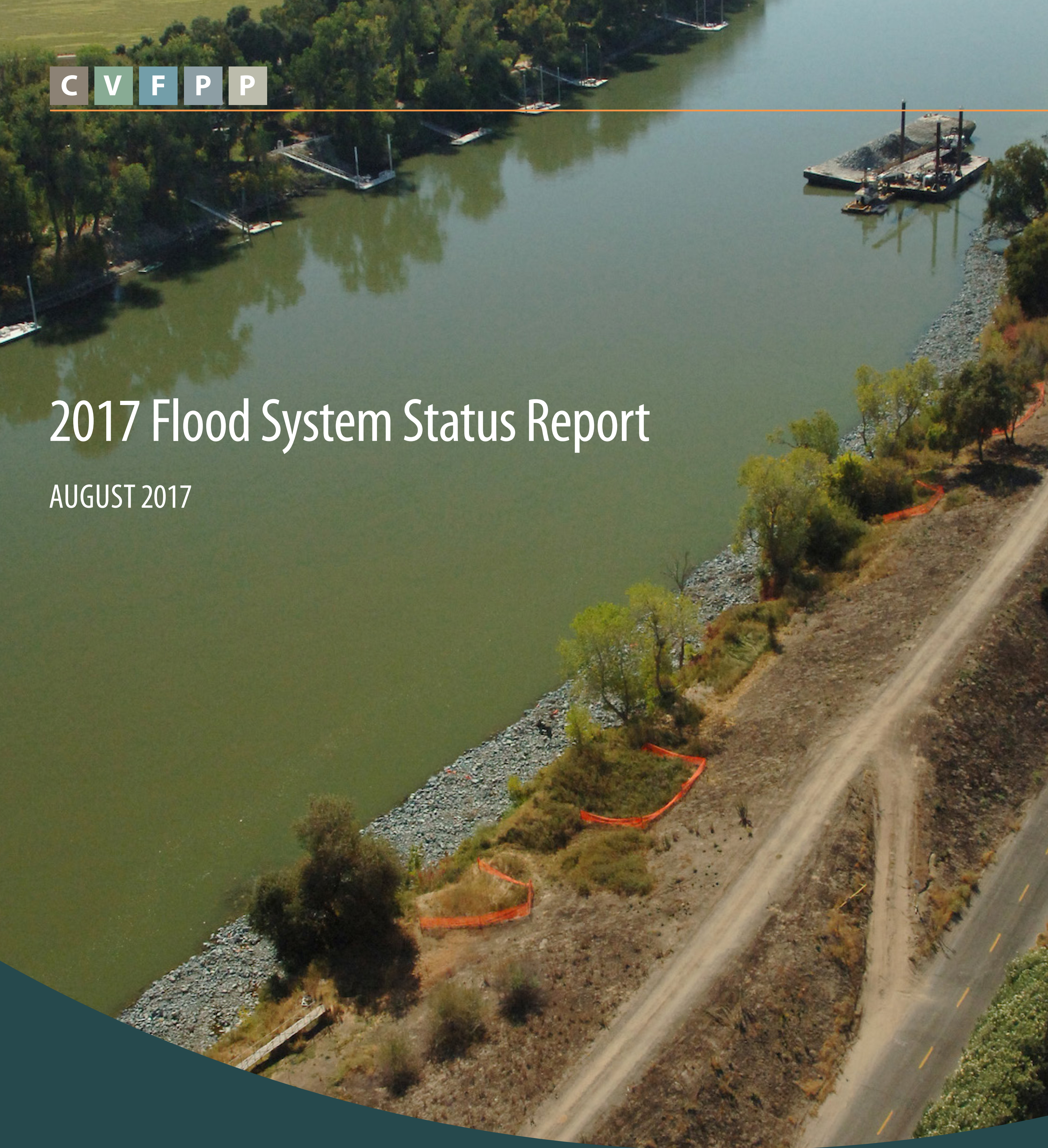
CVFPP



2017 Flood System Status Report

AUGUST 2017

CALIFORNIA DEPARTMENT OF WATER RESOURCES

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2017 Flood System Status Report

August 2017

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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Foreword

On behalf of the Department of Water Resources, we are pleased to present the 2017 Flood System Status Report (FSSR). This report is intended to assist flood management planners and engineers in characterizing facilities within the State Plan of Flood Control (SPFC) and to inform the 2017 Central Valley Flood Protection Plan Update (2017 CVFPP Update). The 2017 FSSR provides a concise repository of the status of SPFC Facilities as noted in related DWR evaluation and inspection efforts, along with the efforts of our local and federal partners. The 2012 CVFPP laid the foundation necessary for compliance with the Central Valley Flood Protection Act of 2008 and a new approach to flood management in the Central Valley.

As a supporting and informational document to the 2017 CVFPP Update, the 2017 FSSR includes information about inspecting and evaluating SPFC facilities. It also details and quantifies major components of existing flood risk within the Sacramento and San Joaquin river watersheds, and the factors that influence flood risk in relation to the various flood control structures within the SPFC. Additionally, the 2017 FSSR informs and details the current conditions of levees and channels within the SPFC, and includes finalized project information from DWR's Levee Evaluations Program. Through updating the status of SPFC facilities, the State of California can continue to make informed decisions related to flood risk management.

This document is a collaborative effort by DWR, local, and federal partners, signifying a step forward in gaining deeper understanding of the flood system's current status and condition in the Central Valley.

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Executive Summary

The Sacramento and San Joaquin river watersheds include an extensive flood management system comprising State of California (State)-federal project facilities and other facilities that are not part of the State-federal project. All State-federal project facilities in the Sacramento and San Joaquin river watersheds are part of the State Plan of Flood Control (SPFC), as defined in the State Plan of Flood Control Descriptive Document (Updated Version — August 2017*)* created by the California Department of Water Resources (DWR). SPFC facilities primarily include project levees, channels, and associated flood control structures in the Sacramento and San Joaquin river watersheds of California. SPFC facilities also include other elements identified in California Water Code Section 8361.

