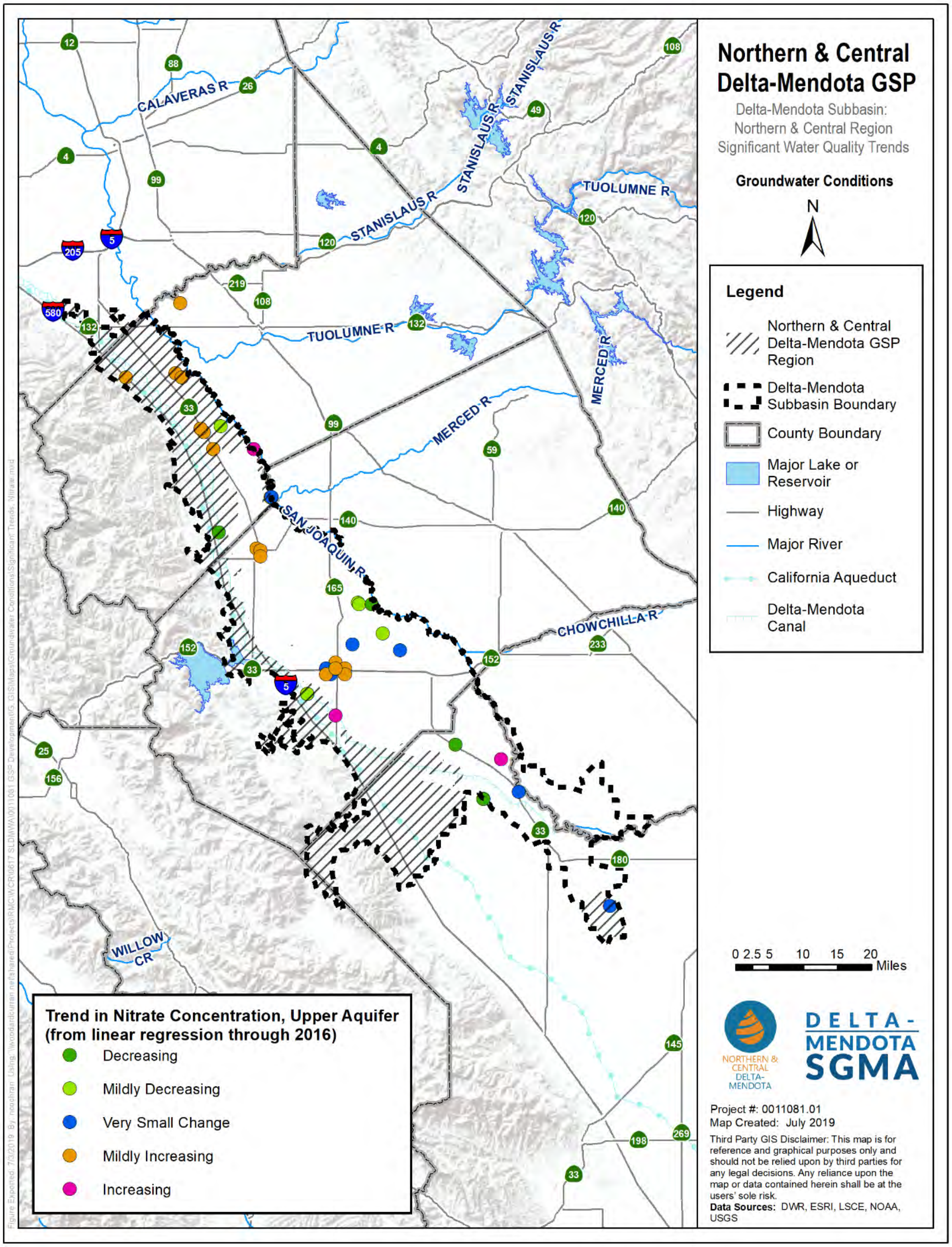

Figure 5-93. Significant Temporal Trends in Nitrate Concentrations, Upper Aquifer

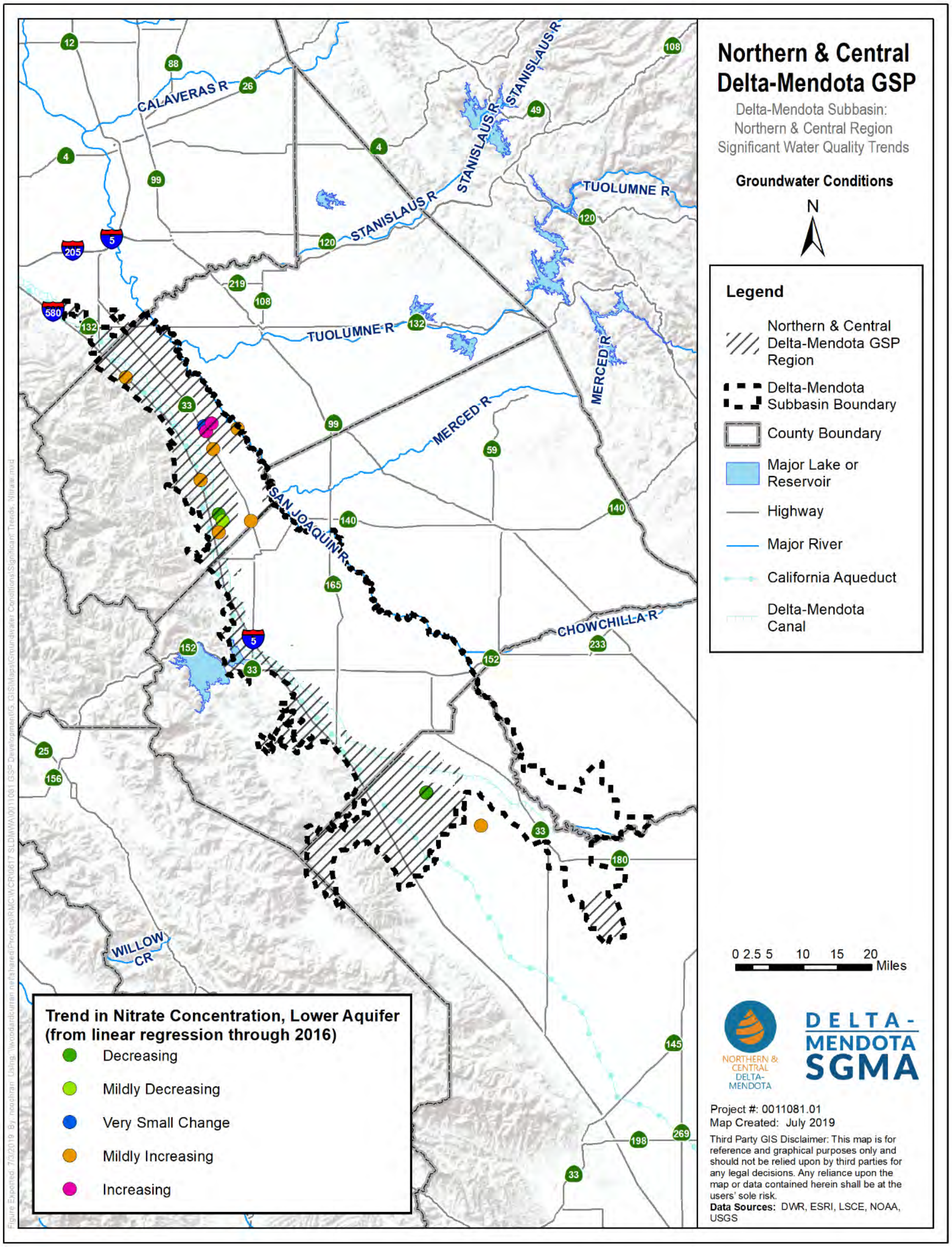

Figure 5-94. Significant Temporal Trends in Nitrate Concentrations, Lower Aquifer

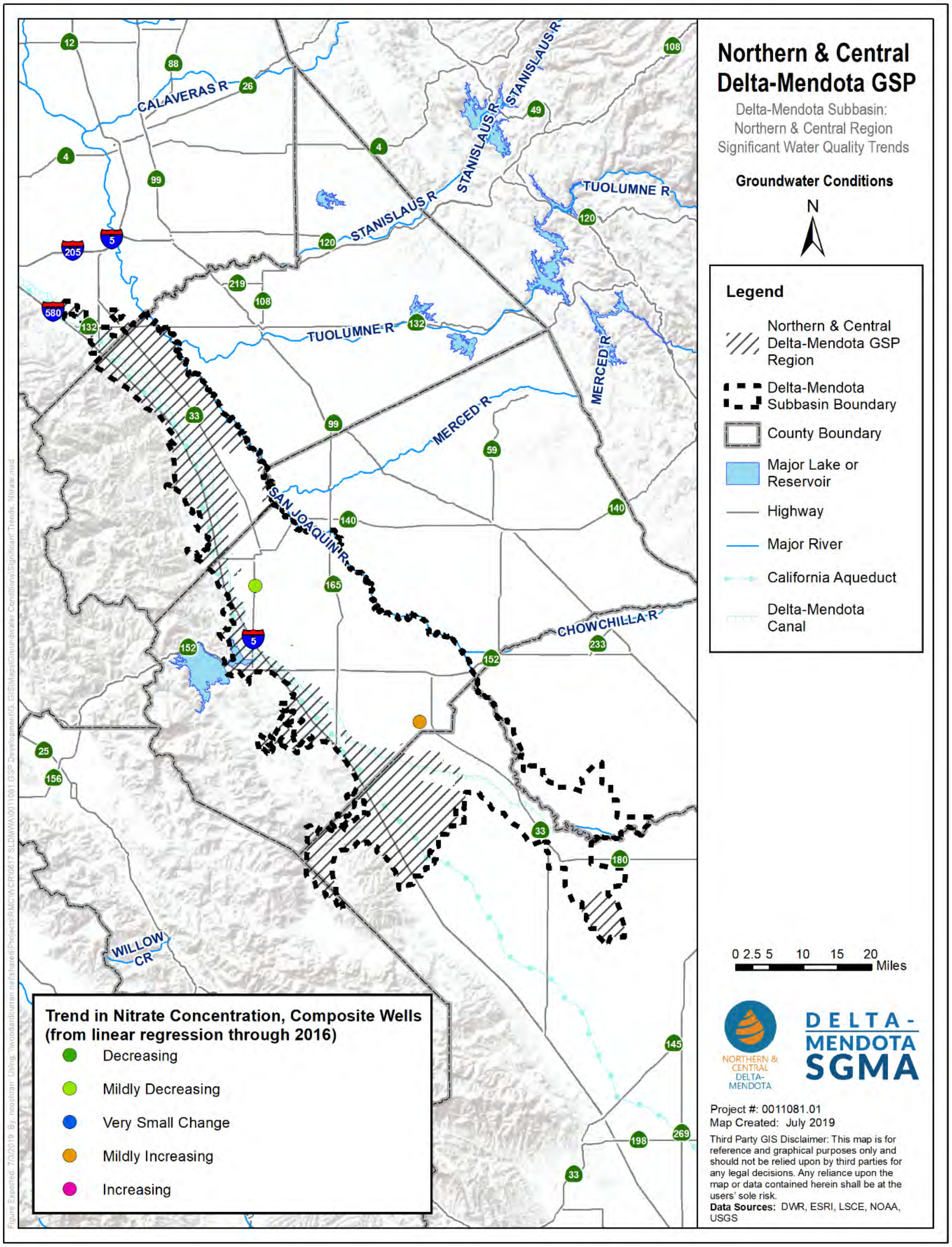

Figure 5-95. Significant Temporal Trends in Nitrate Concentrations, Composite Wells

<u>**Total Dissolved Solids**</u>

The Central Valley SNMP's analysis of TDS showed elevated concentrations throughout much of the Delta-Mendota Subbasin. Ambient TDS conditions follow similar patterns in the upper zone as in the production zone (**Figure 5-96** and **Figure 5-97**). Ambient TDS concentrations exceed 1,000 mg/L in areas to the south and west of Dos Palos, extending to the western and southern borders of the Subbasin, and to the north and southeast of Patterson. The areas of lowest TDS concentration (<250 mg/L) exist on the western border of the Subbasin, west of Newman and Gustine, and just west of Los Banos.

The Western San Joaquin GAR's analysis of TDS data found similar spatial patterns as with nitrate. The majority of wells in the Coalition region have maximum TDS concentrations below 1,000 mg/L. In the Upper Aquifer, higher TDS concentrations (>1,500 mg/L) exist south of Los Banos and to the north along the San Joaquin River (an area with poor drainage). In the Lower Aquifer, data were limited, but most wells had maximum TDS concentrations below 1,500 mg/L. Along the northwestern edge of the Coalition region, TDS concentrations were mostly below 1,000 mg/L (LSCE, 2015). The Grassland GAR's analysis of TDS showed that most TDS concentrations in both the Upper and Lower Aquifers exceeded 1,000 mg/L, although as with nitrate, data were limited (LSCE, 2016).

TDS concentrations in the Upper Aquifer show a combination of stable trends near or below the TDS Secondary MCL of 1,000 mg/L and increasing TDS concentrations exceeding 1,500 mg/L, with data available back to the 1980s (**Figure 5-98** and **Figure 5-99**). In the portion of the Subbasin south of Dos Palos, TDS concentrations are generally higher than the rest of the Subbasin with concentrations considerably higher than 1,500 mg/L; though, noticeable decreases are observed from the 1990s through the early 2000s and since 2010. In the Lower Aquifer, TDS concentrations since the 1990s appear to be largely stable, with exceedances above 1,000 mg/L observed (**Figure 5-100**). Wells south of Dos Palos in the Lower Aquifer have limited data available, but generally concentrations range from 1,000 to 2,000 mg/L. In general, increasing TDS trends in the Upper Aquifer stem from a myriad of causes, including increased salinity concentrations from the leaching of salts from naturally-occurring high salinity formations and land-applied soil amendments, an increasing salinity front from the San Joaquin River and adjacent tile drains, and localized causes such as seepages on Little Panoche Creek, downstream of Little Panoche Creek Reservoir, potentially the result of the concentration of salts in the impoundment through evaporation.

Both the Western San Joaquin (LSCE, 2015) and Grassland Drainage Area (LSCE, 2016) GARs assessed temporal trends of TDS concentrations for all available historical data through 2016 (wells with a minimum of three sampling events) using linear regression trend analysis, with a p-value of 0.05 and 0.1 indicating significance, respectively from each GAR.

Table 5-4 indicates the degree of trends TDS as presented in the GARs. **Figure 5-101** illustrates statistically significant temporal trends in TDS concentration in the Upper Aquifer. There is no discernable spatial pattern in trend direction throughout much of the northern portion of the Delta-Mendota Subbasin except near Los Banos where TDS is Mildly Increasing and Increasing. Southwest of Dos Palos along the Delta-Mendota Canal, there is a cluster of wells with an Increasing trend in TDS concentration, whereas moving downstream along the canal, there are more wells with a Decreasing trend in TDS concentration. **Figure 5-102** illustrates statistically significant temporal trends in TDS concentration in the Lower Aquifer. While sufficient data available for trend analysis are unavailable for the Lower Aquifer, there are several wells near and north of Gustine and near the San Luis Reservoir showing Mildly Increasing trends in TDS concentration. South of Dos Palos, there are two wells showing Decreasing trends and one well showing an Increasing trend in TDS concentration. **Figure 5-103** illustrates statistically significant temporal trends in TDS concentration in composite wells. Only one composite well exhibited statistically significant TDS trends and is located near Patterson showing a very small change.

Table 5-4. TDS Trend Significance

from Western San Joaquin and Grassland GARs

Trend	TDS (mg/L/year)
Increasing	> 50
Mildly Increasing	10 - 50
Very Small Change	-10 - 10
Mildly Decreasing	-50 - -10
Decreasing	< -50

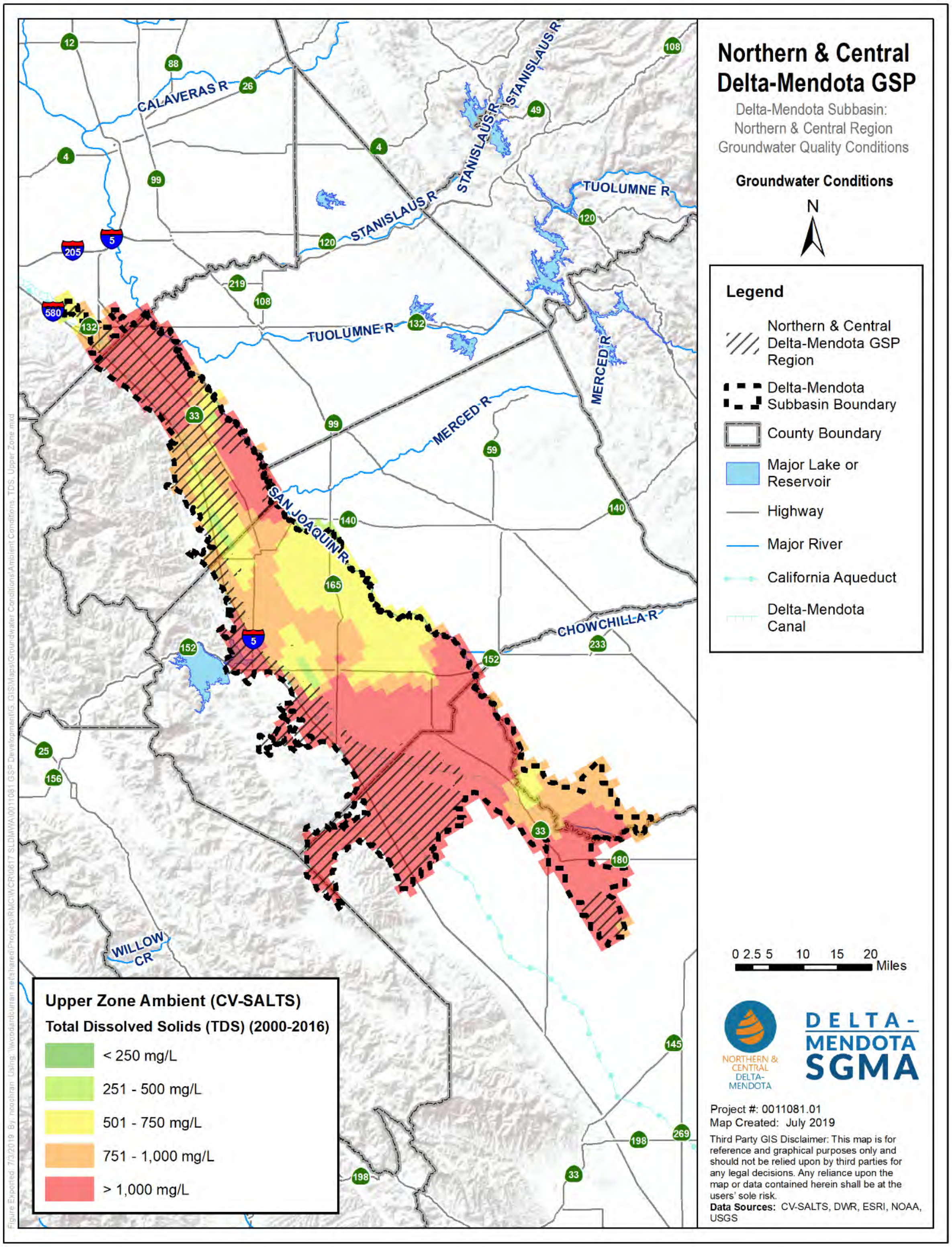

Figure 5-96. Upper Zone Ambient TDS, Delta-Mendota Subbasin

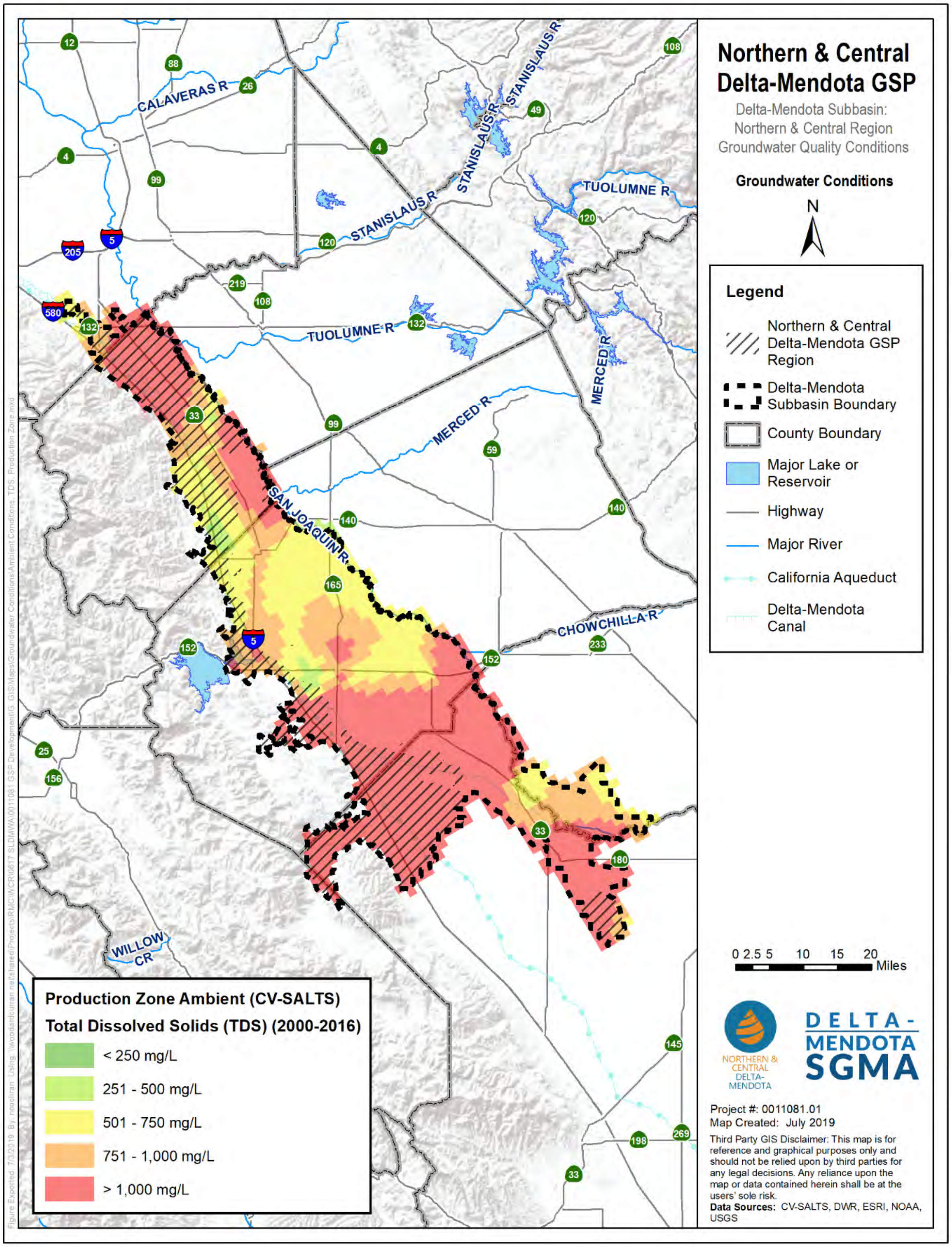

Figure 5-97. Production Zone Ambient TDS, Delta-Mendota Subbasin

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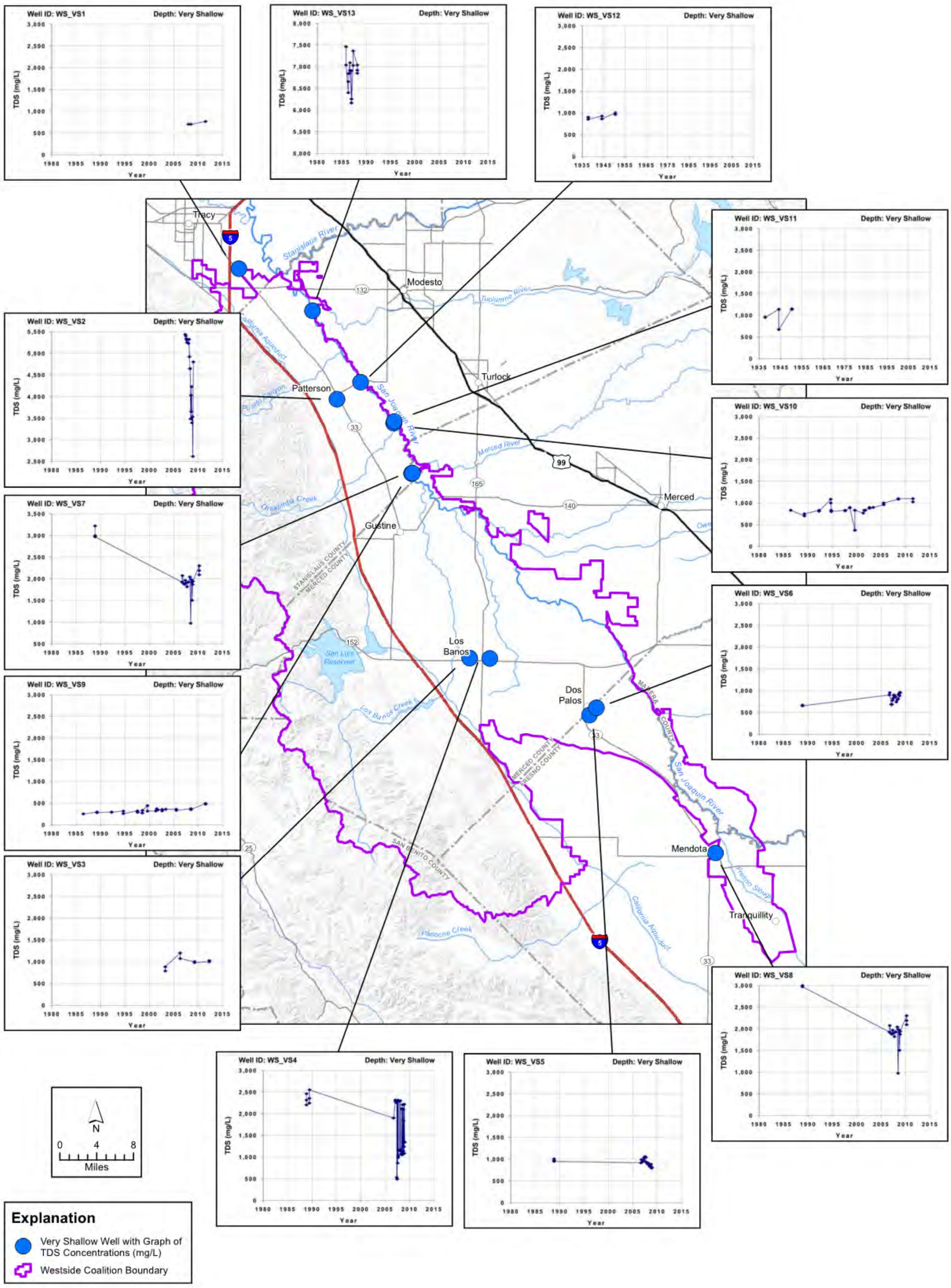
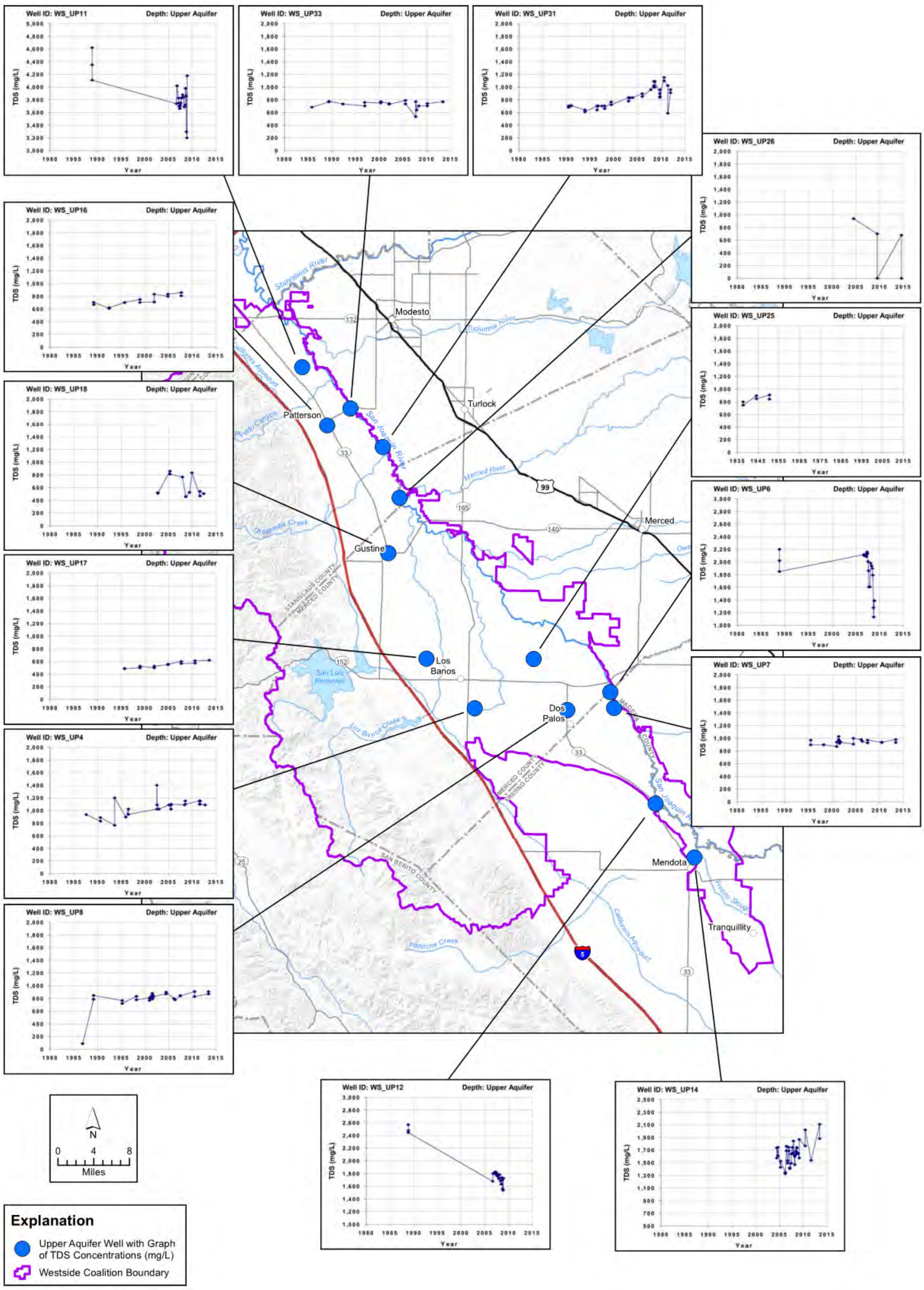


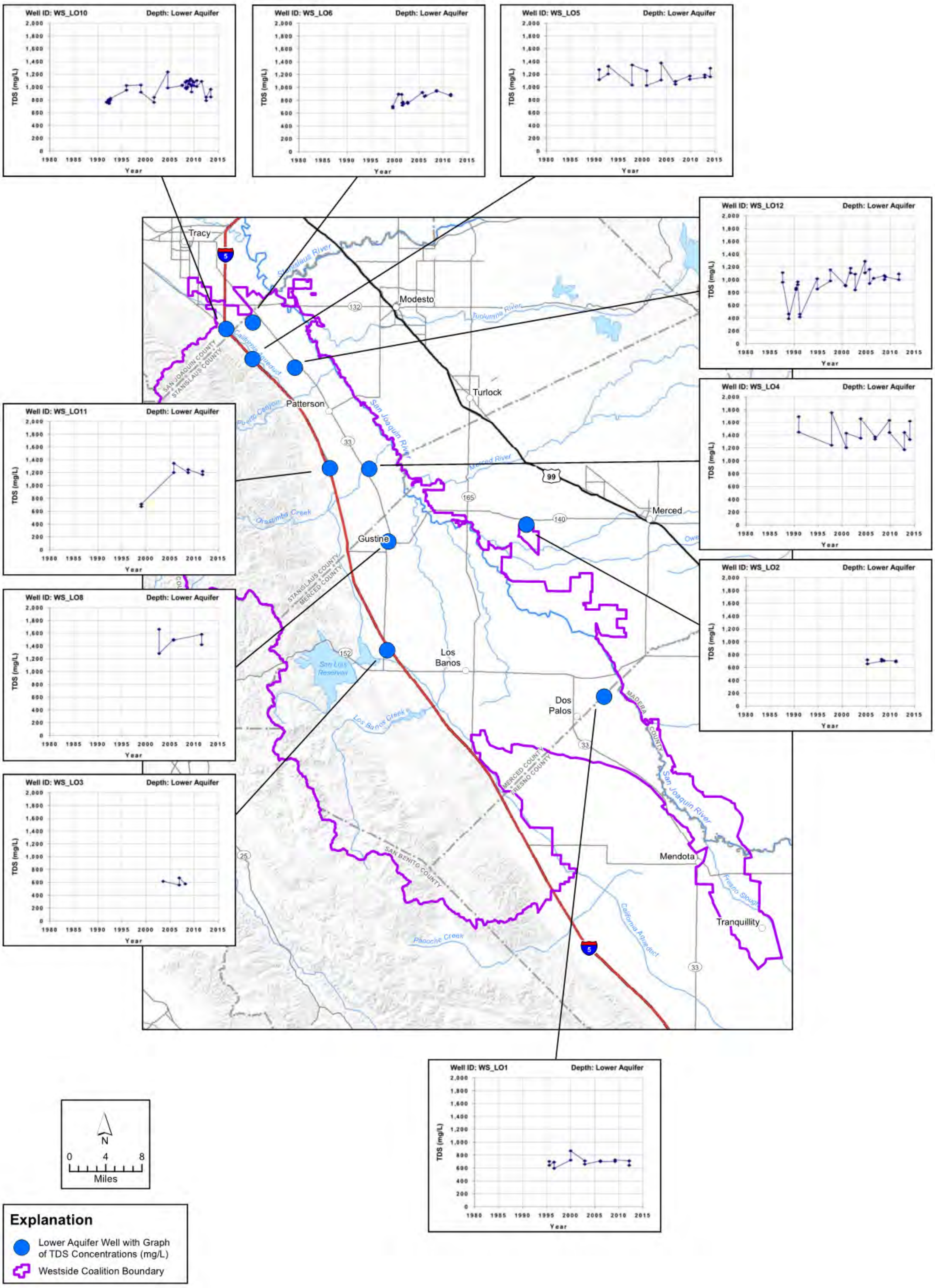
Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-98. Select Graphs of TDS Concentrations, Shallow Groundwater



Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-99. Select Graphs of TDS Concentrations, Upper Aquifer



Source: *Western San Joaquin River Watershed Groundwater Quality Assessment Report*, 2015

Figure 5-100. Select Graphs of TDS Concentrations, Lower Aquifer

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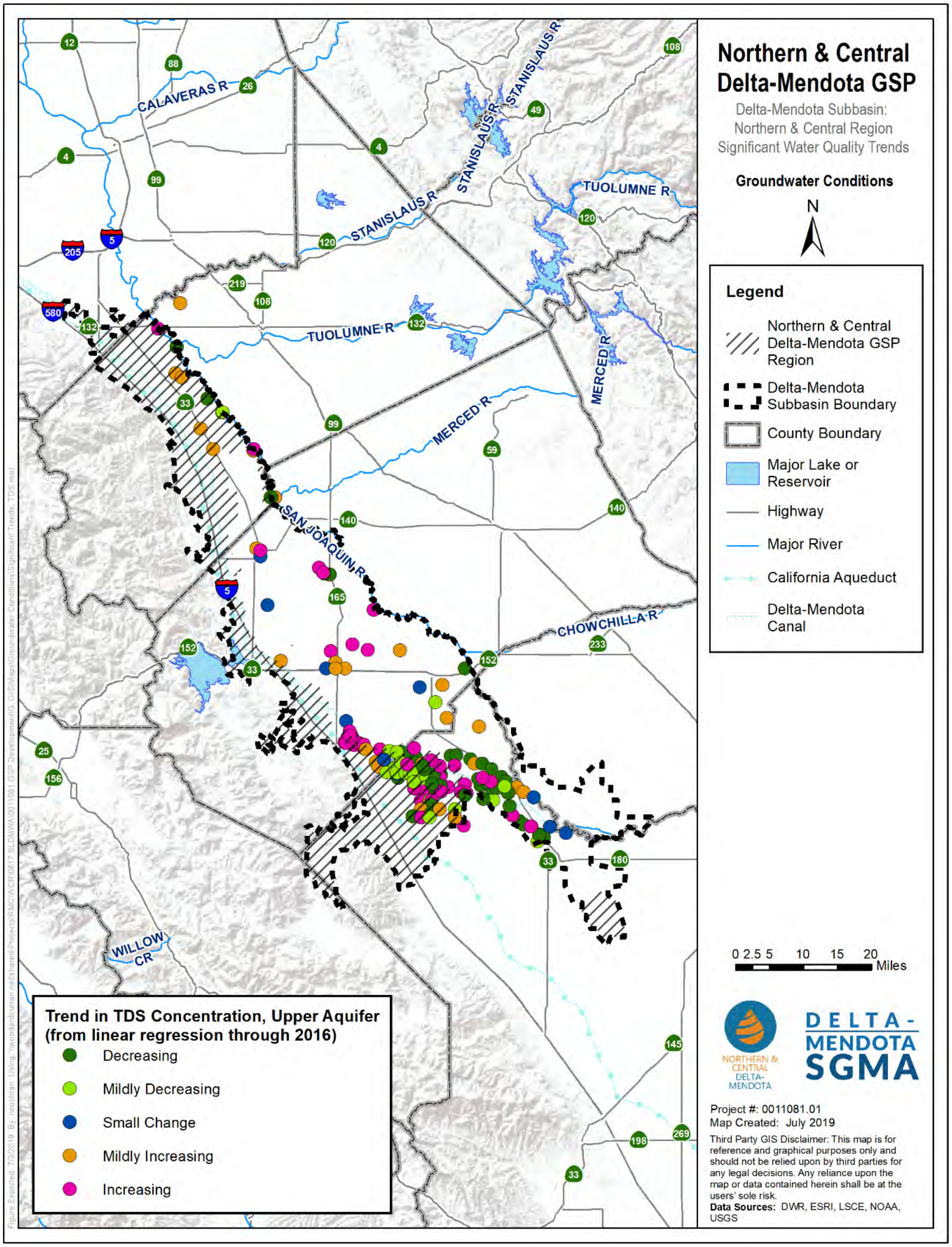