> **California Water Code Section 9120 (a) states:**
>
> "The department shall prepare and the board shall adopt a flood control system status report for the State Plan of Flood Control. This status report shall be updated periodically, as determined by the board. For the purpose of preparing the report, the department shall inspect the project levees and review available information to ascertain whether there are evident deficiencies.
>
> (b) The status report shall include identification and description of each facility, an estimate of the risk of levee failure, a discussion of the inspection and review undertaken pursuant to subdivision (a), and appropriate recommendations regarding the levees and future work activities."

Section 9651 of the California Water Code (CWC) defines the State Plan of Flood Control (SPFC) as follows:

> *"State Plan of Flood Control" means the state and federal flood control works, lands, programs, plans, policies, conditions, and mode of maintenance and operations of the Sacramento River Flood Control Project described in Section 8350, and of flood control projects in the Sacramento River and San Joaquin River watersheds authorized pursuant to Article 2 (commencing with Section 12648) of Chapter 2 of Part 6 of Division 6 for which the board or the department has provided the assurances of nonfederal cooperation to the United States, and those facilities identified in Section 8361.*

This 2017 Flood System Status Report (FSSR) describes the current status (i.e., the physical condition) of SPFC facilities at a systemwide level to support monitoring and tracking of metrics related to performance of the CVFPP over time. While the current list of metrics supports monitoring and tracking of plan performance related to the CVFPP primary goal of improving flood risk management, additional metrics may be developed and added for future updates (such as ecosystem metrics from the Conservation Strategy). DWR prepared this 2017 FSSR to meet the legislative requirements of California Water Code Section 9120, the Central Valley flood Protection Act of 2008, and to contribute to development of the Central Valley Flood Protection Plan (CVFPP). The CVFPP will guide future State investments through projects to address identified problems in the SPFC.

This 2017 FSSR primarily presents information about the physical condition of SPFC facilities, and will help guide future inspection, evaluation, reconstruction, and improvement of those facilities. Information in this 2017 FSSR should not be used to predict how a levee or associated facilities may perform during a specific flood event. In addition, more detailed information, such as additional geotechnical explorations and analyses at a greater frequency, may be necessary to meet other assessment purposes, such as determing whether a levee could be certified under Federal Emergency Management Agency (FEMA) standards to provide base flood protection under the National Flood Insurance Program.

Role of the Flood System Status Report

The 2017 FSSR contributes to development of the 2017 CVFPP Update in the following ways:

- Consolidates all available systemwide information from multiple DWR programs regarding SPFC physical conditions, and presents the information in a format that assists with facilitating future updates.
- Supports the collaboration of DWR and the Central Valley Flood Protection Board (Board) with State, federal, regional, and local agencies when:
  - Defining flood management system challenges and needs
  - Developing alternative solutions
  - Implementing future projects to address identified problems and improve the current condition of the flood management system

In addition to meeting legislative requirements and contributing to the 2017 CVFPP Update, information in this 2017 FSSR may be used to support the core functions and long-term activities of DWR's Division of Flood Management, including emergency response, facility maintenance, and inspections. Periodic updates to the FSSR will help DWR to track progress as ongoing inspections and evaluations are completed and more SPFC facilities are reconstructed or improved to meet current design criteria. Future updates have potential to support monitoring and tracking of additional metrics as they are developed over time (such as ecosystem metrics from the Conservation Strategy).

Need to Evaluate SPFC Status

SPFC facilities were built in increments over many decades, with many of its levees constructed by landowners and local entities after 1850 and through the early 1900s. These levees were constructed before the initial federally authorized project was established (i.e., the Sacramento River Flood Control Project). The United States Army Corps of Engineers (USACE) accepted some of these levees into the federal project without modification, improved some levees, and engineered new levees in other locations. Most levees included in what is now termed the SPFC in the Sacramento River watershed were accepted, improved, or constructed by USACE between

1918 and the mid-1960s. Most SPFC levees in the San Joaquin River watershed downstream from the Merced River confluence were improved as directed by USACE between the mid-1950s and early 1970s. In the San Joaquin River watershed upstream from the Merced River confluence, most SPFC levees were improved or constructed by DWR between the 1960s and early 1970s.

SPFC facilities now face many pressures that were not known or did not exist when they were originally constructed. Design criteria and construction methods have become more stringent over time as the understanding of geotechnical, hydrologic, and other technical aspects of flood management have improved. As a result, most facilities constructed in the early to mid-twentieth century do not meet current criteria. In some cases, facilities are now obsolete or have nearly exceeded their expected service lives, and are in need of major modification or repair. Further, facilities originally constructed primarily for navigation/sediment transport and flood management are now also recognized as important for water supply conveyance, ecosystem functions, recreation, and other beneficial uses.

Approach

To evaluate the condition of SPFC facilities, DWR considered a variety of factors that could influence the performance of SPFC levees, channels, and flood control structures. Information from DWR's inspection and evaluation activities are considered high-level indicators of a levee's physical conditions relative to specified standards. For some factors, DWR's approach may differ from an approach that USACE or other agencies might use for other evaluations or purposes. In these cases, the difference is acknowledged, although only DWR's approach is used as the basis for results presented in this 2017 FSSR.

The DWR Levee Evaluations Program, including its Urban Levee Evaluations Project (ULE) and Nonurban Levee Evaluations Project (NULE), is the primary source of information for evaluating the condition of SPFC levees. ULE and NULE both assessed the geotechnical condition of levees, but urban levees underwent a more comprehensive evaluation because of public safety considerations in densely populated areas. DWR concluded ULE and NULE evaluations in December 2015, and that information is incorporated into this 2017 FSSR.

Levee conditions reported in this 2017 FSSR also rely on information from DWR's annual inspections and other available data that supplement DWR Levee Evaluations Program results.

In general, channel conveyance conditions were determined by using the most recent available hydraulic modeling to evaluate whether the channels have the ability to pass design capacities presented in operations and maintenance (O&M) manuals and design profiles. Channel conditions reported also include DWR's annual inspections for vegetation and sedimentation. In addition, reported flood management structure conditions are based on DWR's annual inspections.

This 2017 FSSR reflects existing facility conditions (including past performance) at the time the 2017 FSSR was prepared, however, some results represent initial findings of ongoing evaluations. Many ongoing inspections, geotechnical evaluations, and hydraulic evaluations will yield additional information on facility conditions. In addition, subsequent facility improvements, repairs, and reconstruction are likely to affect facility conditions reported in this 2017 FSSR. Where applicable, any changes in findings will be reflected in future updates to the FSSR.

Findings

The flood management system has provided tremendous benefits to public safety and protection of property in the Central Valley; it has prevented loss of life and many billions of dollars in flood damages since facilities were originally constructed. However, when evaluated against modern engineering and safety criteria, some SPFC facilities face a higher chance of failure during a flood event than other facilities. Table ES-1 lists factors that influence facility performance, findings related to each factor, and the relative threat posed by the factor.

The relative threat posed by each factor is a subjective representation of the prevalence of the factor and how much the presence of that factor would contribute to a potential facility failure. Factors identified as a “high” relative threat to SPFC facilities generally are the most prevalent and/or greatly contribute to potential facility failure. Those identified as a “low” relative threat to SPFC facilities generally are the least prevalent and/or contribute less to potential facility failure. Likewise, factors identified as a "medium" relative threat to SPFC facilities are moderately prevalent and/or contribute moderately to potential facility failure. As such, the relative threat posed by each factor is subjective in nature and serves only to help identify and prioritize the factors most likely to contribute to SPFC facility failures. Prioritizing relative threats affecting SPFC facilities does not necessarily translate directly into investment priorities. To decide which levels of investment are prudent for repairs or improvements, economic and life safety, and environmental compliance, consequences associated with potential failure must also be considered. The potential consequences of facility failure are not considered in this 2017 FSSR, but are evaluated in the 2017 CVFPP Update.

Table ES-1. Summary of 2017 Flood System Status Report Findings

	Factors	Findings	Relative Threat Posed by Factor[1]
Levees	**Overall Levee Condition (multiple factors)**	• Approximately half of SPFC urban levees do not meet current levee freeboard, stability, or seepage design criteria at the design water surface elevation. • Approximately three-fifths of SPFC nonurban levees have a high potential for levee failure from underseepage, through seepage, structural instability, and/or erosion at the assessment water surface elevation.	See Figure ES-1
	Levee Geometry Check	• Approximately one-third of SPFC urban levees deviate from current standard levee design prism criteria. • Levee geometry deviates significantly from the standard levee design prism criteria for some nonurban SPFC levees.	Medium
	Seepage	• Approximately one-third of SPFC urban levees do not meet current seepage design criteria. • Almost half of SPFC nonurban levees have a high potential for levee failure from underseepage. • Approximately one-quarter of SPFC nonurban levees have a high potential for levee failure from through seepage.	High
	Structural Instability	• Approximately one-fifth of SPFC urban levees do not meet current structural stability design criteria. • Approximately one-eighth of SPFC nonurban levees evaluated in the Sacramento River watershed and 1 percent in the San Joaquin River watershed have a high potential for levee failure from structural instability.	Medium
	Erosion	• Erosion assessments for urban levees are underway, and results are not available at this time. • Almost one-seventh of SPFC nonurban levees have a high potential for levee failure from erosion.	Medium
	Settlement	• Four known localized levee locations have settlement (localized depressions) that endangers the integrity of SPFC levees. [5]	Low
	Penetrations[2]	• More than 7,000 penetrations are documented in SPFC levees, and many more remain undocumented.	Medium
	Levee Vegetation	• About 309 miles of SPFC levees comply with the 2012 Board Vegetation Management Strategy criteria.[3,5]	Low
	Rodent Damage	• More than one-third of the 1,459 miles of SPFC levees studied had at least eight reported occurrences of burrowing activity over a 21-year study span.	Medium
	Encroachments[4]	• Approximately 1,730 encroachment sites were identified as either Minimally Acceptable or Unacceptable.	Medium

Table ES-1. Summary of 2017 Flood System Status Report Findings

	Factors	Findings	Relative Threat Posed by Factor[1]
Channels	**Inadequate Conveyance Capacity**	• Approximately half of the 1,016 miles of SPFC channels evaluated are potentially inadequate to convey design flows, and require additional evaluation to confirm conditions. • Approximately one-quarter of channel design capacities reported in O&M manuals do not agree with flows specified in the design profiles.	Medium
	Channel Vegetation	• Of the 233 miles of SPFC channels inspected by DWR, 13 locations were rated as Unacceptable and 56 locations were rated Minimally Acceptable because of vegetation and obstructions.	Low
	Channel Sedimentation	• Of 233 miles of SPFC channels inspected by DWR, eight locations were rated Unacceptable and 26 locations were rated Minimally Acceptable because of shoaling/sedimentation.[5]	Low
Structures	**Inadequate Hydraulic Structures**	• Of 51 SPFC hydraulic structures inspected by DWR, none were rated as Unacceptable and six were rated as Minimally Acceptable.[5]	Low
	Inadequate Pumping Plants	• Of 13 SPFC pumping plants inspected by DWR, none were rated Unacceptable and only one was rated Minimally Acceptable.[5]	Low
	Inadequate Bridges	• Of 11 SPFC bridges inspected by DWR, two were in need of repair.[5]	Low

Notes:

1 The relative threats listed in Table ES-1 were generated based on professional experience of technical staff from DWR and partner agencies.

2 Penetrations include man-made objects that cross through or under a levee or floodwall and have the potential to provide a preferential seepage path or hydraulic connection with the waterside. Typically, a penetration is a pipe or transportation structure, such as a roadway or rail line.