Figure 5-101. Significant Temporal Trends in TDS Concentrations, Upper Aquifer

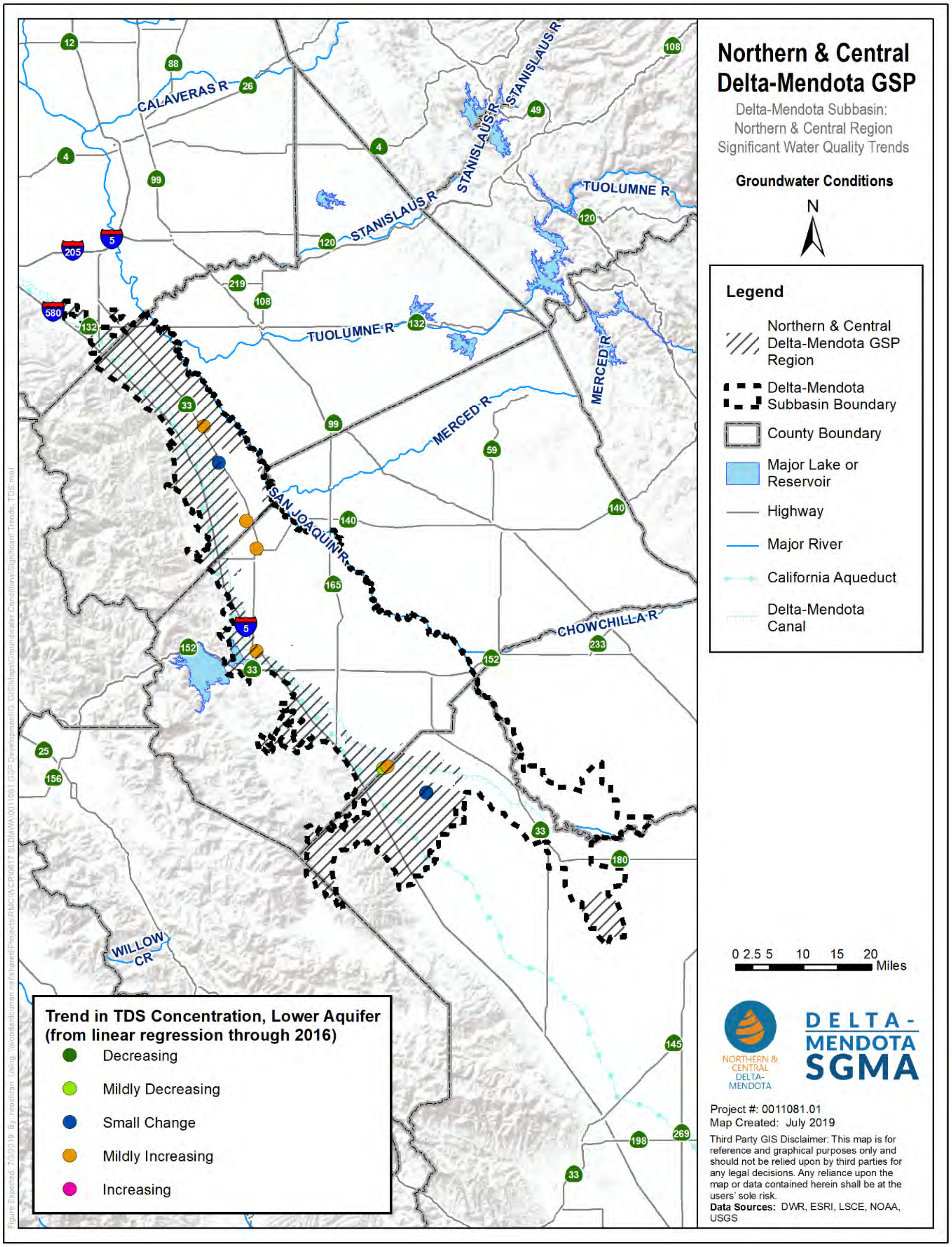


Figure 5-102. Significant Temporal Trends in TDS Concentrations, Lower Aquifer

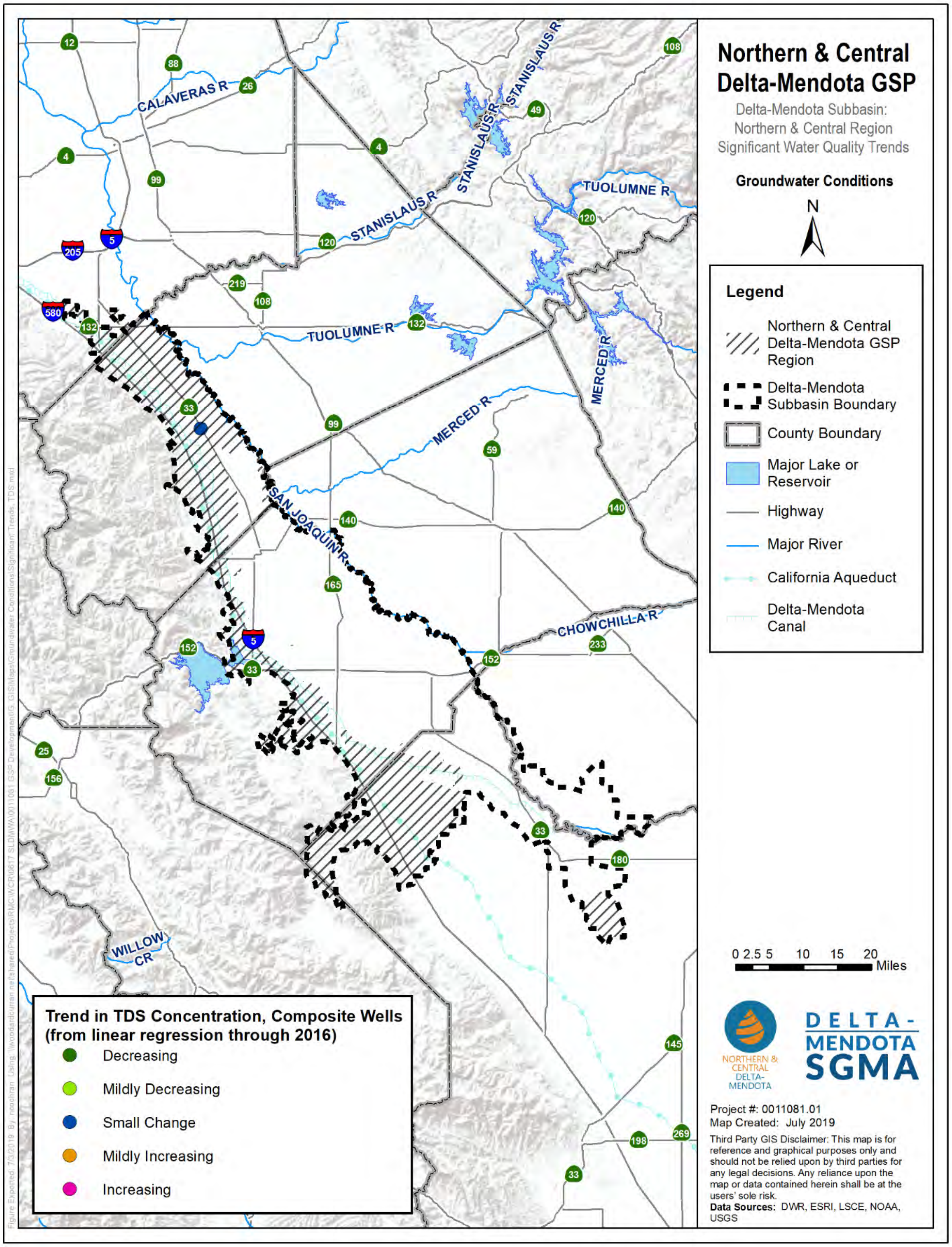


Figure 5-103. Significant Temporal Trends in TDS Concentrations, Composite Wells

Boron

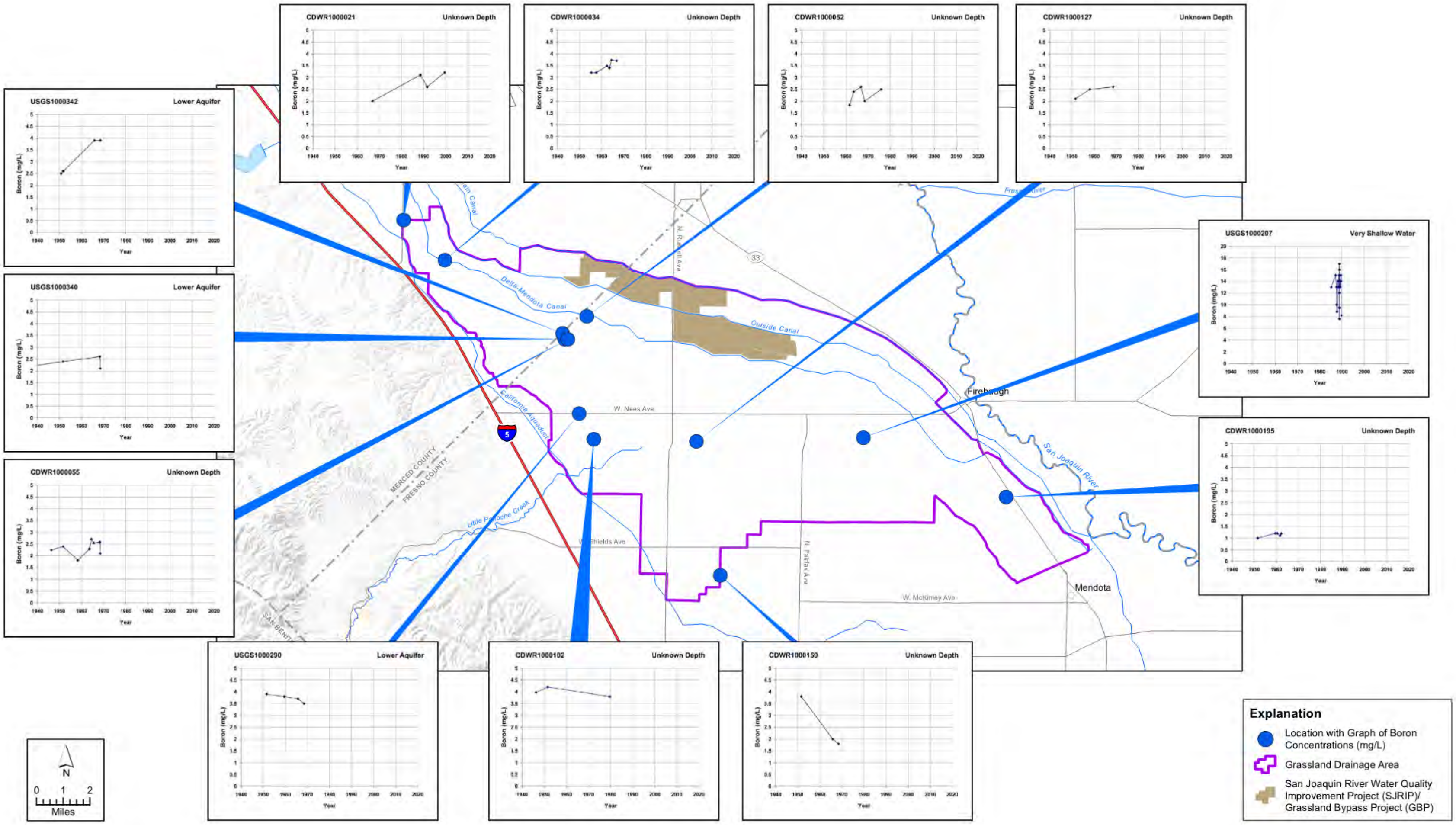
Although boron has no MCL, it has an agricultural goal of 0.7 mg/L as many crops are sensitive to high boron concentrations. Historical data from within the Grassland Drainage Area shows boron concentrations of greater than 2 mg/L, well above the agricultural goal (LSCE, 2016). The City of Patterson Consumer Confidence Reports from 2011 to 2013 show boron levels consistently near 0.4 mg/L. Boron trends were also analyzed within the Grassland Drainage Area (which encompasses portions of the Central Delta-Mendota, Oro Loma Water District, and Widren Water District GSAs). Time series charts of boron concentrations in the Upper Aquifer and Lower Aquifer are presented together in **Figure 5-104** due to a limited number of sites with sufficient data to warrant graphing. Boron trends are generally stable but relatively high, with some seasonal fluctuations likely resulting from irrigation influences.

Table 5-5 indicates the degree of trends for boron as presented in the GAR for all available historical data through 2016 (wells with a minimum of three sampling events). No statistically-significant temporal trends in boron concentrations were observed in the Upper Aquifer for boron. Two wells in the Lower Aquifer have significant trends in boron concentration, one with an Increasing trend and the other with a Mildly Decreasing trend (**Figure 5-105**).

Table 5-5. Boron Trend Significance

from Grassland GAR

Trend	Boron (mg/L/year)
Increasing	> 0.05
Mildly Increasing	0.01 - 0.05
Very Small Change	-0.01 - 0.01
Mildly Decreasing	-0.05 - -0.01
Decreasing	< -0.05



Source: *Grassland Drainage Area Groundwater Quality Assessment Report*, 2016

Figure 5-104. Select Graphs of Boron Concentrations, Various Depths

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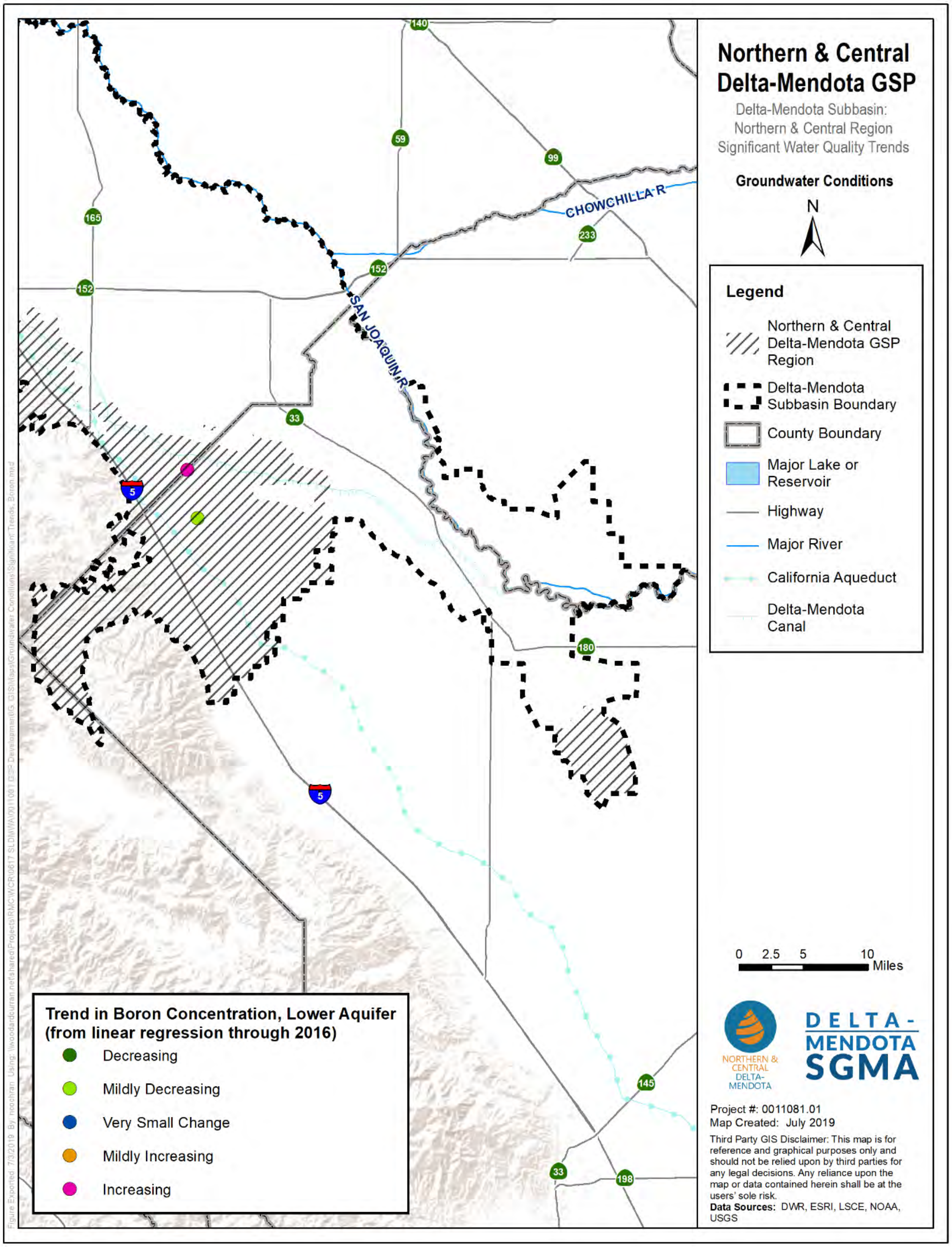

Figure 5-105. Significant Temporal Trends in Boron Concentrations, Lower Aquifer

5.3.6 Land Subsidence

Long-term groundwater level declines can result in a one-time release of "water of compaction" from compacting silt and clay layers (aquitards) resulting in inelastic land subsidence (Galloway et al., 1999). There are several other types of subsidence in the San Joaquin Valley, including subsidence related to hydrocompaction of moisture-deficient deposits above the water table, subsidence related to fluid withdrawal from oil and gas fields, subsidence caused by deep-seated tectonic movements, and subsidence caused by oxidation of peat soils that is a major factor in the Sacramento-San Joaquin Delta (Sneed et al., 2013). However, aquifer-system compaction caused by groundwater pumping causes the largest magnitude and areal extent of land subsidence in the San Joaquin Valley (Poland et al., 1975; Ireland et al., 1984; Farrar and Bertoldi, 1988; Bertoldi et al., 1991; Galloway and Riley, 1999).

Land subsidence is a prevalent issue in the Delta-Mendota Subbasin as it has impacted prominent infrastructure of statewide importance, namely the DMC and the California Aqueduct, as well as local canals, causing serious operational, maintenance, and construction-design issues (Sneed et al., 2013). Reduced freeboard and flow capacity for the DMC and California Aqueduct have rippling effects on imported water availability throughout the State. Even small amounts of subsidence in critical locations, especially where canal gradients are small, can impact canal operations (Sneed and Brandt, 2015). Differential land subsidence can also result in piping ruptures, resulting in the loss of water or other substances. While some subsidence is reversable (referred to as elastic subsidence), inelastic or irreversible subsidence is caused mainly by pumping groundwater from below the Corcoran Clay, thus causing compaction and reducing storage in the lower confined aquifer as well as damaging well infrastructure. As a result, important and extensive damages and repairs have resulted in the loss of conveyance capacity in canals that deliver water or remove floodwaters, the realignment of canals as their constant gradient becomes variable, the raising of infrastructure such as canal check stations, and the releveling of furrowed fields.

5.3.6.1 Available Data

There are six University NAVSTAR Consortium (UNAVCO) Continuous Global Positioning System (CGPS) locations that monitor subsidence within the Delta-Mendota Subbasin, five of which are within the Northern and Central Delta-Mendota Regions (**Figure 5-106**). Changes in land surface elevation have also been measured at DMC Check Structures (**Figure 5-106**). **Figure 5-107** through **Figure 5-112** show the vertical change in land surface elevation from a given time point (specified on charts) for the UNAVCO CGPS stations within the Delta-Mendota Subbasin, along with annual CVP allocations. **Table 5-6** summarizes the greatest land subsidence rate and corresponding year(s) of that change at each UNAVCO CGPS station. Overall, the greatest monthly subsidence rates occurring after January 1, 2015 occurred during the Spring of 2016 to the Spring of 2017.

Land subsidence was measured by United States Bureau of Reclamation (USBR) showing annual subsidence rates from December 2011 to December 2014 (**Figure 5-113**). Based on these data, within the majority of the Northern and Central Delta-Mendota Regions, annual subsidence rates were between -0.15 and 0 feet/year during this period (or between -0.45 and 0 feet of total subsidence over this 3-year period). A small portion within the southwestern horn of the Delta-Mendota Subbasin saw an uplifting of land surface between 0.15 and 0.3 feet/year during this period (0.45 and 0.9 feet total subsidence during this period). From July 2012 to December 2016, during the most recent drought period, subsidence rates increased (**Figure 5-114**). Throughout the majority of the Northern and Central Delta-Mendota Region, subsidence was less than 0.5 feet/year (or less than 2.25 feet total over this 4.5-year period). In the Tranquillity Irrigation District (TRID) area, subsidence rates were higher, around 1 to 1.5 foot/year or more, during the drought years.

Table 5-6. Subsidence Monitoring Trends, UNAVCO CGPS Stations

Station ID	Greatest Monthly Land Subsidence Rate as of January 1, 2015 (feet)	Year(s) of Greatest Monthly Land Subsidence Rate
P255	-0.0292	Spring 2016 to 2017
P259	-0.0183	Spring 2016 to 2017
P252	-0.033	Spring 2016 to 2017
P303	-0.2190	Spring 2016 to 2017
P301	-0.0029	Spring 2016 to 2017
P304	-0.0003	Spring 2013 to 2017

5.3.6.2 Historic Conditions

Along the DMC in the northern portion of the San Joaquin Valley, extensive withdrawal of groundwater from unconsolidated deposits caused subsidence exceeding 8.5 meters (or about 28 feet) between 1926 and 1970 (Poland et al., 1975), reaching 9 meters (or about 30 feet) in 1980 (Ireland, 1986). Land subsidence from groundwater pumping began in the San Joaquin Valley in the mid-1920s (Poland et al., 1975; Bertoldi et al., 1991; Galloway and Riley, 1999) and by 1970, about half of the San Joaquin Valley had land subsidence of more than 0.3 meters (or about 1 foot) (Poland et al., 1975). While groundwater pumping decreased in the Delta-Mendota Subbasin following imported water deliveries from the CVP via the DMC in the early 1950s, compaction rates were reduced in certain areas and water levels recovered. Notable droughts of 1976-1977 and 1987-1992 saw renewed compaction during these periods, with increased groundwater pumping as imported supplies were reduced or unavailable. However, following these droughts, compaction virtually ceased, and groundwater levels rose to near pre-drought levels quite rapidly (Swanson, 1998; Galloway et al., 1999). Similarly, during the 2007-2009 and 2012-2015 droughts, groundwater levels declined during these periods in response to increased pumping, approaching or surpassing historical low levels, which reinstated compaction (Sneed and Brandt, 2015).