3 This finding is based on 2012 Board Vegetation Management Strategy criteria and not on USACE levee vegetation criteria. Comparison with USACE levee vegetation criteria would show that more SPFC levees do not comply.

4 Encroachments are any obstruction or physical intrusion by construction of works or devices, planting or removal of vegetation, or caused by any other means, for any purpose, into a flood control project, waterway area of the flood control project, or area covered by an adopted plan of flood control per Title 23 of the California Code of Regulations, Chapter 1, Article 2, Section 4 (m). Encroachments include boat docks, ramps, bridges, sand and gravel mining, placement of fill, fences, retaining walls, pump stations, residential structures, and irrigation and landscaping materials/facilities.

5 Inspection results reported are from DWR's 2015 inspections.

Key:
DWR = California Department of Water Resources
O&M = operations and maintenance
SPFC = State Plan of Flood Control
USACE = United States Army Corps of Engineers

The overall condition of urban levees, nonurban levees, channels, and flood control structures of the SPFC can be summarized as follows:

- **Urban levees** – Approximately over half (185 miles) of the SPFC urban levees evaluated (320 miles) do not meet current levee freeboard, stability, or seepage design criteria at the design water surface elevation. Of the approximate 110 miles of Non-SPFC Urban levees evaluated, roughly half (50 miles) do not meet current levee freeboard, stability, or seepage design criteria at the design water surface elevation. Design criteria are based on USACE's Engineer Manual (EM) 1110-2-1913, Design and Construction of Levees (USACE, 2000) and DWR's Urban Levee Design Criteria (ULDC) (DWR, 2012a).

- **Nonurban levees** – Approximately 597 miles of about 1,100 miles of SPFC nonurban levees evaluated do not meet acceptable criteria for underseepage, through seepage, structural instability, and/or erosion at the assessment water surface elevation. Of the 187 miles of non-SPFC, nonurban levees, approximately 70 miles do not meet acceptable criteria for underseepage, through seepage, structural instability, and/or erosion at the assessment water surface elevation. Where available, the 1955/57 design water surface elevations were used as the assessment water surface elevation. In the absence of 1955/57 design water surface elevations, the assessment water surface elevation was based on freeboard requirements for each levee segment (i.e., generally 3 feet below the levee crown).

  Nonurban levees were evaluated based on systematic, consistent, repeatable analyses that correlated geotechnical data with levee performance history, not relative to any current design criteria. This approach was selected because the NULE study area was significantly greater than the ULE study area, making it difficult to conduct the same level of field explorations and collect similar amounts of geotechnical data.

- **SPFC channels** – Approximately half of the 1,025 miles of channels evaluated in the SPFC have a potentially inadequate capacity to convey design flows, and require additional evaluation to confirm conditions.

- **SPFC flood control structures** – None of the 32 hydraulic structures or 11 pumping plants inspected by DWR for the SPFC were rated Unacceptable during the 2009 inspections. Of the 10 SPFC bridges inspected by DWR in 2009, two were in need of repairs.

The findings in Table ES-1 are relative to DWR's current criteria for use in the CVFPP. In most cases, these criteria are identical, or similar to, USACE criteria. However, differences between DWR and USACE levee vegetation criteria are significant enough that comparison of levees with USACE criteria would likely show more SPFC levees do not comply with current USACE criteria.

Figure ES-1 shows the overall physical condition of SPFC levees considering most of the levee factors in Table ES-1. To simplify representation of levee conditions, Figure ES-1 includes ULE and NULE assessment results that are not directly comparable, because different evaluation methodologies were used for ULE and NULE. Figure ES-1 broadly illustrates which levee reaches are of relatively higher, medium, or lower concern based on the levee's physical condition. Levees shown in purple (higher concern) on Figure ES-1 generally display more performance problems than those shown in green (lower concern). These assessment results do not reflect life safety, economic, or environmental consequences of flooding, which are key factors in planning system repairs and improvements. Potential life safety and economic consequences associated with flooding are evaluated as part of the CVFPP.

To adequately address current and increasing future demands on the SPFC, significant and sustained actions are needed to improve the performance level of existing SPFC facilities. This will include continued efforts at the State, federal, regional, and local levels to assess and evaluate programs and policies affecting the SPFC and conditions of non-SPFC facilities that affect performance of the flood system. Implementing appropriate management actions in a systemwide approach to improve identified problems properly, and to improve flood management throughout the Sacramento and San Joaquin river watersheds, will take many years with incremental improvements occurring over time. It is important to recognize that improvements to the SPFC will be costly and require the active involvement of State, federal, regional, and local interests. Significant amounts of funding will be needed for future project planning, development, implementation by USACE and the State, and for more sustainable long-term O&M.

Local communities, both urban and nonurban, will require significant financial and technical assistance from the State and federal governments over the next 25 to 30 years to implement the CVFPP. FSSR findings provide important information for the CVFPP as part of an iterative approach to monitoring and tracking flood system conditions over time and for informing flood management actions.

Recommendations

Key 2017 FSSR recommendations regarding future DWR work include the following:

- Pursue Board adoption of 2017 FSSR findings, as required by California Water Code Section 9120, and support the Board in communicating 2017 FSSR recommendations to the California Legislature.
- Update the FSSR periodically per California Water Code Section 9120(a), and as requested by the Board following possible adoption of the 2017 CVFPP Update, by incorporating updated results of inspections, evaluations, and special studies into the FSSR.
- Continue to work with State, federal, regional, and local agencies to create a broadly supported CVFPP to guide long-term investments related to the SPFC over the next several decades.
- Recognize that the public expects the flood system to provide other important functions, such as water supply conveyance, ecosystem support, recreational use, and other beneficial uses.
- Build on and improve existing partnerships with federal, regional, and local agencies to develop site-specific actions for the SPFC that are consistent with the integrated, systemwide approach developed in the CVFPP.

- Continue to partner with agencies, and form new partnerships to conduct special studies to improve understanding of the various factors that present threats to SPFC facilities. These studies include continued efforts to research the impacts of levee vegetation, assess locations and importance of levee penetrations, characterize the probability of levee failure, and other technical studies.

- Proceed with multiagency work efforts to further evaluate facility status, identify needed flood system repairs and improvements, and implement them, as State, federal, and local funding becomes available.

- Continue to improve data sharing and accessibility of annual inspection results for partner agencies and the public.

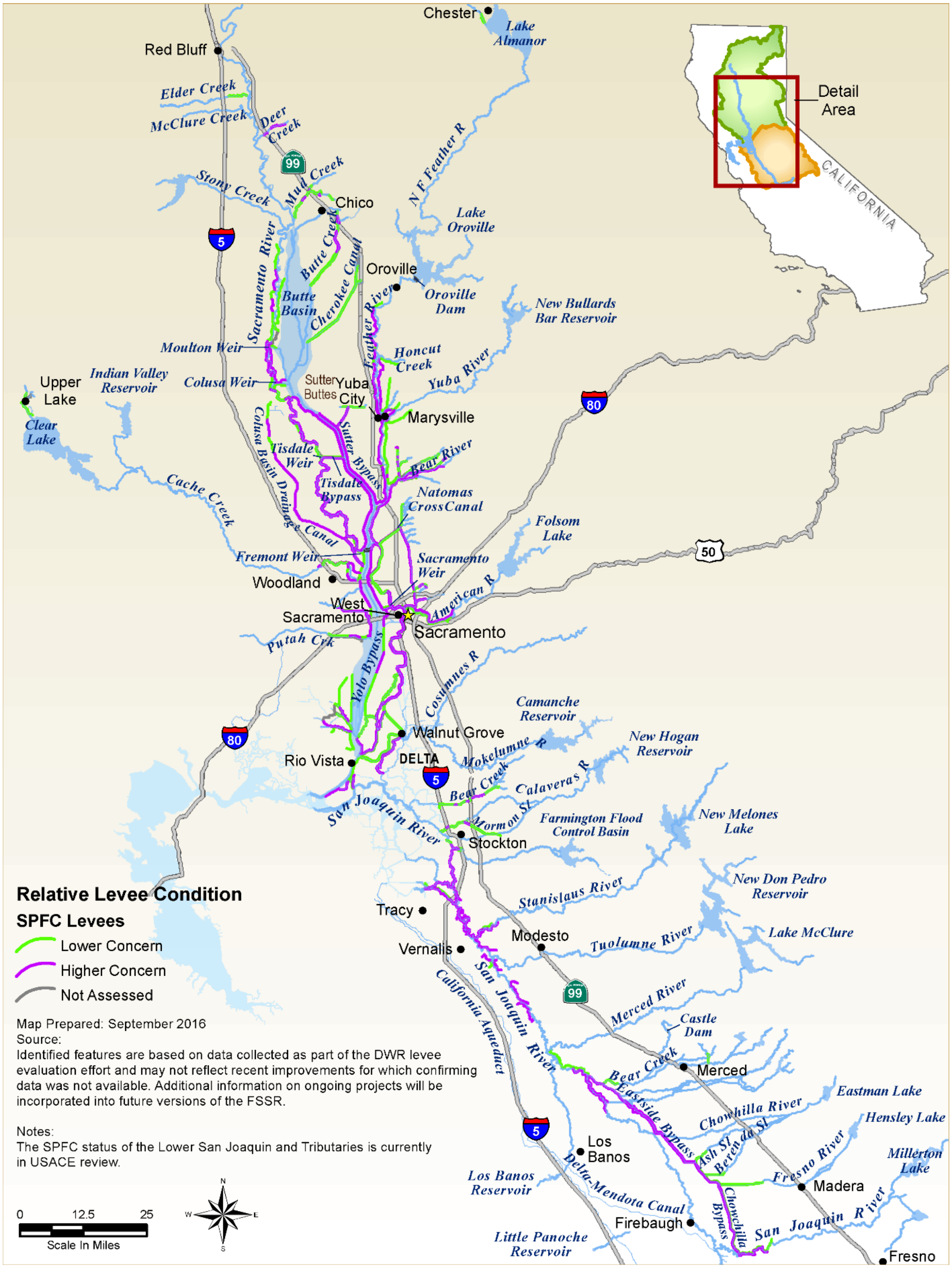

Figure ES-1. Composite Map of Physical Levee Conditions Based on ULE and NULE Results

1.0 Introduction

The Sacramento and San Joaquin river watersheds include an extensive flood management system comprising State of California (State)-federal project facilities and other facilities that are not part of the State-federal project. All State-federal project facilities in the Sacramento and San Joaquin river watersheds are part of the State Plan of Flood Control (SPFC), as defined in the State Plan of Flood Control Descriptive Document (DWR, 2010a). SPFC facilities primarily include project levees, channels, and associated structures in the Sacramento and San Joaquin river watersheds of California.[1]

This 2017 Flood System Status Report (FSSR) describes the current status (i.e., physical condition) of SPFC facilities at a systemwide level. The California Department of Water Resources (DWR) prepared this 2017 FSSR to meet the legislative requirements of California Water Code Section 9120, and to contribute to development of the Central Valley Flood Protection Plan (CVFPP).

This 2017 FSSR is primarily intended to present information about the physical condition of SPFC facilities, and to help guide future inspection, evaluation, reconstruction, and improvement of the facilities.

1.1 Limitations

Information presented in this 2017 FSSR should not be used to predict how a levee or associated facilities may perform during a specific flood event. For example, more detailed information (such as additional geotechnical explorations and analyses at a greater frequency) would be necessary to assess whether a levee could be certified under Federal Emergency Management Agency (FEMA) standards to provide base flood protection under the National Flood Insurance Program.