Subsidence contours for 1926-1970 (Poland et al., 1975) show the area of maximum active subsidence was southwest of the community of Mendota. Historical subsidence rates in the Mendota area exceeded 500 millimeters/year (or about 20 inches/year) during the mid-1950s and early 1960s (Ireland et al., 1984). The area southwest of Mendota has experienced some of the highest levels of subsidence in California, where from 1925 to 1977, this area sustained over 29 feet of subsidence (USGS, 2017). Historical subsidence rates along Highway 152 calculated from leveling-survey data from 1972, 1988, and 2004 show that for the two 16-year periods (1972-1988 and 1988-2004), maximum subsidence rates of about 50 millimeters/year (or about 2 inches/year) were found just south of El Nido (Sneed et al., 2013). Geodetic surveys completed along the DMC in 1935, 1953, 1957, 1984, and annually from 1996-2001 indicated that subsidence rates were greatest between 1953 and 1957 surveys, and that the maximum subsidence along the DMC (about 3 meters, or about 10 feet) was just east of DMC Check Structure Number 18.

Subsidence related to the California Aqueduct, which runs parallel and in close proximity to the Delta-Mendota Canal across the Subbasin, is of statewide importance. During the construction of the California Aqueduct, it was thought that subsidence within the San Joaquin Valley would cease with the delivery of water from the State Water Project, though additional freeboard to attempt to mitigate future subsidence was incorporated into the design and construction of the Aqueduct (DWR, June 2017). After water deliveries from the Aqueduct began, subsidence rates decreased to an average of less than 0.1 inches/year during normal to wet hydrologic years. During dry to critical hydrologic years, subsidence increased to an average of 1.1 inches per year. The 2012-2015 drought produced subsidence similar to those seen before the Aqueduct began delivering water, with some areas experiencing nearly 1.25 inches of sinking per month (based on NASA Uninhabited Aerial Vehicle Synthetic Aperture Radar [UAVSAR] flight measurements). Dry and critically dry water years since Aqueduct deliveries began have resulted in extensive groundwater withdrawals, causing some areas near the Aqueduct to subside nearly 6 feet.

After 1974, land subsidence was demonstrated to have slowed or largely stopped (DWR, June 2017); however, land subsidence remained poised to resume under certain conditions. Such an example includes the severe droughts that occurred between 1976 and 1977 and between 1987 and 1991. Those droughts lead to diminished deliveries of imported water, which prompted some water agencies and farmers (especially in the western Valley) to refurbish old pumps, drill new water wells, and begin pumping groundwater to make up for cutbacks in the imported water supply. The decisions to renew groundwater pumping were encouraged by the fact that groundwater levels had recovered to near-predevelopment levels. During the most recent drought of 2012-2015, subsidence rates were greatest between March 2015 and August 2015 with as much as nearly 9 inches of subsidence in 6 months along the Aqueduct. With water levels near or below historical lows were observed during the most recent drought, it indicates that preconsolidation stress was likely exceeded, meaning the resulting subsidence is likely mostly permanent (Sneed and Brandt, 2015).

5.3.6.3 Current Conditions

Based on subsidence rates observed over the last decade, it is anticipated that subsidence will continue to impact operations of the DMC and California Aqueduct without mitigation. For example, recently, Reach 4A of the San Joaquin River near Dos Palos (at the lower end of the Northern and Central Delta-Mendota Regions, where most land subsidence has historically occurred) experienced between 0.38 and 0.42 feet/year in subsidence between 2008 and 2016. As a result of subsidence, freeboard in Reach 4A is projected to be reduced by 0.5 foot by 2026 as compared to 2016, resulting in a 50 percent reduction in designed flow capacity (DWR, May 2018). Reduced flow capacities in the California Aqueduct will impact deliveries and transfers throughout the State and result in the need to pump more groundwater, thus contributing to further subsidence.

More recent subsidence measurements indicate subsidence hot spots within and adjacent to the Subbasin, including the area east of Los Banos and the TRID area. The USGS began periodic measurements of the land surface in parts of the San Joaquin Valley over the last decade. Between December 2011 and December 2014, total subsidence in the area east of Los Banos, within the Merced Subbasin (also referred to as the El Nido-Red Top area, ranged from 0.15 to 0.75 feet, or 1.8 to 9 inches respectively (Schmidt, 2015). The National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL) at the California Institute of Technology has also been monitoring subsidence in California using interferometric synthetic aperture radar (or InSAR), and a recent progress report documenting data for the period from May of 2015 to September of 2016 indicates that the two previously-identified primary subsidence areas near the community of Corcoran (and centered on El Nido) was joined by a third area of significant subsidence near TRID. For the study period (as shown in **Figure 5-115**), maximum total subsidence of 22 inches was measured near Corcoran, while the El Nido area subsided 16 inches and the TRID area subsided around 20 inches. Analyses at two particular stations near El Nido show interesting trends. At Station P303, between 2007 and 2014, 50 mm of subsidence occurred at this location (or nearly 2 inches). Vertical displacement at P303 showed subsidence at fairly consistent rates during and between drought periods (**Figure 5-116**), indicating that these areas continued to pump groundwater despite climatic variations (possibly due to a lack of surface water availability). Residual compaction may also be a factor. Vertical displacement at Station P304 indicated that most subsidence occurred during drought periods and very little subsidence occurring between drought periods (**Figure 5-116**). This suggests that this area received other sources of water, most likely surface water, between drought periods, and also that residual compaction did not significantly occur in this area. These two areas demonstrate a close link between the availability of surface water, groundwater pumping, and inelastic land subsidence. Total land subsidence in the San Joaquin Valley from May 7, 2015 to September 10, 2016 is shown in **Figure 5-116**.

As managers of the DMC, the San Luis & Delta-Mendota Water Authority (SLDMWA) has been making periodic subsidence surveys along the DMC to identify key areas of active land subsidence and to estimate subsidence rates. **Table 5-7** summarizes the average yearly elevation change along the DMC between 2014, 2016 and 2018. **Figure 5-117** shows the change in land surface elevation between the 2014 and 2016 and the 2014 and 2018 subsidence surveys performed by SLDMWA at each milepost along the DMC.

Lower Aquifer groundwater extractions has been identified as one of the key causes of inelastic land subsidence in the Delta-Mendota Subbasin. The City of Patterson, which is the only major municipality within the Plan area, relies solely on groundwater from the Lower Aquifer for potable supply. The City of Patterson is located directly east of the DMC within Pool 7, where subsidence occurred at a rate of 0.22 feet/year during the most recent drought (2014-2016) and decreased to 0.06 feet/year immediately following the drought (2016-2018) (**Table 5-7**); thus reinforcing the connection between Lower Aquifer groundwater pumping and inelastic subsidence.

Table 5-7. Subsidence Rates Along the Delta-Mendota Canal in the Northern and Central Delta-Mendota Regions Elevation Differences between 2014, 2016, and 2018 Subsidence Surveys

Pool	Milepost Range	Checkpoints	Average Yearly Elevation Change (ft/yr)		
			2014-2016	2016-2018	2014-2018
3	16.20-20.63	2 – 3	-0.08	-0.12	-0.1
4	20.64 - 24.43	3 – 4	-0.11	-0.14	-0.13
5	24.44 - 29.82	4 – 5	-0.15	-0.11	-0.13
6	29.83 - 34.42	5 – 6	-0.19	-0.11	-0.15
7	34.43 - 38.68	6 – 7	-0.22	-0.06	-0.14
8	38.69 - 44.26	7 – 8	-0.27	-0.01	-0.14
9	44.27 - 48.62	8 – 9	-0.26	0.02	-0.12
10	48.63 - 54.41	9 – 10	-0.26	0.02	-0.12
11	54.42 - 58.28	10 – 11	-0.24	0.01	-0.12
12	58.29 - 63.98	11 – 12	-0.21	-0.03	-0.12
13	63.99 - 70.01	12 – 13	-0.17	-0.04	-0.1
14	70.02 - 74.40	13 – 14	-0.14	-0.01	-0.07
15	74.41 - 79.64	14 – 15	-0.14	0.02	-0.07
16	79.65 - 85.09	15 – 16	-0.15	0.01	-0.08
17	85.10 - 90.54	16 – 17	-0.17	-0.05	-0.11
18	90.55 - 96.81	17 – 18	-0.23	-0.09	-0.16

For the TRID area at the southern end of the Northern & Central Delta-Mendota Region GSP Plan area, regular surveys of wellhead elevations between 2014 and 2018 have provided insight into subsidence rates in this area. Per these data, TRID has experienced over two feet of subsidence between 2014 and 2018, with an average subsidence rate of 0.53 feet/year for that period.

5.3.6.4 Groundwater Trends

The rapid decline of groundwater levels in the San Joaquin Valley during post-1975 droughts in response to relatively small volumes of pumping (compared to those of the 1960s) results from a loss of storage space in the aquifer system — mostly from inelastic compaction of aquitards during the 1950s and 1960s — and from reduced hydraulic conductivity (permeability) of those compacted aquitards that restrict drainage of water to permeable parts of the aquifer system (Borchers and Carpenter, 2014). Observations showed that Lower Aquifer water levels were considerably higher than during the 1960s, yet there was renewed land subsidence during droughts. Since 1962, groundwater storage in the Central Valley aquifer system has been depleted at an average rate of 1.85 km^3/year (or about 1.5 million AF/year) and at more than twice this rate during the most recent drought of 2012-2015 (Faunt et al., 2015). This illustrates the complex effects of unequal distribution of preconsolidation stress within the aquitards and between the aquitards and more permeable units of the aquifer system.

Subsidence monitoring in the Delta-Mendota Subbasin, and in the San Joaquin Valley as a whole, demonstrated significant inelastic land subsidence as a result of the last drought, with effects continuing to the present time (as evidenced by continued subsidence between 2016 and 2018 through the SLDMWA surveys). While the impacts appeared to have slowed, the temporal and spatial impacts of continued subsidence have not yet been evaluated.

Land use changes in some parts of the San Joaquin Valley are likely to impact future subsidence. Trends toward the planting of permanent crops since 2000, such as vineyards and orchards, and away from non-permanent land uses like rangeland and row crops can result in "demand hardening," which requires stable water supplies to irrigate crops that cannot be fallowed (Sneed et al., 2013 and Faunt et al., 2015). As land use and surface water availability continue to vary in the San Joaquin Valley, additional water level declines and associated subsidence are likely to occur. Increased monitoring of groundwater levels and land subsidence will be essential to better understand the connection between land use, groundwater levels, and subsidence and enable management strategies to mitigate subsidence hazards and impacts while optimizing water supplies.

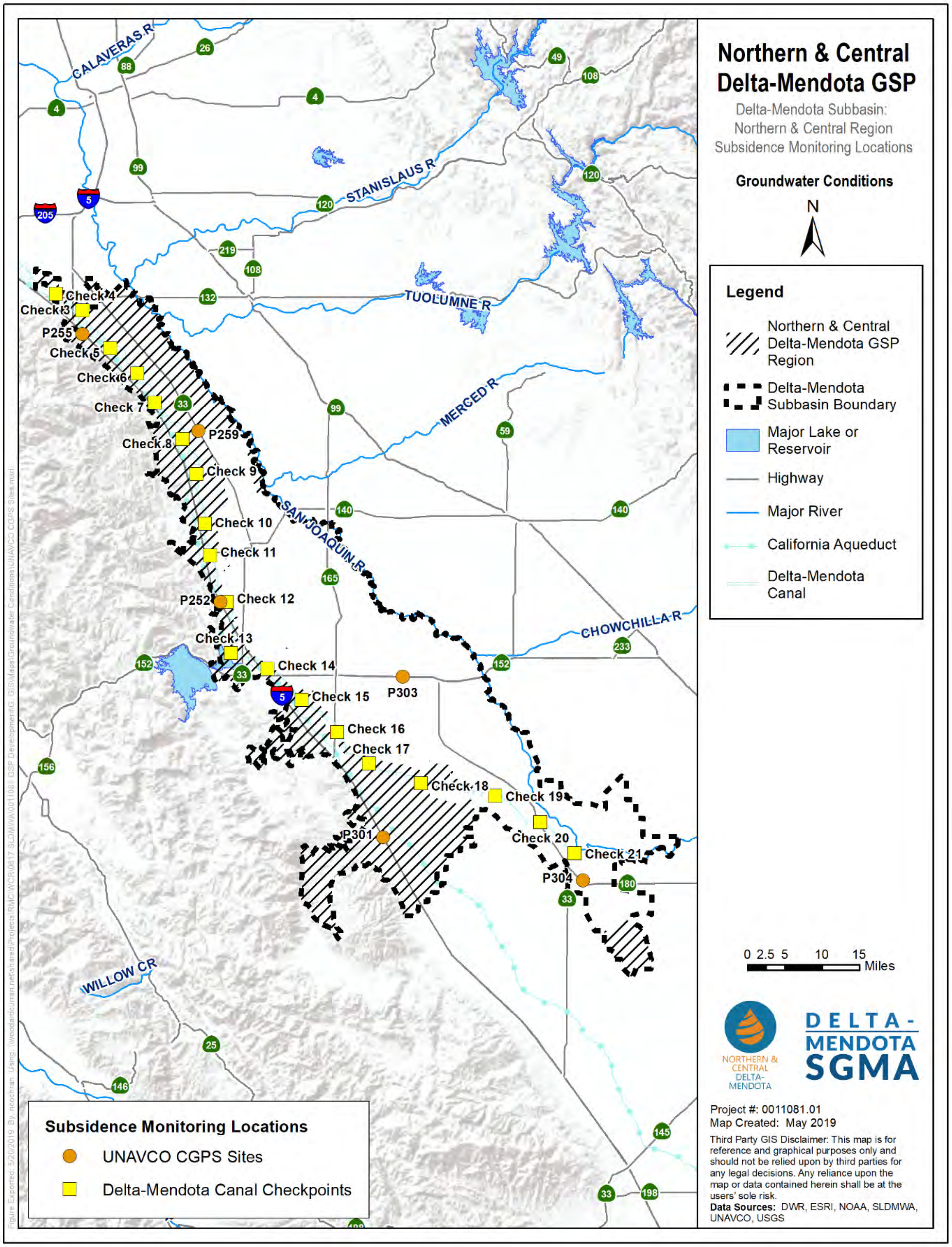

Figure 5-106. Subsidence Monitoring Locations, Delta-Mendota Subbasin

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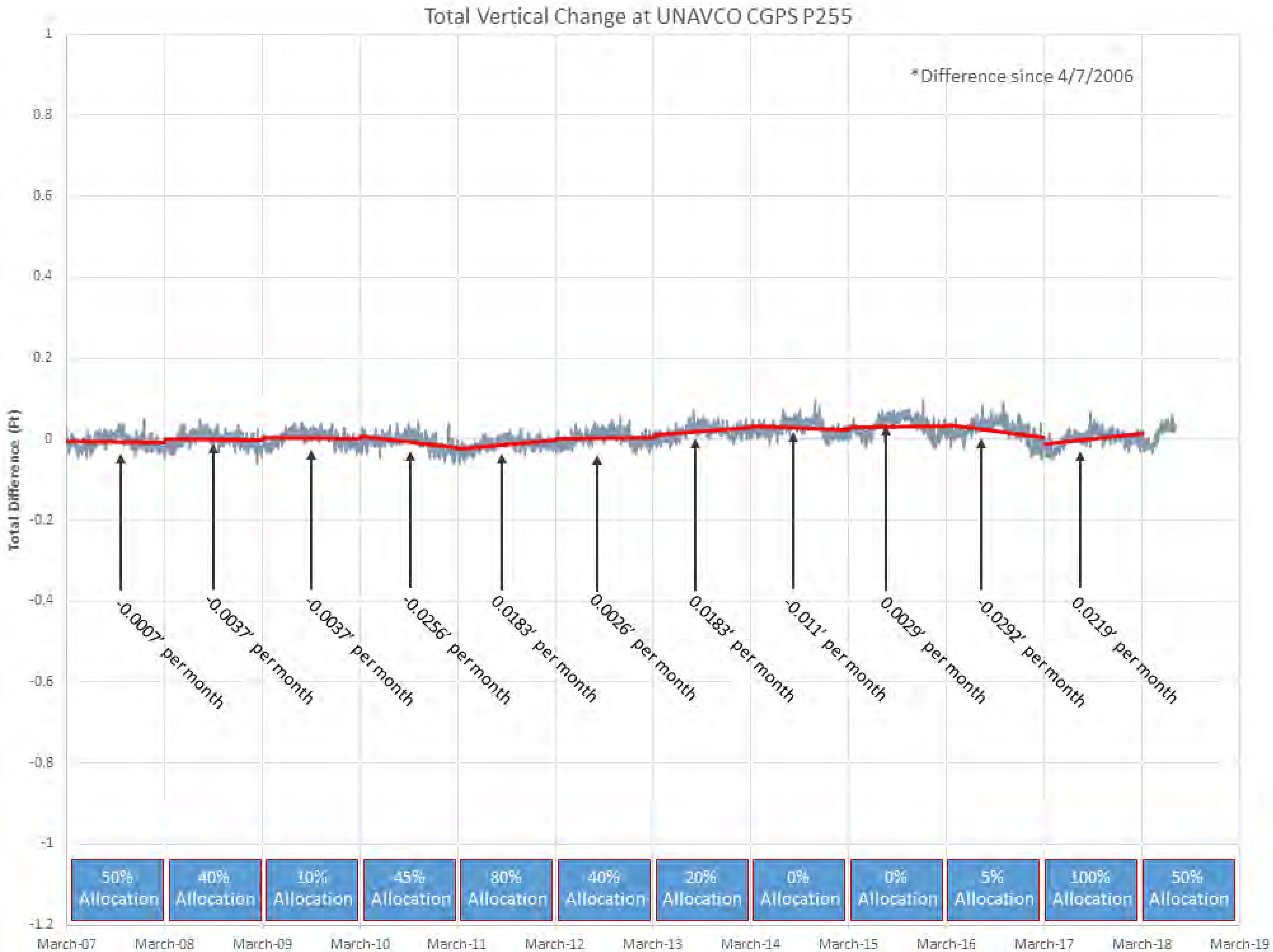