1.2 Report Purpose and Scope

In 2007, the California State Legislature directed DWR to prepare a FSSR for the SPFC according to Section 9120 of the California Water Code, which states the following:

> *§9120. (a) The department shall prepare and the board shall adopt a Flood Control System Status Report for the State Plan of Flood Control. This status report shall be updated periodically, as determined by the board. For the purpose of preparing the report, the department shall inspect the project levees and review available information to ascertain whether there are evident deficiencies.*

[1] State Plan of Flood Control facilities also include other elements identified in California Water Code Section 8361.

(b) The status report shall include identification and description of each facility, an estimate of the risk of levee failure, a discussion of the inspection and review undertaken pursuant to subdivision (a), and appropriate recommendations regarding the levees and future work activities.

California Water Code Section 9651 defines the SPFC as follows:

"State Plan of Flood Control" means the state and federal flood control works, lands, programs, plans, policies, conditions, and mode of maintenance and operations of the Sacramento River Flood Control Project described in Section 8350, and of flood control projects in the Sacramento River and San Joaquin River watersheds authorized pursuant to Article 2 (commencing with Section 12648) of Chapter 2 of Part 6 of Division 6 for which the board or the department has provided the assurances of nonfederal cooperation to the United States, and those facilities identified in Section 8361.

The purpose of this 2017 FSSR is to comply with California Water Code Section 9120 and contribute to 2017 CVFPP Update development along with the other supporting efforts. In 2012, DWR fulfilled California Water Code requirements through preparation of two foundational, base condition documents, including the Flood Control System Status Report (FCSSR):

- ***State Plan of Flood Control Descriptive Document*** – The SPFC Descriptive Document (DWR, 2010a) identifies and describes each component of the SPFC (facilities, lands, programs, plans, conditions, modes of operations and maintenance (O&M)). This report fulfills part of the legislative requirement expressed in California Water Code Section 9120 (a) and (b).

- ***Flood Control System Status Report (FCSSR)*** – The FCSSR (DWR, 2011c) described and analyzed the SPFC, and made recommendations regarding SPFC levees and future work activities.

Key documents are shown in Figure 1-1.

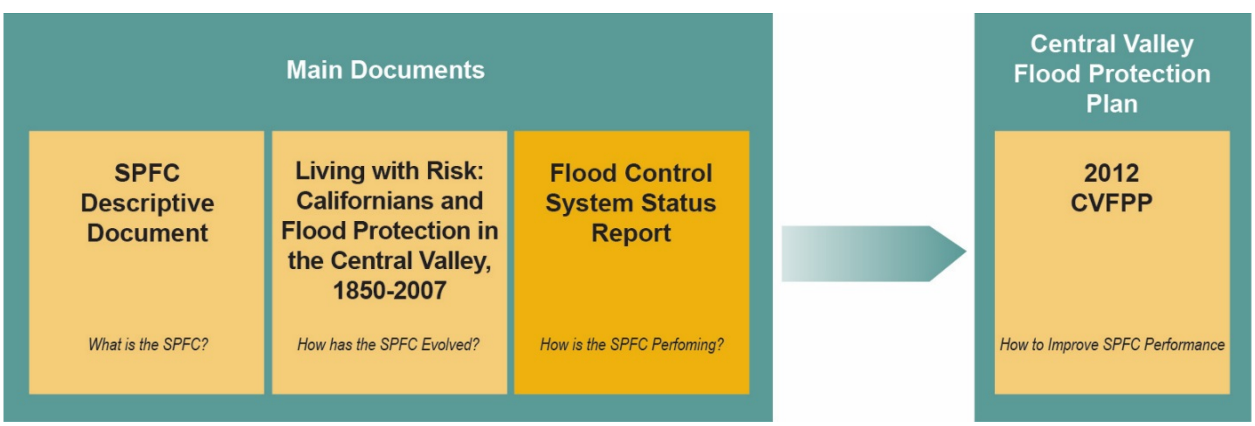

Figure 1-1. Main Documents for the 2012 CVFPP

This 2017 FSSR specifically contributes to development of the 2017 CVFPP Update through the following:

- Consolidates all available systemwide information from multiple DWR programs regarding SPFC physical conditions, and presents the information in a format suitable to facilitate continued future updates.
- Supports the collaboration of DWR and the Central Valley Flood Protection Board (Board) with State, federal, regional, and local agencies in defining flood management system problems and needs, developing alternative solutions, and implementing future projects to address identified problems and improve the current condition of the flood management system.

In addition to meeting legislative requirements and contributing to the CVFPP, information in the FSSR may be used to support core functions and long-term activities of DWR's Division of Flood Management, including emergency response, facility maintenance, and inspections. Periodic updates of the FSSR will enable DWR to track progress as ongoing inspections and evaluations are completed and more SPFC facilities are reconstructed or improved to meet current design criteria.

The scope of this 2017 FSSR is to use available information to describe the physical condition of SPFC levees, channels, and structures in the Sacramento and San Joaquin river watersheds (Figure 1-1) at a systemwide level. Information presented in this report should be viewed as the best indication of facility condition for major reaches (many miles) of SPFC facilities rather than to identify individual problems at specific SPFC facility locations.

The SPFC is only a portion of the larger system that provides flood protection for the Central Valley. The performance of SPFC facilities relies on many non-SPFC facilities constructed by the United States Army Corps of Engineers (USACE), DWR, the United States Department of the Interior, the Bureau of Reclamation, and local agencies along many of the rivers, creeks, and streams in the Central Valley. Major non-SPFC facilities that affect the performance of SPFC facilities (or provide flood risk reduction benefits to areas protected by SPFC levees) include levees that are not part of the federal project (i.e., nonproject levees), modifications and alterations to SPFC levees that have not been State-authorized, debris management facilities (such as the Yuba Goldfields), and most of the reservoirs in the Central Valley.

This 2017 FSSR reflects existing facility conditions (including past performance) at the time it was prepared, and some results represent initial findings of ongoing evaluations. Many ongoing inspections, geotechnical evaluations, and hydraulic evaluations will yield additional information on facility conditions. In addition, subsequent facility improvements, repairs, and reconstruction would likely affect facility conditions reported in this 2017 FSSR. Where applicable, any changes in findings will be reflected in future updates to this 2017 FSSR.

For some factors, DWR's approach may differ from an approach that USACE or other agencies would use for other evaluations or purposes. In these cases, the difference is acknowledged, although only DWR's approach is used as the basis for the results presented.

Figure 1-2. Sacramento and San Joaquin River Watersheds for the State Plan of Flood Control

1.3 Need to Evaluate Status

SPFC facilities were built in increments over many decades, with many levees constructed by landowners and local entities after 1850 and through the early 1900s, before the initial federally authorized (Sacramento River Flood Control Project [project]) was established. USACE accepted some of these levees into the federal project without modification, improved some levees, and engineered new levees in other locations. Most levees included in what is now termed the SPFC in the Sacramento River watershed were accepted, improved, or constructed by USACE between 1918 and the mid-1960s. Most SPFC levees in the San Joaquin River watershed downstream from the Merced River confluence were improved as directed by USACE between the mid-1950s and early 1970s. In the San Joaquin River watershed upstream from the Merced River confluence, most SPFC levees were improved or constructed by DWR between the 1960s and early 1970s.

SPFC facilities now face many pressures that were not known or did not exist when the facilities were originally constructed. Design criteria and construction methods have become more stringent over time as understanding of geotechnical, hydrologic, and other technical aspects of flood management have improved. As a result, most facilities constructed in the early to mid-twentieth century were not designed or constructed to meet current criteria. In some cases, facilities are now obsolete or have nearly exceeded their expected service lives, and are in need of major modification or repair. Further, facilities originally constructed primarily for navigation/sediment transport and flood management are now also recognized as important for water supply conveyance, ecosystem functions, recreation, and other beneficial uses.

1.4 Report Overview

This 2017 FSSR describes inspection and evaluation activities related to the SPFC, and information on the physical condition of SPFC levees, channels, and flood control structures. It also includes basic findings and recommendations regarding SPFC levees and future work activities. All map-based data presented are in geographic information system (GIS) format. Data and other information collected and evaluated from a multitude of inspection and evaluation activities are used as a basis for summarizing physical conditions with respect to SPFC facilities. The 2017 FSSR contains the following sections:

- **Section 1.0 (Introduction)** provides background information, including the purpose and scope of the FSSR, overview of documents complementary to the FSSR, the need to evaluate the status of SPFC facilities, and this report overview.

- **Section 2.0 (Inspection and Evaluation Activities Related to SPFC Status)** describes annual inspection and reporting done by DWR, periodic inspections by USACE, and joint USACE-DWR inspections. Section 2.0 also describes in detail DWR evaluation activities underway to evaluate geotechnical and hydraulic conditions, and presents an overview of USACE evaluations. Data collected and evaluated through many of these activities are used as the basis for SPFC conditions summarized in Sections 3.0 through 6.0.

- **Section 3.0 (Flood Risk in Sacramento and San Joaquin River Watersheds)** presents a brief overview of flood risk, and factors that influence flood risk. This section includes an evaluation of geotechnical hazard[2] as it relates to the risk of levee failure. Geotechnical hazard information is based on analysis from the Urban Levee Evaluation Project (ULE) and Nonurban Levee Evaluation Project (NULE) of DWR's Levee Evaluations Program. Geotechnical hazard is assessed considering geotechnical factors for levee performance.

- **Section 4.0 (Levee Status)** presents SPFC levee conditions based on data from inspections and evaluations described in Section 2.0, and is organized according to the following subsections, with each subsection including a discussion of status evaluation methodology, limitations, and results of the status evaluations:

  - **Levee geometry check**, with conditions summarized from results of a levee geometry check conducted by the DWR Levee Evaluations Program that compares existing levee geometry to a standard levee design prism.

  - **Seepage**, with conditions summarized from results of the DWR Levee Evaluations Program. ULE evaluated compliance with current seepage design criteria for urban levees, and NULE evaluated potential for levee failure from underseepage and through seepage.

  - **Structural instability**, with conditions summarized from results of the DWR Levee Evaluations Program. ULE evaluated compliance with current structural stability design criteria for urban levees, and NULE evaluated potential for levee failure from structural instability.

  - **Erosion**, with conditions summarized from results of the DWR Levee Evaluations Program. ULE erosion assessment is under development. NULE evaluated the potential for levee failure from erosion.

  - **Settlement**, with conditions summarized from results of DWR's 2015 annual inspections for crown surface/depressions/rutting.

  - **Penetrations,**[3] with conditions summarized from locations of penetrations through levees throughout the SPFC, cataloged by the DWR Levee Evaluations Program.

  - **Levee vegetation**, with conditions summarized from results of DWR's 2015 annual inspections for vegetation on earthen levees based on DWR's 2012 Central Valley Flood Protection Plan Levee Vegetation Management Strategy (DWR, 2012b).

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[2] As reported in the FSSR, "hazard" refers specifically to geotechnical hazard when discussed in relation to the assessments performed under ULE and NULE.

[3] Penetrations include man-made objects that cross through or under a levee or floodwall and have the potential to provide a preferential seepage path or hydraulic connection with the waterside. Typically, a penetration is a pipe or transportation structure, such as a roadway or rail line.

- **Rodent damage**, with conditions summarized from results of a 2015 DWR assessment of animal burrow persistence on SPFC levees using inspection data from 1984 through 2008.
- **Encroachments,**[4] with conditions summarized from results of DWR's 2015 annual inspections for encroachments.