Figure 5-107. Vertical Elevation Change at UNAVCO CGPS P255, Spring 2007 to 2018

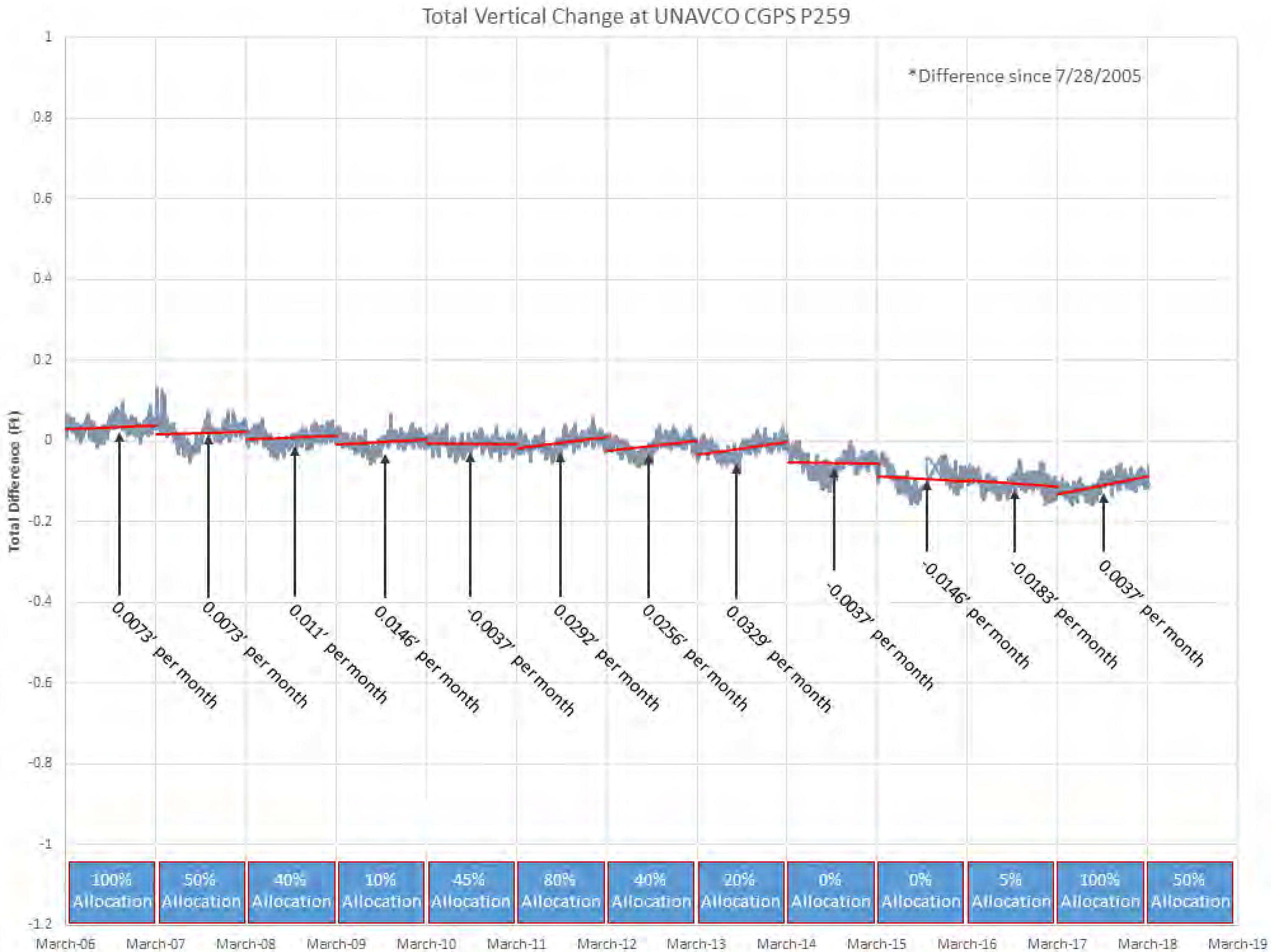

Figure 5-108. Vertical Elevation Change at UNAVCO CGPS P259, Spring 2006 to 2018

Figure 5-109. Vertical Elevation Change at UNAVCO CGPS P252, Spring 2006 to 2018

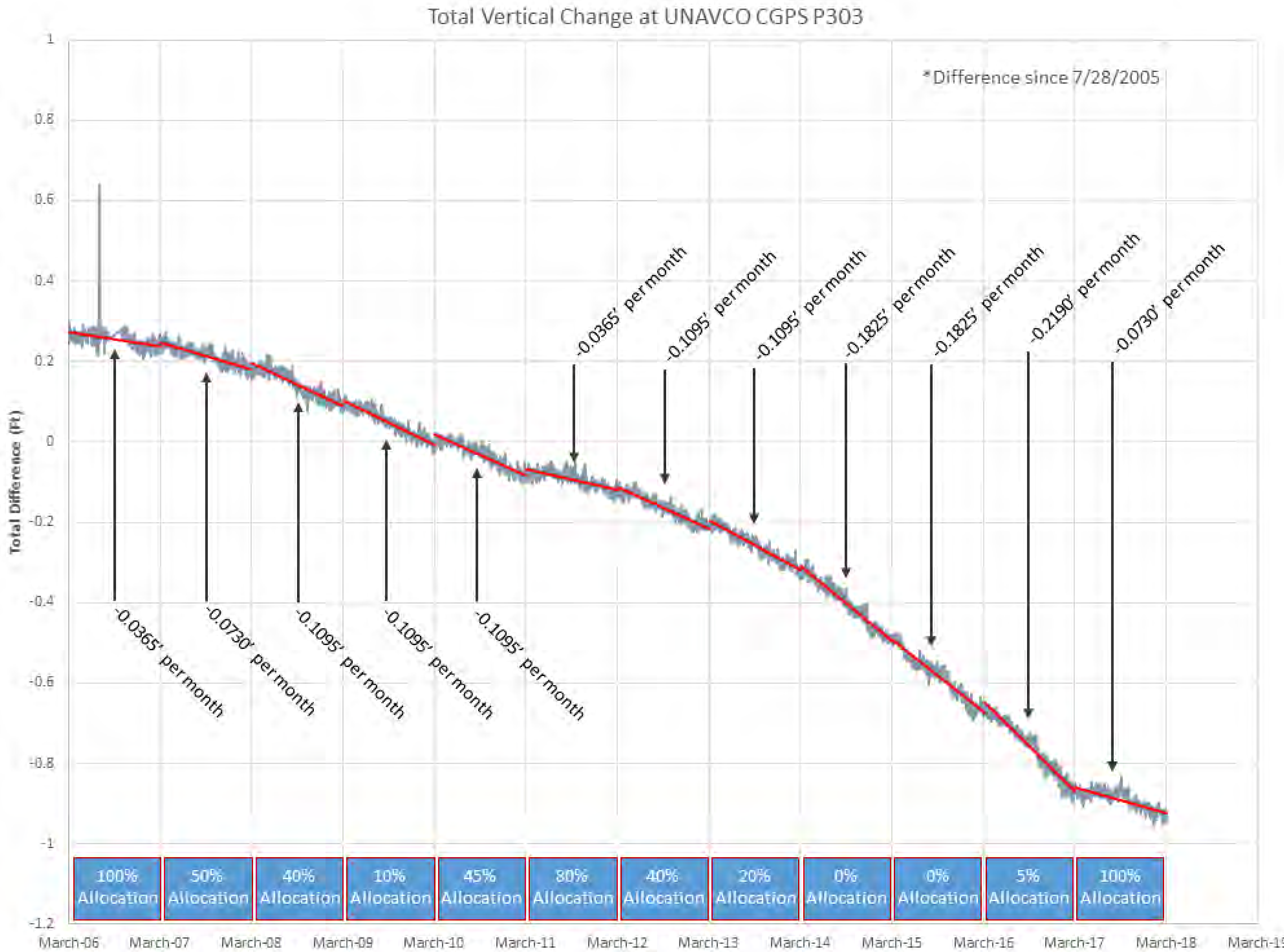

Figure 5-110. Vertical Elevation Change at UNAVCO CGPS P303, Spring 2006 to 2018

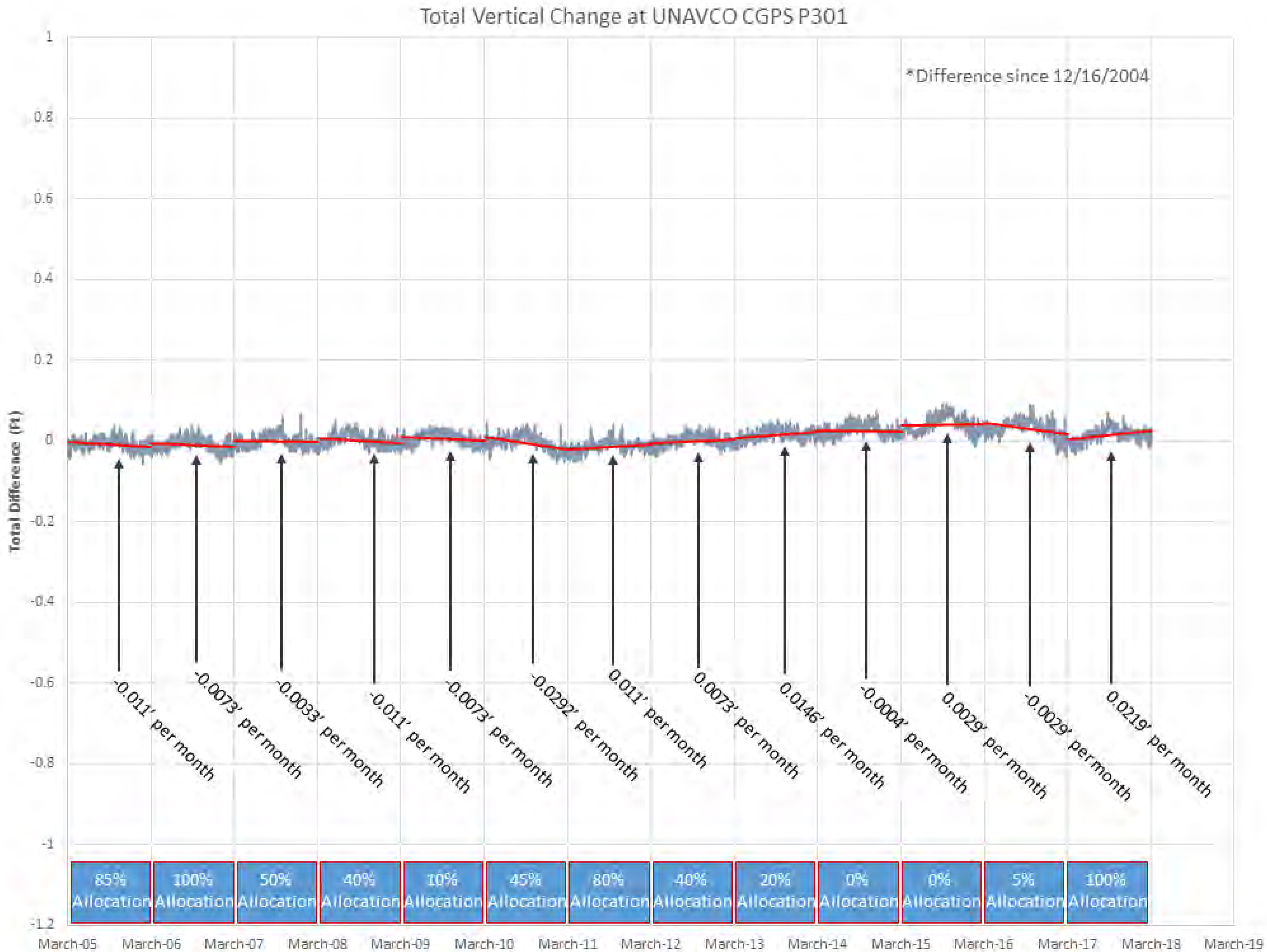

Figure 5-111. Vertical Elevation Change at UNAVCO CGPS P301, Spring 2005 to 2018

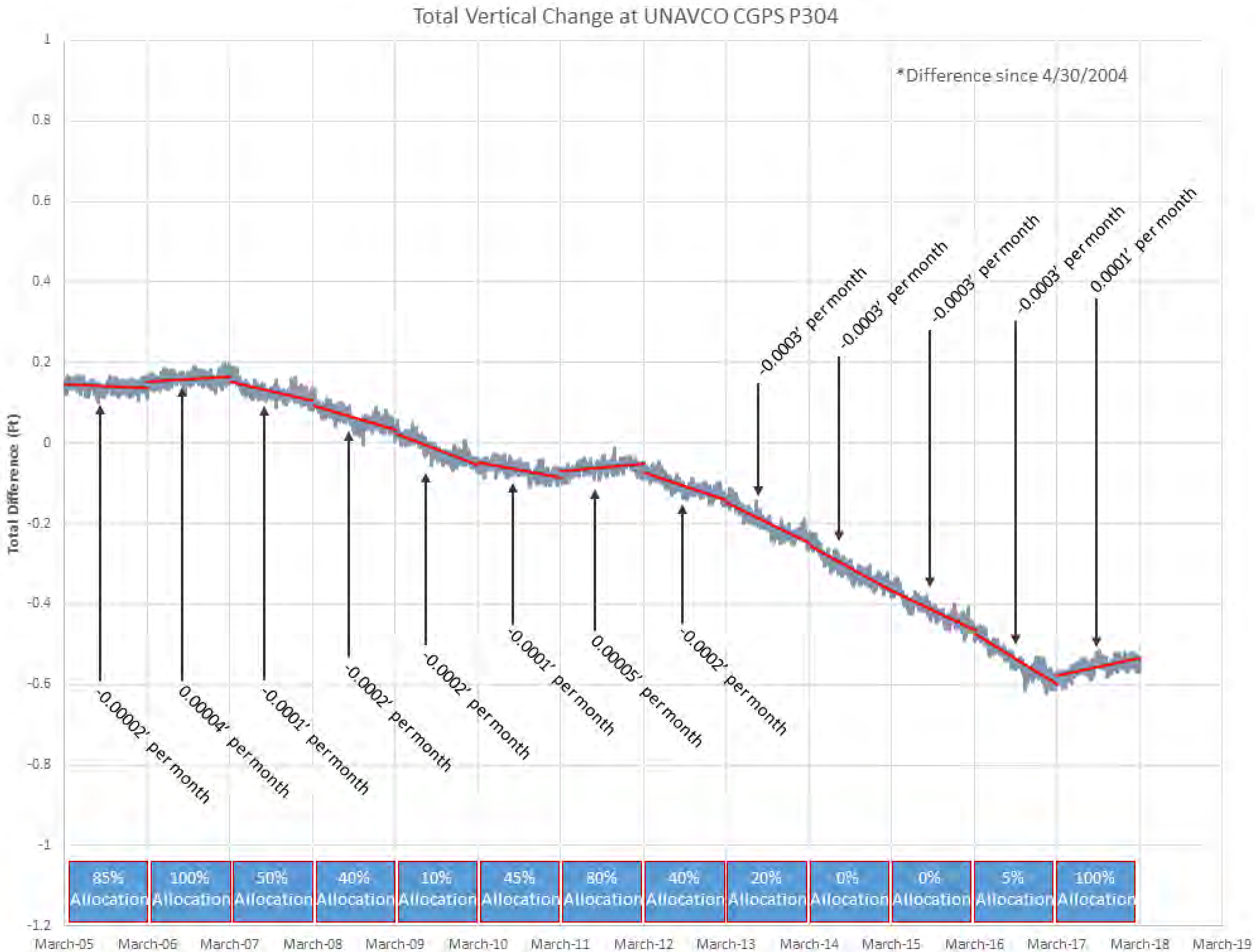

Figure 5-112. Vertical Elevation Change at UNAVCO CGPS P304, Spring 2005 to 2018

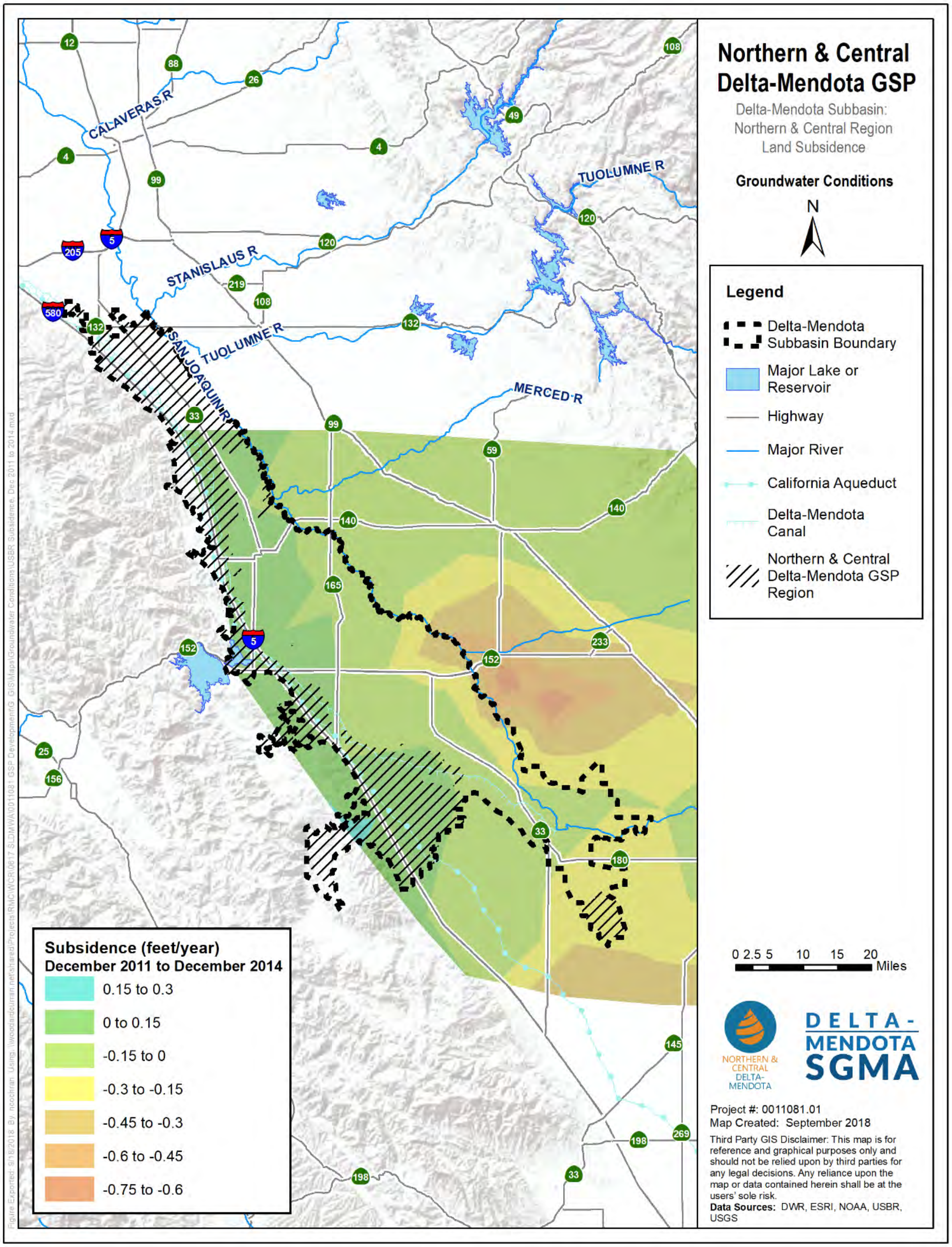

Figure 5-113. Land Subsidence, December 2011 to December 2014

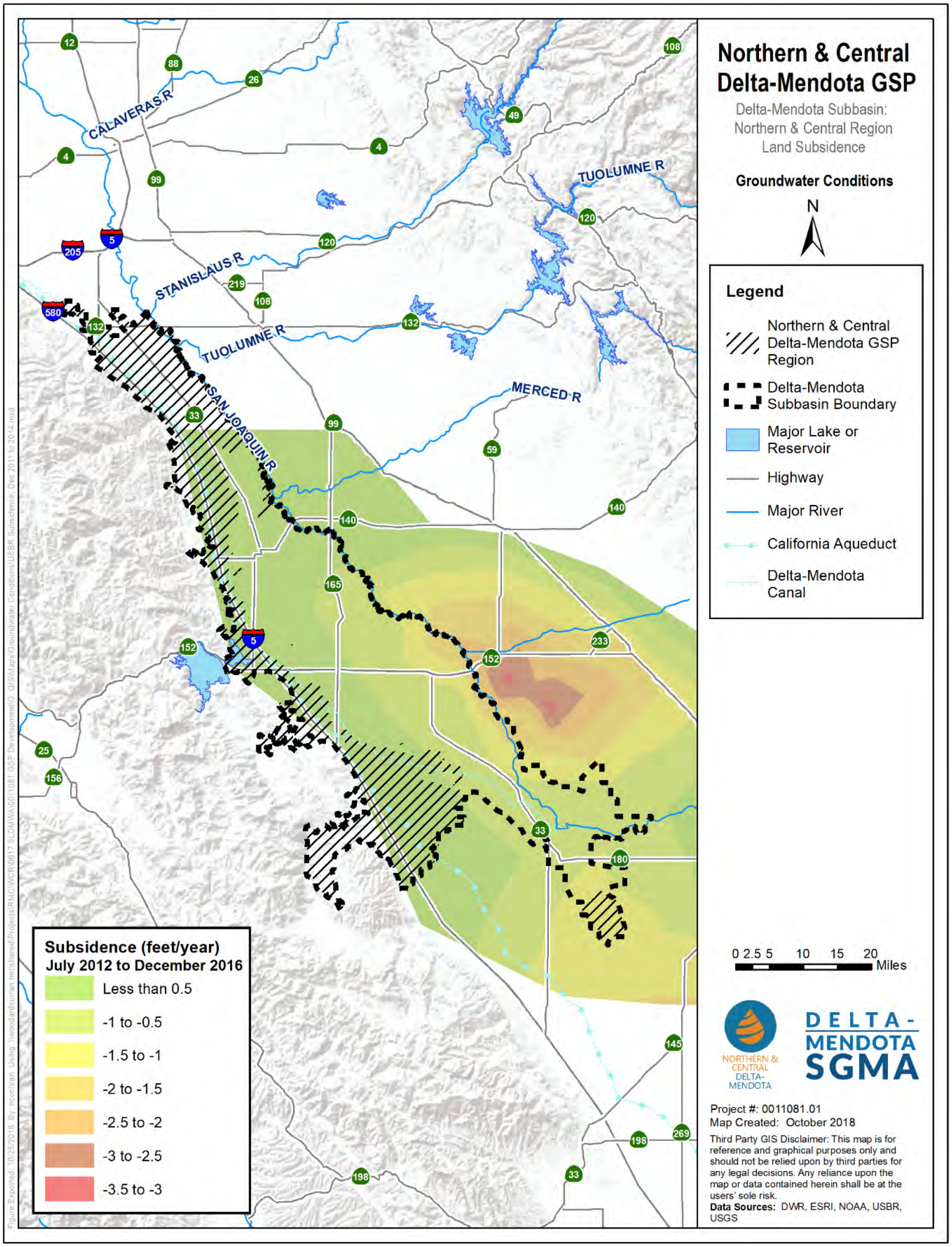

Figure 5-114. Land Subsidence, July 2012 to December 2016

Figure 5-115. Recent Land Subsidence at Key San Joaquin Valley Locations (Source: *Progress Report: Subsidence in California, March 2015 – September 2016*, Farr et. al. JPL, 2017)

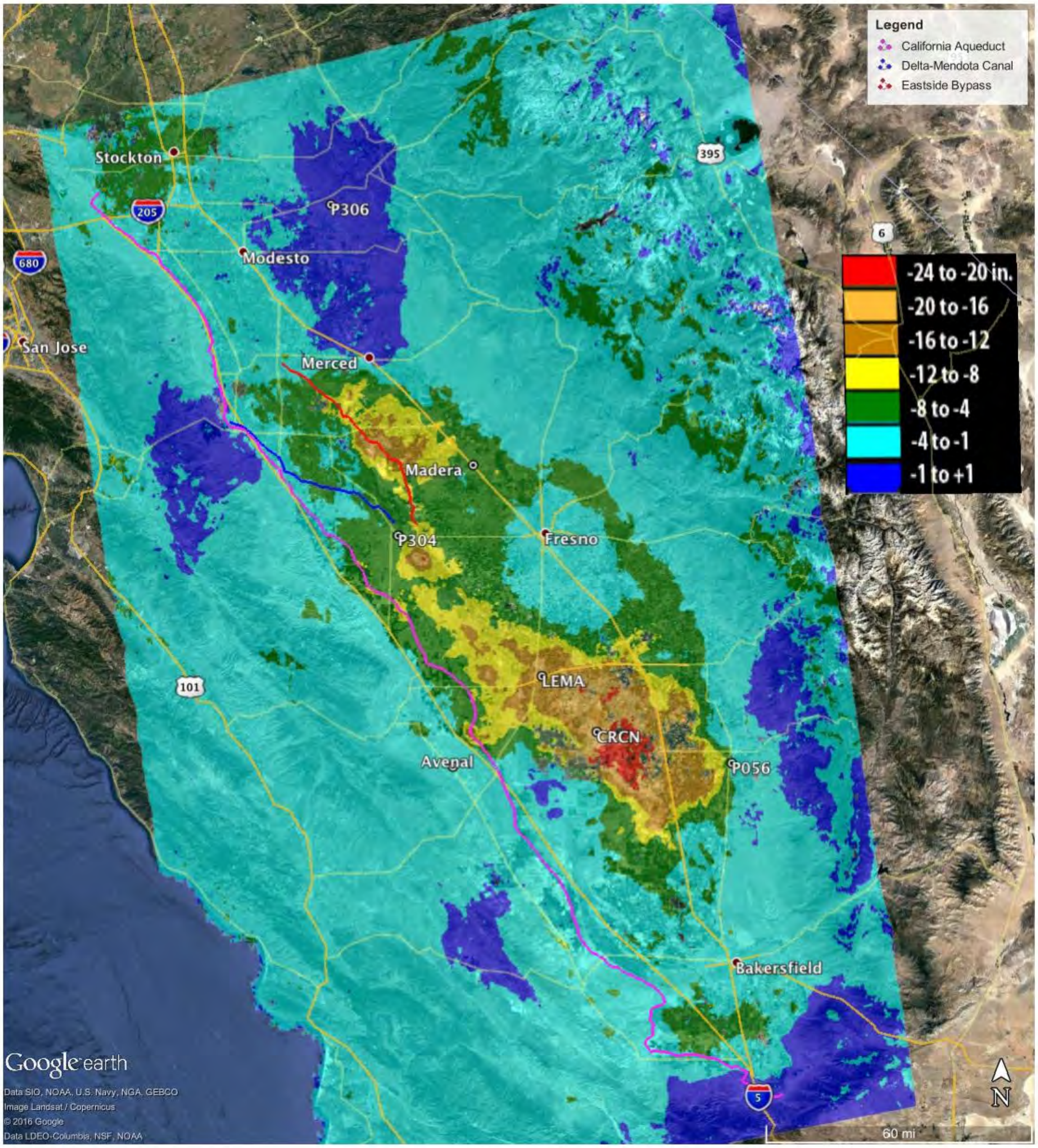

Figure 5-116. Total Land Subsidence in San Joaquin Valley from May 7, 2015 – September 10, 2016 as measured by ESA's Sentinel-1A and processed by JPL (Source: *Progress Report: Subsidence in California, March 2015 – September 2016*, Farr et. al. JPL, 2017

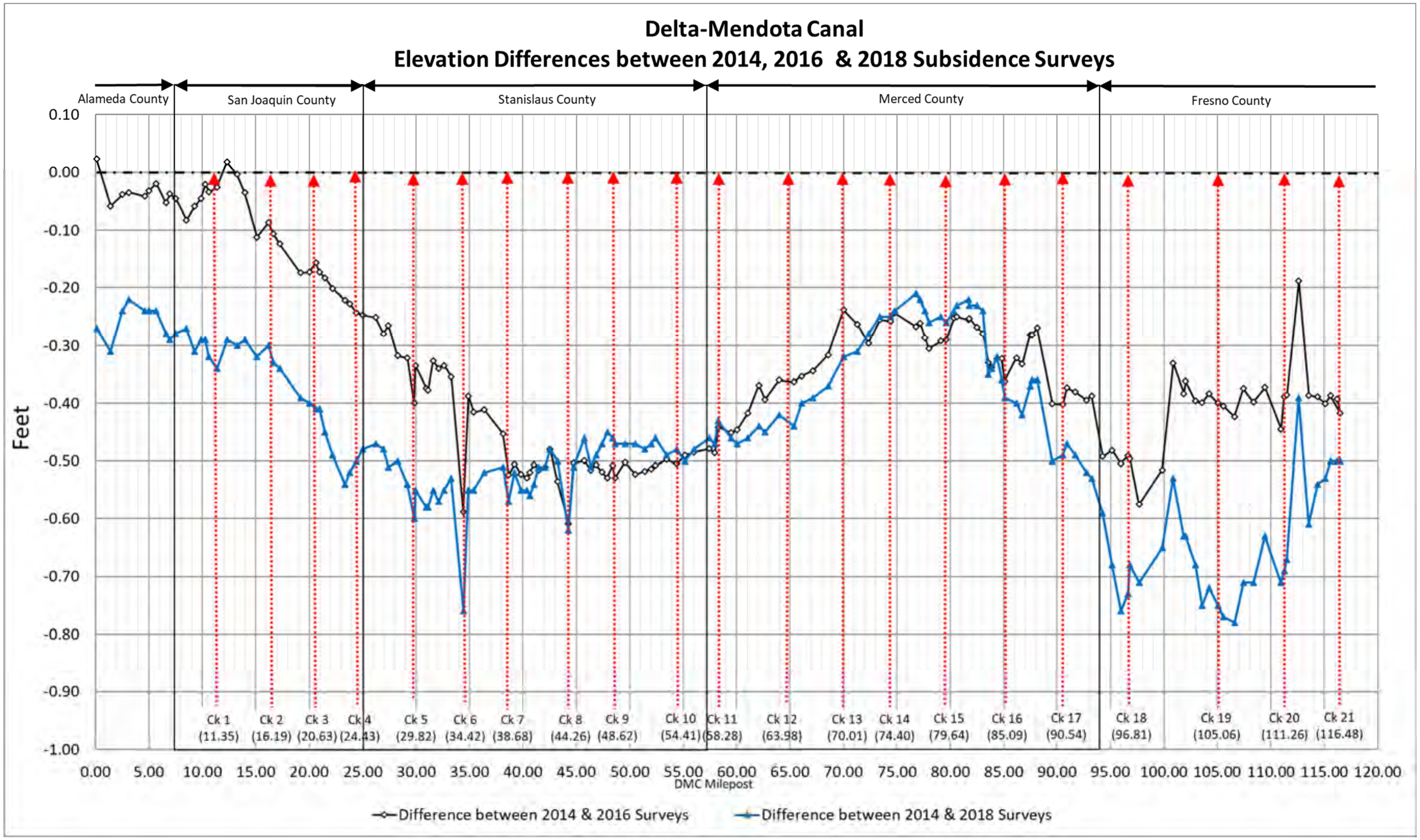

Figure 5-117. Elevation Change along the Delta-Mendota Canal, 2014 through 2018

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5.3.7 Interconnected Surface Water Systems

Understanding the location, timing and magnitude of groundwater pumping impacts on interconnected surface water systems is important for the proper management of groundwater resources in order to minimize impacts on interconnected surface waters and the biological communities and permitted surface water diverters that rely on those resources. Historically, throughout the San Joaquin Valley, many interconnected stream reaches have transitioned from net-gaining to net-losing streams (TNC, 2014). Gaining streams occur when streamflows increase as a result of groundwater contribution, and losing streams occur when streamflows decrease due to infiltration into the surrounding groundwater basin through the bed of the stream (McBain & Trush, Inc., 2002). Lowered groundwater levels have the ability to result in stream depletion similar in amount to the consumptive use of applied water, with the nature, rate, and location of increased pumping being a function of distance to the river, as well as depth, timing, and rate of groundwater pumping; however, it is important to recognize that groundwater pumping adjacent to an interconnected surface water body may be one of many causes of loss of surface water flows.

5.3.7.1 Available Data

Two communities in the Northern and Central Delta-Mendota Regions are most vulnerable to impacts from the loss of interconnected surface water as a result of the lowering of groundwater elevations: San Joaquin River surface water diverters and GDEs. These communities represent the primary users of interconnected surface water and groundwater. Permitted San Joaquin River diverters at the northern end of the Delta-Mendota Subbasin include West Stanislaus Irrigation District (post-1914 appropriative rights holder) and Patterson Irrigation District (which holds a pre-1914 water right), in addition to smaller agencies and private diverters. Similarly, GDEs in the Northern and Central Delta-Mendota Regions are found adjacent to the San Joaquin River, predominantly at the San Joaquin National Wildlife Refuge, which provides important habitat to birds and wildlife. Streams stemming from the west side of the Delta-Mendota Subbasin are ephemeral in nature, and only two of these creeks reach the San Joaquin River (Del Puerto Creek and Orestimba Creek). These creeks lose their flows to the underlying vadose zone (net-losing streams) and therefore do not represent areas of potential GDEs.

Groundwater dependent ecosystems are defined under Article 2 Definitions, § 351 Definitions of the GSP Emergency Regulations as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface." The Natural Communities Commonly Associated with Groundwater (NCCAG) dataset (2018a) provided by DWR in conjunction with The Nature Conservancy (TNC) was initially used to identify GDEs within the Delta-Mendota Subbasin, following the associated guidance document provided by TNC (Rohde et al., 2018). Local verification efforts were conducted in the Delta-Mendota Subbasin by different GSA representatives to ground-truth GDEs based on local knowledge. Specifically, areas where natural communities have been urbanized or otherwise modified were eliminated from the data set use to identify GDEs.

5.3.7.2 Identification of Interconnected Surface Water Systems

The San Joaquin River is the primary surface water body interconnected with Delta-Mendota Subbasin groundwater. Within the Northern and Central Delta-Mendota Regions, four reaches of the San Joaquin River have been identified as gaining streams with their associated California Data Exchange Center (CDEC) stream gauges: Newman (NEW) to Crows Landing (SCL), Crows Landing to Patterson (SJP), Patterson to Maze Road Bridge (MRB), and Maze Road Bridge to Vernalis (VNS). These reaches of the San Joaquin River were identified as gaining from a compendium of sources including a 2014 analysis of diversion water demand for diverters of the San Joaquin River between Hills Ferry Bridge and Mossdale Bridge (Provost & Pritchard, June 2014) as well as the following:

- Babbit, C., D.M. Dooley, M. Hall, R.M. Moss, D.L. Orth, and G.W. Sawyers. July 2018. *Groundwater Pumping Allocations under California's Sustainable Groundwater Management Act: Considerations for Groundwater Sustainability Agencies*.

https://www.edf.org/sites/default/files/documents/edf_california_sgma_allocations.pdf. Accessed on November 13, 2018.

- Cantor, A., D. Owen, T. Harter, N.G. Nylen, and M. Kiparsky. March 2018. *Navigating Groundwater-Surface Water Interactions under the Sustainable Groundwater Management Act*. Center for Law, Energy & the Environment, UC Berkeley School of Law, Berkeley, CA. 50 pp. https://doi.org/10.15779/J23P87. Accessed on August 7, 2018.
- Hall, M., C. Babbitt, A.M. Saracino, and S.A. Leake. 2018. *Addressing Regional Surface Water Depletions in California: A Proposed Approach for Compliance with the Sustainable Groundwater Management Act*. https://www.edf.org/sites/default/files/documents/edf_california_sgma_surface_water.pdf. Accessed on November 13, 2018.
- McBain & Trush, Inc. 2002. *San Joaquin River Restoration Study Background Report*, prepared for Friant Water Users Authority, Lindsay, CA, and Natural Resources Defense Council. https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/mcbainandtrush_2002.pdf. Accessed on October 1, 2018.
- San Joaquin River Restoration Program. April 2011. *DRAFT Program Environmental Impact Statement/Report, Chapter 12.0 Hydrology – Groundwater*. https://www.usbr.gov/mp/nepa/includes/documentShow.php?Doc_ID=7557. Accessed on August 29, 2018.
- San Joaquin River Restoration Program. August 2013. *Flow Loss Analysis (DRAFT)*. http://www.restoresjr.net/?wpfb_dl=686. Accessed on August 28, 2018.
- San Luis & Delta-Mendota Water Authority. March 22, 2011. *Guidelines for Use of the San Luis Drain during Flood Conditions*. Received via personal communication via Andrew Garcia on October 2, 2018.
- The Nature Conservancy. 2014. Groundwater and Stream Interaction in California's Central Valley: Insights for Sustainable Groundwater Management. https://www.scienceforconservation.org/assets/downloads/GroundwaterStreamInteraction_2016.pdf. Accessed on August 29, 2018.
- The Nature Conservancy. January 2018. *Groundwater Dependent Ecosystems under the Sustainable Groundwater Management Act: Guidance for Preparing Groundwater Sustainability Plans*. https://www.scienceforconservation.org/assets/downloads/GDEsUnderSGMA.pdf. Accessed on February 1, 2018.
- United States Bureau of Reclamation. April 2005. *CALSIM II San Joaquin River Model (DRAFT)*. http://www.calwater.ca.gov/science/pdf/calsim/CALSIMSJR_DRAFT_072205_1-50.pdf and http://www.calwater.ca.gov/science/pdf/calsim/CALSIMSJR_DRAFT_072205_51-100.pdf. Accessed on December 28, 2018.

5.3.7.3 Historic Conditions

The San Joaquin River and its tributaries drain approximately 13,500 mi^2 (measured at the USGS gaging station at Vernalis) along the western flank of the Sierra Nevada and eastern flank of the Coast Range, and flows northward into the Sacramento-San Joaquin Delta where it is joined by the Calaveras and Mokelumne Rivers before combining with the Sacramento River. Typical of Mediterranean climate catchments, river flows vary widely seasonally and from year to year. Three major tributaries join the San Joaquin from the east: the Merced, Tuolumne, and Stanislaus Rivers. Smaller tributaries include the Fresno River, Chowchilla River, Bear Creek, and Fresno Slough (from the Kings River). Precipitation is predominantly snow above about 5,500 to 6,000 feet in the Sierra Nevada, with rain in the middle and lower elevations of the Sierra foothills and in the Coast Range. As a result, the natural hydrology historically reflected a mixed runoff regime dominated by winter-spring rainfall runoff and spring-summer snowmelt runoff. Most flow is derived from snowmelt from the Sierra Nevada, with relatively little runoff contributed from the western side of the drainage basin in the rain shadow of the Coast Range. The unimpaired average annual water yield (WY 1906-2002) of the San Joaquin River, as measured immediately above Millerton Reservoir, is 1,801,000 AF (USBR, 2002); the post-Friant Dam average annual water yield (WY 1950-2000) to the lower San Joaquin River is 695,500 AF (USGS, 2000). As average precipitation decreases from north to south, the San Joaquin River basin (including the Stanislaus, Tuolumne, and Merced Rivers) contributes about 22% of the total runoff to the Delta (DWR, 1998).

5.3.7.4 Current Conditions

Historically, most of the San Joaquin River, which forms the great majority of the Delta-Mendota Subbasin's eastern border, was a gaining reach. Snowmelt runoff during the spring and early summer resulted in these conditions through a good portion of the year. However, significant decreases in groundwater elevations due to pumping, storage, and upstream diversions on the river have reversed this condition so most reaches are now losing reaches. Some localized gaining reaches still remain on the lower river, such as between the Stanislaus and Merced Rivers, corresponding to the reaches of the San Joaquin River boarding the Northern and Central Delta-Mendota Regions.

5.3.7.5 Estimates of Timing and Quantity of Gains/Depletions

Using available data, the quantity of gains and/or depletions from the groundwater at each reach of the San Joaquin River identified along the Northern and Central Delta-Mendota Regions was estimated. **Table 5-8** summarizes these estimates. Estimates of the timing of gains and/or depletions were unavailable in related literature, and insufficient data were available to estimate the timing of losses and gains in the Northern and Central Delta-Mendota Regions. Such information will be gathered through future monitoring efforts related to this GSP.

Table 5-8. Estimated Quantity of Gains/Depletions for Interconnected Stream Reaches, Northern and Central Delta-Mendota Regions

Reach	Quantified Gain (cubic feet per second [cfs])	Reach Length (mile [mi])
Newman to Crows Landing [1]	50	11
Crows Landing to Patterson [1]	-50 to 200	10
Patterson to Maze Road Bridge [2]	190	30.8
Maze Road Bridge to Vernalis [2]		

[1] Provost & Pritchard, 2014

[2] Cooley, 2001

5.3.7.6 Groundwater Dependent Ecosystems

A GDE is defined under the GSP Emergency Regulations as referring "to ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (§351(m)). Under §354.16(g) of the GSP Emergency Regulations, each Plan is required to identify GDEs within the subbasin utilizing data provided by the Department of Water Resources, or the best available information. The following section describes the process for verifying GDEs within the Delta-Mendota Subbasin and the location of verified and potential GDEs.

The NCCAG dataset (2018a) provided by DWR was used in conjunction with information provided by TNC to identify GDEs within the Delta-Mendota Subbasin. To further screen available information regarding GDEs, the following standards were set for identifying GDEs in the Northern and Central Delta-Mendota Regions: (1) areas with depths to groundwater levels greater than 30 feet were eliminated unless the vegetation identified in those areas were consistent with species with deep root systems (e.g. live oaks); (2) seasonally-managed areas and wetlands were eliminated due to their dependence on applied surface water; and (3) a 100-foot buffer was applied around the San Joaquin River within the Northern Delta-Mendota Region to include all communities in the NCCAG dataset as potential GDEs, except where professional judgement and local knowledge determined GDEs were not present. The selected 100-foot buffer corresponds with Caltrans standards under the Coastal Act that requires a 100-foot setback around wetland resources for their protection during project construction. To determine where groundwater is typically deeper than 30 feet below the ground surface, Spring 2015 depth to water contour mapping was used as a basis for establishing a connection between shallow groundwater and potential GDEs. The ESRI World Imagery layer (2017) was also used by local GSA representatives for ground-truthing and identifying potential mapping errors.

Based on the screening process described above, GDE polygons determined not to be GDEs were removed from the mapping. There were no GDE communities added to the mapping for the Northern and Central Delta-Mendota Regions. **Figure 5-118** and **Figure 5-119** summarize the results of the GDE analysis for the Subbasin, where red polygon indicates the Northern and Central Delta-Mendota Regions. Results are compiled into two habitat classes: wetlands (**Figure 5-118**) and vegetation (**Figure 5-119**). Wetland features are commonly associated with surface expression of groundwater under natural, unmodified conditions. Vegetation feature types are commonly associated with the sub-surface presence of groundwater (phreatophytes – deep rooted plants). Out of a total of 13,253 acres identified in the NCCAG dataset within the Northern and Central Delta-Mendota Regions, 11,711 acres were retained as Possible GDEs. Confirmed GDEs have been grouped into larger polygons based on proximity and aquifer connection.

In general, identified Possible GDEs are located along the San Joaquin River corridor. Possible GDEs in the Northern and Central Delta-Mendota Regions are located primarily in the northern portion of the Plan area, within about two miles from the San Joaquin River. Possible GDEs have also been identified along streams originating from the Coast Range; however, these areas are topographically disconnected from the Subbasin's principal aquifers and are located in areas of *de minimus* or zero groundwater use and are therefore are unmanageable through the Sustainable Groundwater Management Act (SGMA). **Table 5-9** includes all freshwater species within the Northern and Central Delta-Mendota Regions, as identified by TNC (2018). These species (listed in **Table 5-9**) have either been observed or have the potential to exist within the Northern and Central Delta-Mendota Regions. Future efforts in GDE mapping prior to the 2025 5-Year GSP Update will further refine GDE locations within the Plan area.

As a result of the identification of Possible GDEs for the purpose of this GSP under SGMA, no land use protections for GDEs are conveyed unless the law otherwise requires. Management and protection of GDEs may require more focus on land use or irrigation activities more so than groundwater management. This rigorous analysis to identify potential GDEs was developed to focus groundwater management activities on the most appropriate areas.

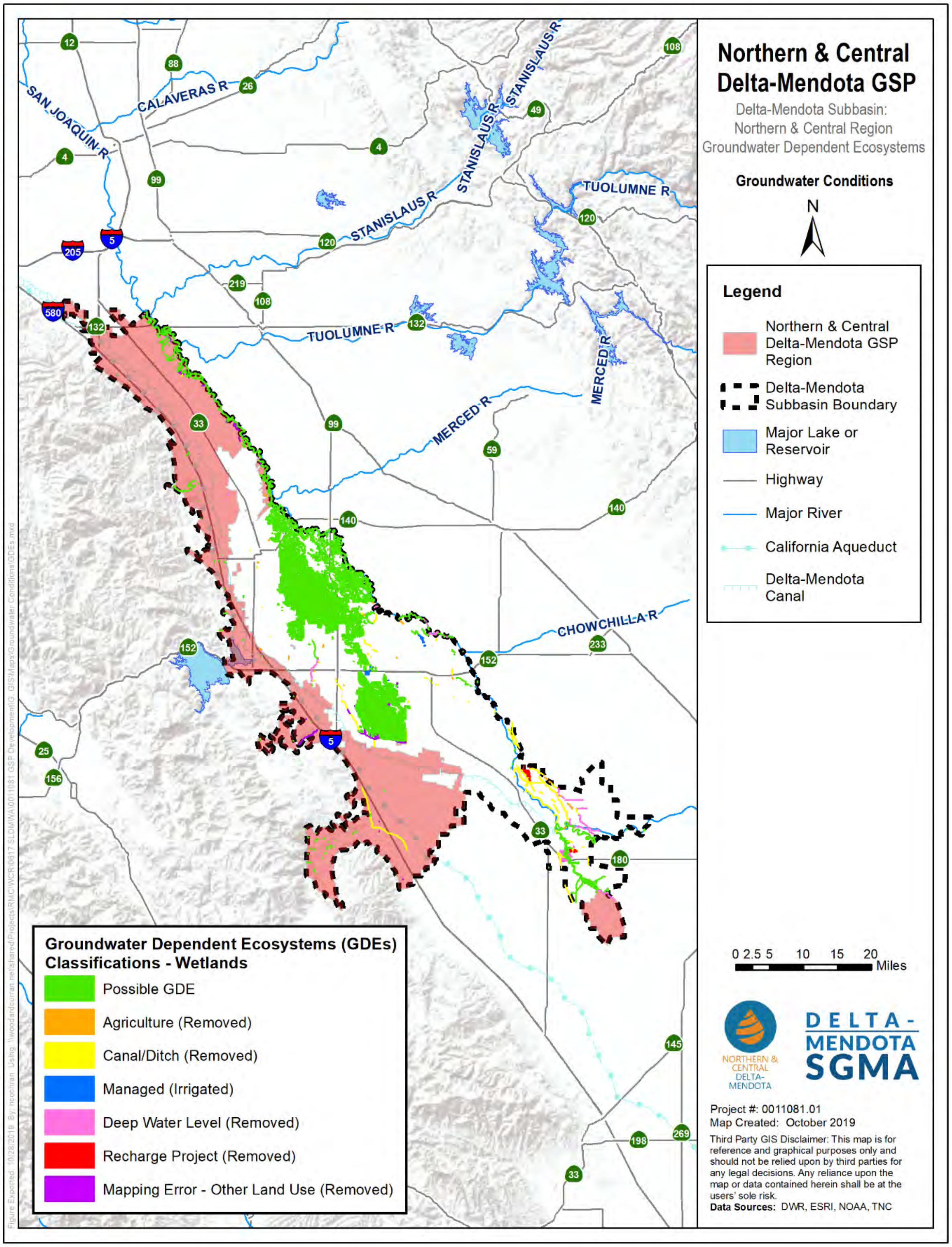

Figure 5-118. Groundwater Dependent Ecosystems in the Delta-Mendota Subbasin, Wetlands

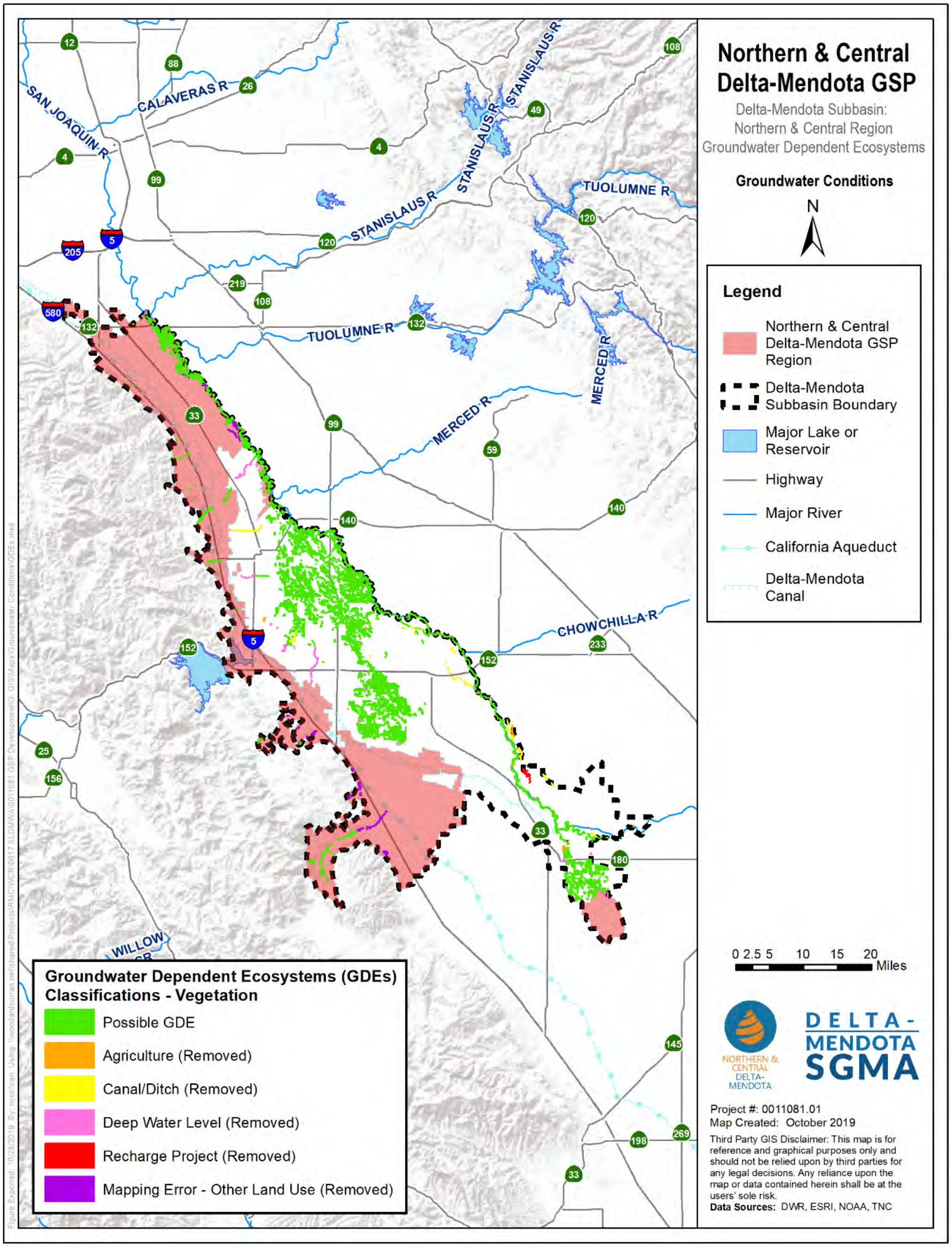

Figure 5-119. Groundwater Dependent Ecosystems in the Delta-Mendota Subbasin, Vegetation

Table 5-9. List of Potential Freshwater Species, Northern and Central Delta-Mendota Regions

Scientific Name	Common Name	Group	Federal Protection Status	State Protection Status
Actitis macularius	Spotted Sandpiper	Birds		
Aechmophorus clarkii	Clark's Grebe	Birds		
Aechmophorus occidentalis	Western Grebe	Birds		
Agelaius tricolor	Tricolored Blackbird	Birds	Bird of Conservation Concern	Special Concern
Aix sponsa	Wood Duck	Birds		
Anas acuta	Northern Pintail	Birds		
Anas americana	American Wigeon	Birds		
Anas clypeata	Northern Shoveler	Birds		
Anas crecca	Green-winged Teal	Birds		
Anas cyanoptera	Cinnamon Teal	Birds		
Anas discors	Blue-winged Teal	Birds		
Anas platyrhynchos	Mallard	Birds		
Anas strepera	Gadwall	Birds		
Anser albifrons	Greater White-fronted Goose	Birds		
Ardea alba	Great Egret	Birds		
Ardea herodias	Great Blue Heron	Birds		
Aythya affinis	Lesser Scaup	Birds		
Aythya americana	Redhead	Birds		Special Concern
Aythya collaris	Ring-necked Duck	Birds		
Aythya marila	Greater Scaup	Birds		
Aythya valisineria	Canvasback	Birds		Special
Botaurus lentiginosus	American Bittern	Birds		
Bucephala albeola	Bufflehead	Birds		
Bucephala clangula	Common Goldeneye	Birds		
Butorides virescens	Green Heron	Birds		
Calidris alpina	Dunlin	Birds		
Calidris mauri		Birds		
Calidris minutilla	Least Sandpiper	Birds		
Chen caerulescens	Snow Goose	Birds		
Chen rossii	Ross's Goose	Birds		
Chlidonias niger	Black Tern	Birds		Special Concern
Chroicocephalus philadelphia	Bonaparte's Gull	Birds		

Scientific Name	Common Name	Group	Federal Protection Status	State Protection Status
Cistothorus palustris	Marsh Wren	Birds		
Cygnus columbianus	Tundra Swan	Birds		
Cypseloides niger	Black Swift	Birds	Bird of Conservation Concern	Special Concern
Egretta thula	Snowy Egret	Birds		
Empidonax traillii	Willow Flycatcher	Birds	Bird of Conservation Concern	Endangered
Fulica americana	American Coot	Birds		
Gallinago delicata	Wilson's Snipe	Birds		
Gallinula chloropus		Birds		
Geothlypis trichas		Birds		
Grus canadensis	Sandhill Crane	Birds		
Haliaeetus leucocephalus	Bald Eagle	Birds	Bird of Conservation Concern	Endangered
Himantopus mexicanus	Black-necked Stilt	Birds		
Icteria virens	Yellow-breasted Chat	Birds		Special Concern
Limnodromus scolopaceus	Long-billed Dowitcher	Birds		
Lophodytes cucullatus	Hooded Merganser	Birds		
Megaceryle alcyon	Belted Kingfisher	Birds		
Mergus merganser	Common Merganser	Birds		
Mergus serrator	Red-breasted Merganser	Birds		
Numenius americanus	Long-billed Curlew	Birds		
Numenius phaeopus	Whimbrel	Birds		
Nycticorax	Black-crowned Night-Heron	Birds		
Oxyura jamaicensis	Ruddy Duck	Birds		
Pandion haliaetus		Birds		Watch list
Pelecanus erythrorhynchos	American White Pelican	Birds		Special Concern
Phalacrocorax auritus	Double-crested Cormorant	Birds		
Phalaropus tricolor	Wilson's Phalarope	Birds		
Plegadis chihi	White-faced Ibis	Birds		Watch list
Pluvialis squatarola	Black-bellied Plover	Birds		
Podiceps nigricollis	Eared Grebe	Birds		
Podilymbus podiceps	Pied-billed Grebe	Birds		
Porzana carolina	Sora	Birds		
Rallus limicola	Virginia Rail	Birds		
Recurvirostra americana	American Avocet	Birds		
Riparia	Bank Swallow	Birds		Threatened

Scientific Name	Common Name	Group	Federal Protection Status	State Protection Status
Setophaga petechia	Yellow Warbler	Birds		
Tachycineta bicolor	Tree Swallow	Birds		
Tringa melanoleuca	Greater Yellowlegs	Birds		
Tringa semipalmata	Willet	Birds		
Vireo bellii		Birds		
Vireo bellii pusillus		Birds	Endangered	Endangered
Xanthocephalus		Birds		Special Concern
Branchinecta lynchi	Vernal Pool Fairy Shrimp	Crustaceans	Threatened	Special
Lepidurus packardi	Vernal Pool Tadpole Shrimp	Crustaceans	Endangered	Special
Oncorhynchus mykiss - CV		Fishes	Threatened	Special
Oncorhynchus mykiss irideus		Fishes		
Pogonichthys macrolepidotus		Fishes		Special Concern
Actinemys marmorata	Western Pond Turtle	Herps		Special Concern
Ambystoma californiense	California Tiger Salamander	Herps	Threatened	Threatened
Anaxyrus boreas	Boreal Toad	Herps		
Pseudacris regilla	Northern Pacific Chorus Frog	Herps		
Rana boylii	Foothill Yellow-legged Frog	Herps	Under Review in the Candidate or Petition Process	Special Concern
Rana draytonii	California Red-legged Frog	Herps	Threatened	Special Concern
Spea hammondii	Western Spadefoot	Herps	Under Review in the Candidate or Petition Process	Special Concern
Thamnophis atratus		Herps		
Thamnophis elegans		Herps		
Thamnophis gigas	Giant Gartersnake	Herps	Threatened	Threatened
Thamnophis sirtalis	Common Gartersnake	Herps		
Capnia hitchcocki		Insects & other inverts		
Mesocapnia bulbosa		Insects & other inverts		
Paraleptophlebia associata		Insects & other inverts		
Castor canadensis	American Beaver	Mammals		
Lontra canadensis		Mammals		
Neovison vison	American Mink	Mammals		
Ondatra zibethicus	Common Muskrat	Mammals		
Anodonta californiensis	California Floater	Mollusks		Special
Margaritifera falcata	Western Pearlshell	Mollusks		Special
Pyrgulopsis diablensis		Mollusks		Special
Arundo donax		Plants		

Scientific Name	Common Name	Group	Federal Protection Status	State Protection Status
Baccharis salicina		Plants		
Cotula coronopifolia		Plants		
Eryngium castrense		Plants		
Eryngium spinosepalum		Plants		Special
Eryngium vaseyi vallicola		Plants		
Eryngium vaseyi		Plants		
Hydrocotyle verticillata		Plants		
Juncus xiphioides		Plants		
Ludwigia peploides		Plants		
Persicaria lapathifolia		Plants		
Persicaria maculosa		Plants		
Phacelia distans		Plants		
Pilularia americana		Plants		
Plantago elongata		Plants		
Potamogeton foliosus		Plants		
Puccinellia simplex	Little Alkali Grass	Plants		
Salix gooddingii		Plants		
Schoenoplectus acutus occidentalis		Plants		
Schoenoplectus americanus		Plants		
Typha domingensis		Plants		

5.3.8 Data Gaps

The Delta-Mendota Subbasin is an extensive subbasin covering a large area extending along the northwestern end of the San Joaquin Valley. While there is a significant amount of data available regarding various groundwater-related aspects of the Subbasin, much is still not known in multiple locations around the Northern and Central Delta-Mendota Regions. To this end, the following data gaps have been identified and will be addressed as part of the interim period between adoption of this GSP and its first 5-year update.

- Information regarding subsidence varies in extent around the region. While there is a large amount of land elevation survey data available in association with the DMC and other regional infrastructure, other areas in the Northern and Central Delta-Mendota Regions require additional data collection to both further establish and monitor future land subsidence rates.

- Only three shallow groundwater wells exist proximate to the San Joaquin River within the Northern and Central Delta-Mendota Regions, the primary interconnected surface water body in the Delta-Mendota Subbasin. Additional nested or clustered monitoring wells are required adjacent to the river to evaluate horizontal and vertical groundwater gradients, and in connection with river stage monitoring, an assessment of the interconnection between the San Joaquin River and the Delta-Mendota Subbasin.

- There are a large number of wells in the Northern and Central Delta-Mendota Regions where no construction information available. Video surveys and other surveys should be conducted to (1) identify where the wells are screened, and (2) determine if the well(s) are appropriate as additions to the Regions' groundwater monitoring programs.

- Mapping of GDEs in the Northern and Central Delta-Mendota Regions, as contained in this GSP, is an initial assessment of their location. This mapping needs to be refined using most recent groundwater elevation/depth to water contour mapping.

- Monitoring networks contained in this GSP are preliminary and were formulated based on existing well information. As additional wells are installed in the Subbasin and additional well construction information is obtained for existing wells, these networks will need to be refined to improve on the spatial (areal and vertical) distribution of monitoring points and the data collected for evaluation of conditions of the groundwater basin.

- In developing the water budgets contained herein, it was discovered that several of the California Irrigation Management Information System (CIMIS) stations available for use have questionable data. Additional CIMIS and/or other weather stations need to be established around the Subbasin, both to provide good quality data and to further refine the spatial variability of precipitation and evapotranspiration (ET) around the Subbasin.

- The sustainable yield estimates contained in this GSP for both the Upper and Lower Aquifers were developed using limited data. As additional data are collected over the first five years, improved sustainable yield estimates and estimates of water in storage in both principle aquifers should be prepared utilizing the new data.

- An updated DMC Conveyance Capacity Analysis should be conducted to provide data for refining the sustainability indicators for subsidence in the Northern and Central Delta-Mendota Regions.

5.4 WATER BUDGETS

This section describes the historic, current, and projected water budgets developed for the Northern and Central Delta-Mendota Regions as required by §354.18 of the Groundwater Sustainability Plan (GSP) Emergency Regulations. These water budgets provide an accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the Northern and Central Regions of the Delta-Mendota Subbasin under the respective conditions, and the change in volume of water stored. Specifically, the water budgets quantify the following:

- Total surface water entering and leaving the Plan area by water source type
- Inflow to the groundwater system by water source type
- Outflows from the groundwater system by water use sector
- The change in the annual volume of groundwater in storage between seasonal high conditions
- If overdraft conditions occur, a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions
- The water year type associated with the annual supply, demand, and change in groundwater stored
- An estimate of sustainable yield for the Delta-Mendota Subbasin

5.4.1 Useful Terms

A list and description of technical terms used throughout this section to discuss water budgets are included below. The terms and their descriptions are identified here to guide readers through this section and are not a definitive definition of each term.

- **Land Surface System -** The collective term for the land surface area above an aquifer and the interacting flows and into and out of that control volume.
- **Groundwater System -** The collective term for the groundwater aquifer and the interacting flows into and out of the groundwater aquifer(s).
- **Water Budget -** An accounting of water flows into and out of a defined area, which are tabulated as total volumes transmitted over a given time period.
- **Land Surface Budget -** An accounting of water flows into and out of the land surface above an aquifer within a defined area. Inflows and outflows include flow between adjacent land surface areas, the atmosphere, and the groundwater aquifer below.
- **Groundwater Budget -** An accounting of water flows into and out of the groundwater aquifer(s) within a defined area. Inflows and outflows include flow between adjacent aquifer areas and the above land surface.
- **Balance Error -** The difference between actual inflow and outflow equals actual change in storage (Inflow – Outflow – Change in Storage = 0). The difference between estimated inflow and estimated outflow does not equal estimated change in storage, where this difference is the balance error (Estimated Inflow – Estimated Outflow – Estimated Change in Storage = Balance Error).
- **Applied Water -** The collective name for water applied to the land surface, excluding precipitation.

- **ET_0 -** Crop Evapotranspiration (Crop-ET_0) is a value used for calculating reference and crop evapotranspiration from meteorological data and crop coefficients.

- **Water Losses -** The collective name for water leaving the land surface.

- **Water Year -** The annual period beginning October 1st of a specific year and ending September 30th of the subsequent year.

- **Historic Water Budget -** Water budget tabulating the flows into and out of the Northern & Central Delta-Mendota Region GSP Plan area during Water Years (WYs) 2003 through 2012, which is an accounting of annual observed flows and calculated flows.

- **Current Water Budget -** Water budget tabulating the flows into and out of the Northern & Central Delta-Mendota Region GSP Plan area during WY2013. This is an accounting of observed flows and calculated flows for the 'current year.'

- **Baseline Projected Water Budget -** Water budget tabulating predicted flows into and out of the Northern & Central Delta-Mendota Region GSP Plan area during WYs 2014 through 2070. This is an accounting of annual predicted flows based on the existing climate scenario, without the influence of additional projects or management actions for the purposes of the Sustainable Groundwater Management Act (SGMA) and for establishing changes in the system as a result of projected future land use and water use patterns.

- **Projected Water Budget with Climate Change (CC) -** Water budget tabulating predicted flows into and out of the Northern & Central Delta-Mendota Region GSP Plan area during the WYs 2014 through 2070 with the California Department of Water Resources' (DWR's) climate change factors (CCFs) applied to Subbasin hydrology. This is an accounting of annual predicted flows based on the climate change scenario, without the influence of additional projects or management actions for the purposes of SGMA and evaluating the impacts of CCF application to the water budget.

- **Projected Water Budget with Climate Change and Projects & Management Actions -** Water budget tabulating predicted flows into and out of the Northern & Central Delta-Mendota Region GSP Plan area during WYs 2014 through 2070. This is an accounting of annual predicted flows based on the climate change scenario with the additional influence of additional projects and management actions for the purposes of SGMA and evaluating the impacts of future projected conditions on the GSP region.

5.4.2 Water Budget Purpose and Information

Historic, current and projected water budgets were developed to provide a quantitative accounting of water entering and leaving the Northern and Central Delta-Mendota Regions over a specified period of time. Water entering the Plan area includes water entering at the surface and through the subsurface. Similarly, water leaving the Plan area leaves at the surface and through the subsurface. Water enters and leaves naturally, such as through precipitation and streamflow, and through human activities, such as pumping and recharge from irrigation. **Figure 5-120** presents a simplified vertical slice through the land surface and underlying aquifers of the Delta-Mendota Subbasin to summarize the water balance components used in the following analysis.

The values presented in the water budgets provide information about historic, current, and projected conditions as they relate to hydrology, water demand, water supply, land use, population, climate change, groundwater and surface water interaction, and subsurface groundwater flow. This information can assist in managing groundwater in the Plan area by identifying the scale of different uses, highlighting potential risks, and identifying potential opportunities to improve water supply conditions.

Water budgets can be developed on different spatial scales. For agricultural purposes, water budgets may be limited to the root zone in soil, improving irrigation techniques by estimating the inflows and outflows of water from the upper portion of the soil accessible to plants through their roots. In a strictly groundwater study, water budgets may be limited to water flow in the subsurface, helping analysts understand how water flows beneath the surface. In this section, consistent with the SGMA regulations, water budgets investigate the combined land surface and groundwater system in the Northern and Central Delta-Mendota Regions. The combined water budgets for the entire Delta-Mendota Subbasin are presented in the Delta-Mendota Subbasin Common Chapter.

Water budgets can be developed at various temporal scales. Daily water budgets may be used to demonstrate how evaporation and transpiration increase during the day and decrease at night. Monthly water budgets may be used to demonstrate how groundwater pumping increases in the dry, hot summer months and decreases in the cool, wet winter months. In this section, and consistent with SGMA regulations, the water budgets contained herein are annual, representing a full water year (i.e., the 12 months spanning from October of the previous year to September of the current year).

The SGMA regulations require that annual water budgets are based on three different periods: a ten-year historic period, the ‘current’ year, and a 50-year (minimum) projected period. The historic water budget is intended to evaluate availability and reliability of past surface water supply deliveries, aquifer response to water supply, and demand trends relative to water year type. The current water budget is intended to evaluate the effects of current land and water use on groundwater conditions, and to accurately estimate current inflows and outflows. The projected water budgets are used to estimate future conditions of supply, demand, and aquifer response to Plan implementation, and to identify the uncertainties of these projected water budget components.

Water budgets are developed to capture typical conditions during an identified time period. Typical conditions are developed by averaging over hydrologic conditions that incorporate droughts, wet periods, and normal periods. By incorporating these varied conditions in the water budgets, an analysis of the water system under certain hydrologic conditions, such as drought, can be performed along with and compared to an analysis of long-term average conditions.

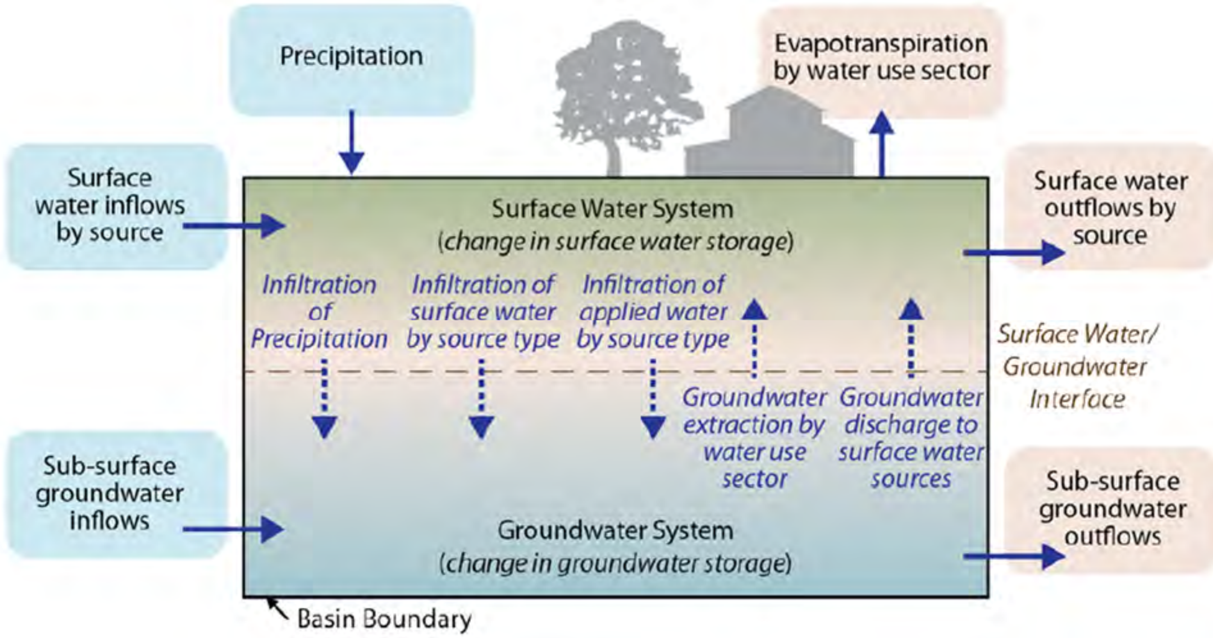

Figure 5-120. Generalized Water Budget Diagram

5.4.3 Key Coordinated Water Budget Decisions

The hydrologic time periods for the historic, current, and projected water budgets of the Delta-Mendota Subbasin were the recommendation of the Delta-Mendota Subbasin Technical Working Group (Technical Working Group), approved by the Delta-Mendota Subbasin Coordination Committee (Coordination Committee), and implemented by the Northern and Central Delta-Mendota Regions in their GSP-specific water budgets. This section documents those decisions, along with other key coordinated decisions agreed upon by all GSPs developed within the Delta-Mendota Subbasin, such as hydrologic period selection and application of climate change factors. A list of all common assumptions and decisions reached by the Delta-Mendota Subbasin GSP Groups may be found as an attachment to the Subbasin Coordination Agreement (**Appendix A**).

Historic Water Budget

The historic water budget period is defined as WY2003 through WY2012. The Coordination Committee determined that the WY2003-2012 timeframe captured a balance of wet and dry conditions largely prior to the most recent drought (**Figure 5-121**). The selected time period is also consistent with GSP Emergency Regulations §354.18(c)(2)(C), which requires "a quantitative assessment of the historic water budget, starting with the most recently available information and extending back a minimum of 10 years…," where WY2013 is defined as the year with the most recently available information.

Current Water Budget

The current water budget year is defined as WY2013. While "current water budget conditions" are defined in the GSP Emergency Regulations §354.18(c)(1) as the year with "the most recent population, land use, and hydrologic conditions," WY2015, WY2016 and WY2017 were not thought to be representative of the Delta-Mendota Subbasin under "normal" or "average" conditions. Response to the most recent drought began in WY2014 with some initial fallowing of lands. By WY2015 and WY2016, which are both classified as dry years, more lands were fallowed throughout the Subbasin in response to multiple dry year conditions. Agricultural production was higher in WY2017, compared to WY2015 and WY2016, but the delivery allocations from the Central Valley Project (CVP) came late in the season, so a considerable amount of land was still fallowed. By WY2018, agricultural land production increased and was similar to conditions in WY2013, however complete datasets were not yet available for use in the water budgets. Therefore, the Coordination Committee agreed that WY2013 represents the most recent water year with a complete data set representing typical demands and supplies.

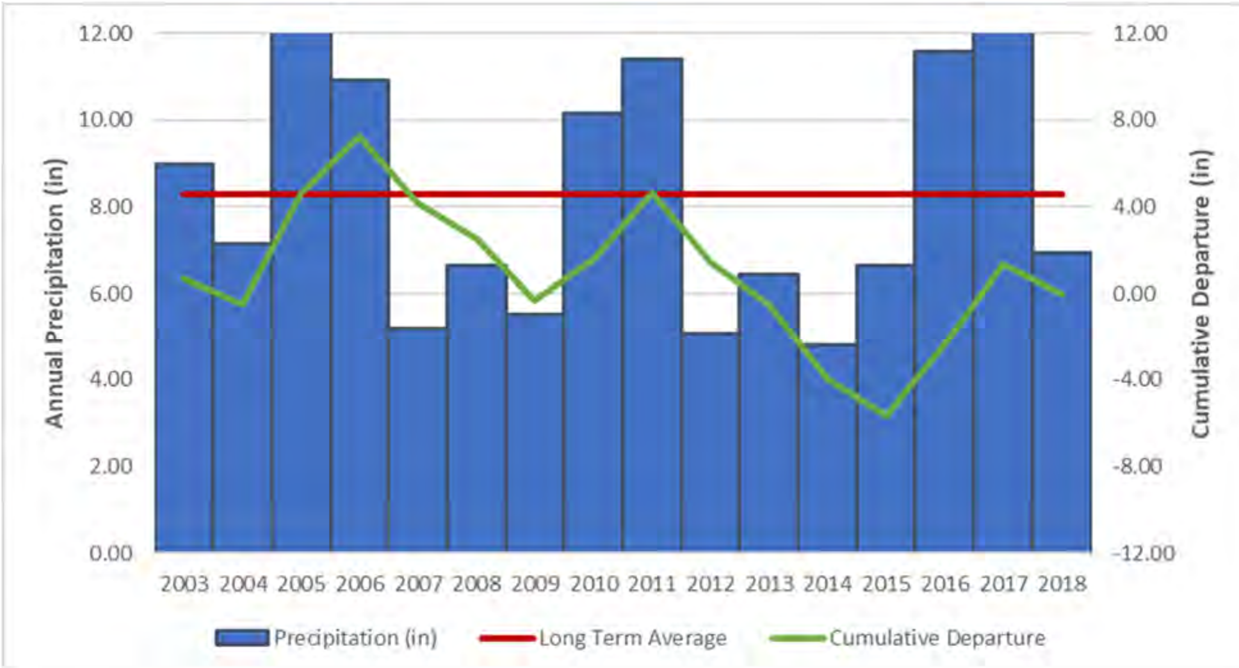

Figure 5-121. Precipitation and Cumulative Departure from Mean, WY2003-2018

Projected Water Budgets

The projected water budget period is defined as WY2014 through WY2070. According to the GSP Emergency Regulations §354.18(c)(3)(A), "projected hydrology shall utilize 50 years of historical precipitation, evapotranspiration, and streamflow information as the baseline condition for estimating future hydrology." The selected period for the projected water budgets meets this requirement by establishing a 50-year period, where the timeframe is continuous between the historic, current, and projected water budgets. Where available, actual data was incorporated for WY2014 through WY2018.

Based on discussion among the Technical Working Group members, the hydrologic period for simulating the projected water budget hydrologic schema was chosen as WY1979-2017, then wrapping around to include WY1965-1978 hydrology to fill the projected water budget period. Actual data and hydrology were used for WY2014 through WY2017, with the representative water years simulating WY2018 and beyond (e.g. WY2018 is represented by the hydrology from WY1979; WY2019 is represented by the hydrology from WY1980; and so forth).

Climate change data under 2030 and 2070 conditions was provided by DWR for use in development of the projected water budgets with climate change conditions (DWR, 2018b). These data, however, did not span the full projection period, with a gap in CCFs provided for WY2051 through WY2056. Per communications with DWR and in coordination with the Technical Working Group and Coordination Committee, hydrologic water years from the DWR dataset were selected for these years in order to identify the appropriate CCF. The methodology for applying DWR-provided climate change factors was agreed upon by the Technical Working Group. Climate change factors under 2030 conditions were applied to WY2018 through WY2045 and climate change factors under 2070 conditions were applied to WY2046 through WY2070. The precipitation and evapotranspiration datasets provided by DWR include monthly climate change factors from Calendar Year 1915 through 2011. The hydrologic years chosen to fill gaps in the CCF dataset for the precipitation and evapotranspiration climate change factors for representative WY2012 through WY2017 are shown in **Table 5-10**. These hydrologic years were selected to best approximate the water conditions of the representative water year.

Streamflow climate change factors from DWR were not applied within the Northern and Central Delta-Mendota Regions' projected water budgets as they were based on out-of-date modeling and, when applied, resulted in skewed results for future surface water deliveries that were not deemed to be reasonable. Agencies within the Northern and Central Delta-Mendota Regions instead provided projections by water year type for future surface water deliveries.

Table 5-10. Representative Water Years for Climate Change Factors, Precipitation, and Evapotranspiration

Simulated Projected Water Budget Year	Hydrologic Year	Proxy Water Year for Climate Change Factors
2051	2012	2001
2052	2013	1992
2053	2014	1976
2054	2015	1977
2055	2016	2002
2056	2017	2011

Other Common Decisions

The following water year type designations were agreed upon by all GSP Groups: Wet, Average, Dry, and Shasta Critical (**Table 5-11**). Wet and Dry water year designations are consistent with the San Joaquin River Index and "Average" combines the Above Normal and Below Normal designations from the San Joaquin River Index. Shasta Critical years are also designated upon the request of the San Joaquin River Exchange Contractors (SJREC), as it impacts surface water deliveries to exchange contracts through the CVP. Shasta Critical designations are dependent on the volume of storage in Shasta Reservoir and U.S. Bureau of Reclamation's operating rules for CVP deliveries.

Since there are no known barriers restricting horizontal gradients between GSP Groups, boundary flows to and from portions of the Delta-Mendota Subbasin adjacent to the Northern and Central Delta-Mendota Regions were coordinated with the GSP Groups preparing those water budgets and compared for consistency prior to the adoption of the historic and current water budgets. Representatives from the Northern and Central Delta-Mendota Regions met with the SJREC and Fresno County GSP Groups to compare boundary flow conditions.

Table 5-11. Modeled Water Year by Water Year Type

Modeled Year	Hydrologic Year	San Joaquin River Index Water Year Type	Delta-Mendota Subbasin Water Year Type	Modeled Year	Hydrologic Year	San Joaquin River Index Water Year Type	Delta-Mendota Subbasin Water Year Type
2003	2003	Below Normal	Average	2037	1998	Wet	Wet
2004	2004	Dry	Dry	2038	1999	Above Normal	Average
2005	2005	Wet	Wet	2039	2000	Above Normal	Average
2006	2006	Wet	Wet	2040	2001	Dry	Dry
2007	2007	Critical	Dry	2041	2002	Dry	Dry
2008	2008	Critical	Dry	2042	2003	Below Normal	Average
2009	2009	Below Normal	Average	2043	2004	Dry	Dry
2010	2010	Above Normal	Average	2044	2005	Wet	Wet
2011	2011	Wet	Wet	2045	2006	Wet	Wet
2012	2012	Dry	Dry	2046	2007	Critical	Dry
2013	2013	Critical	Dry	2047	2008	Critical	Dry
2014	2014	Critical	Shasta Critical	2048	2009	Below Normal	Average
2015	2015	Critical	Shasta Critical	2049	2010	Above Normal	Average
2016	2016	Dry	Dry	2050	2011	Wet	Wet
2017	2017	Wet	Wet	2051	2012	Dry	Dry
2018	1979	Above Normal	Average	2052	2013	Critical	Dry
2019	1980	Wet	Wet	2053	2014	Critical	Shasta Critical
2020	1981	Dry	Dry	2054	2015	Critical	Shasta Critical
2021	1982	Wet	Wet	2055	2016	Dry	Dry
2022	1983	Wet	Wet	2056	2017	Wet	Wet
2023	1984	Above Normal	Average	2057	1965	Wet	Wet
2024	1985	Dry	Dry	2058	1966	Below Normal	Average
2025	1986	Wet	Wet	2059	1967	Wet	Wet
2026	1987	Critical	Dry	2060	1968	Dry	Dry
2027	1988	Critical	Dry	2061	1969	Wet	Wet
2028	1989	Critical	Dry	2062	1970	Above Normal	Average
2029	1990	Critical	Dry	2063	1971	Below Normal	Average
2030	1991	Critical	Shasta Critical	2064	1972	Dry	Dry
2031	1992	Critical	Shasta Critical	2065	1973	Above Normal	Average
2032	1993	Wet	Wet	2066	1974	Wet	Wet
2033	1994	Critical	Dry	2067	1975	Wet	Wet
2034	1995	Wet	Wet	2068	1976	Critical	Dry
2035	1996	Wet	Wet	2069	1977	Critical	Dry
2036	1997	Wet	Wet	2070	1978	Wet	Wet

5.4.4 Methodology Selected and Spreadsheet Model Development

Groundwater Sustainability Agencies (GSAs) in the Northern and Central Delta-Mendota Regions initially planned to use the Central Valley Hydrologic Model 2 (CVHM2) to develop water budgets for their GSP regions. In recent years, local agencies within the Delta-Mendota Subbasin invested in a cooperative agreement with the U.S. Geological Survey (USGS) to refine CVHM2 and increase the amount of local data from the Subbasin incorporated in the model update. Funding and data were provided to USGS from local agencies for this effort. As of July 2019, CVHM2 remains under development by the USGS and therefore not available for use in developing the required water budgets.

A beta version of CVHM2 was released in April 2018 for use by the Northern and Central Delta-Mendota Regions, with a subsequent updated version provided in July 2018. An evaluation of the calibration status of the July 2018 version determined that this version of CVHM2 was not adequately calibrated to the Plan area and therefore would not produce reasonable and usable water budgets. Additional groundwater pumping, surface water delivery, and canal seepage data from local entities were provided to the USGS for further local calibration in July and August 2018. However, as previously noted, as of July 2019, USGS is still in the process of further calibrating CVHM2 within the Plan area. Due to differences in USGS's timeline for the release of CVHM2 and the timeline for this GSP, an alternative approach was selected for developing the required water budgets.

The selected alternative approach for water budget development for the Northern and Central Delta-Mendota Regions is a hybrid approach that combines the use of local data and CVHM2 parameters with standard numerical calculations derived from peer-reviewed literature or professional judgment. All water budgets presented herein are based primarily on local land use, water supply, and groundwater elevation data received from agencies as well as data from publicly available sources. Where local data are unavailable, data from CVHM2 is used. Groundwater gradient, underflow, and change in storage calculations are derived from available hydrograph data for the historic and current water budget time periods. Inputs related to approved projects and management actions were derived from other planning documents, such as Integrated Regional Water Management Plans, or from local agencies. For more detail regarding the spreadsheet model developed for the Northern and Central Delta-Mendota Regions, refer to **Appendix D** *Water Budgets Model Development Technical Memorandum*.

The spreadsheet model for the Northern and Central Delta-Mendota Regions was used to develop five water budget scenarios:

- **Historic water budget** represents land surface system and groundwater system conditions from WY2003 through WY2012.
- **Current water budget** represents land surface system and groundwater system conditions during WY2013.
- **Projected Baseline water budget** represents the simulated future condition of the land surface system and groundwater system from WY2014 through WY2070 under historic hydrologic conditions and water use patterns within the Plan area.
- **Projected water budget with Climate Change (CC)** represents the simulated future condition of the land surface system and groundwater system from WY2014 through WY2070 relative to the projected baseline water budget with the addition of the application of DWR's climate change factors.
- **Projected water budget with Climate Change (CC) and Projects & Management Actions (P&MAs)** represents simulated future condition of the land surface system and groundwater system from WY2014 through WY2070 relative to the projected baseline water budget with the addition of DWR's climate change factors as well as projects and management actions to achieve groundwater sustainability within the Plan area by 2040, as required by SGMA.