- **Section 5.0 (Channel Status).** Channel conditions are presented in Section 5.0. The section presents SPFC channel conditions based on data from inspections and evaluations described in Section 2.0, and is organized according to the following subsections:
  - **Channel conveyance capacity**, with conditions summarized from a comparison of design and estimated flood flow capacities for each SPFC channel. Existing capacities are estimated through systemwide modeling as documented in c Information is also presented to show where design capacities in USACE O&M manuals are inconsistent with design profiles (e.g., 1955, 1957, 1965) (USACE, 1955a; USACE, 1957a; USACE, 1957b; and USACE, 1965).
  - **Channel vegetation**, with conditions summarized from results of DWR's 2015 annual inspections for channel vegetation.
  - **Channel sedimentation**, with conditions summarized from results of DWR's 2015 annual inspections for channel shoaling and sedimentation.
- **Section 6.0 (Flood Control Structures Status)** presents SPFC flood control structure conditions based on data from DWR inspection activities described in Section 2.0. The section is organized according to the following subsections:
  - **Hydraulic structures** (dams, weirs, drop structures, control structures, drainage structures, and outfall gates), with structural, vegetation, encroachment, and erosion/bank caving and shoaling/sedimentation conditions summarized from DWR's 2015 annual inspections for hydraulic structures.
  - **Pumping plants**, with conditions summarized from DWR's 2015 annual inspections for pumping plants.
  - **Bridges,** with conditions summarized from DWR's 2015 annual bridge inspections.
- **Section 7.0 (Approach for SPFC Improvements)** describes the approach and work organization for improving existing conditions of SPFC facilities, including development of the CVFPP.

[4] Encroachments are any obstruction or physical intrusion by construction of works or devices, planting or removal of vegetation, or caused by any other means, for any purpose, into a flood control project, waterway area of the flood control project, or area covered by an adopted plan of flood control (California Code of Regulations Title 23 Chapter 1 Article 2 Section 4 (m)). Encroachments include boat docks, ramps, bridges, sand and gravel mining, placement of fill, fences, retaining walls, pump stations, residential structures, and irrigation and landscaping materials/facilities.

- **Section 8.0 (Findings and Recommendations)** presents findings from the information presented in Sections 3.0 through 6.0, and provides recommendations specific to levees and future work activities.

- **Section 9.0 (References)** lists the sources used to prepare this 2017 FSSR.

- **Section 10.0 (Acronyms and Abbreviations)** lists acronyms and abbreviations used in this 2017 FSSR.

Appendixes to the main report include the following:

- **Appendix A (Levee Status)** provides supplemental information related to levee conditions described in Section 4.0, including USACE periodic inspection results; historical data; recent, ongoing, and planned improvements and projects; and ongoing actions to improve future evaluations.

- **Appendix B (Channel Status)** provides supplemental information related to channel conditions described in Section 5.0, including a tabular list of channel capacities and conditions; recent, ongoing, and planned improvements and projects; and ongoing actions to improve future evaluations.

- **Appendix C (Flood Control Structures Status)** provides supplemental information related to flood control structure conditions described in Section 6.0, including recent, ongoing, and planned remedial actions, and ongoing actions to improve future evaluations.

2.0 Inspection and Evaluation Activities Related to SPFC Status

This section describes inspection and evaluation activities related to the physical condition of SPFC facilities. While regular inspections can collect large amounts of information on SPFC status quickly, visual inspections alone are inadequate to develop a comprehensive evaluation of SPFC physical conditions. Characterizing other factors that impact the integrity of SPFC facilities requires additional data collection and evaluations. While collection and evaluation activities can provide more detailed information on SPFC conditions than visual inspections alone, they are often time-consuming and require significant resources.

Seepage is a condition that exemplifies the need for data collection and evaluation for levees. Visual inspections can document occurrences of landside boils and/or seepage areas during high water events. However, visual inspections alone cannot provide the necessary information to assess subsurface conditions leading to landside boils and/or seepage.

2.1 Inspection and Reporting for SPFC Facilities

This section describes DWR, Board, and USACE inspection and reporting activities for SPFC facilities.

2.1.1 DWR Inspections and Reporting

The role of DWR in performing annual visual inspections is to comply with USACE inspection and maintenance requirements, and to work with maintaining agencies (including levee districts, reclamation districts, cities, counties, and other public agencies and municipalities) to oversee their maintenance of SPFC facilities. Federal Flood Control Regulations (Title 33 of the Code of Federal Regulations, Section 208.10) require that federal flood protection levees and floodwalls be inspected at least four times per year: immediately before the beginning of flood season, immediately after each major high water period (flood event), and otherwise at intervals not exceeding 90 days. Federal Flood Control Regulations also require that channels and floodways be inspected periodically. Pumping plants are to be inspected at intervals not to exceed 30 days during the flood season, and 90 days during nonflood seasons. In addition, inspections are often necessary at intermediate times to determine if maintenance measures for SPFC facilities are being performed effectively. A semiannual report must then be “submitted to the District Engineer covering inspection, maintenance, of the protective works” (Title 33 of the Code of Federal Regulations, Section 208.10).

In compliance with these federal requirements, DWR conducts several types of inspections. DWR-generated maintenance inspection reports are described in Table 2-1.

Annual Inspection Report of the Central Valley State-Federal Flood Protection System

DWR conducts two comprehensive levee inspections (spring and fall) and one channel and flood control structure inspection each year (summer). Maintaining agencies conduct their own levee inspections in winter and summer and report their results to DWR. DWR and other maintaining agencies also patrol and inspect all SPFC levees during and after high water events. DWR inspections identify status of features (e.g., encroachments, animal burrows, vegetation, and their types and locations) and document their conditions in the form of ratings. DWR reports the results for individual issues according to maintaining agency, levee unit, and levee mile. Based on results of these inspections, DWR and other maintaining agencies plan their maintenance activities and work toward improving ratings before the next inspection.

USACE has significantly increased federal inspection requirements in recent years to improve knowledge of system conditions. The federal policies and programs require engineering evaluations (such as invasive inspections of penetrations) that present compliance challenges for DWR and other maintaining agencies.

Table 2-1. Description of DWR-Generated Maintenance Inspection Reports

Report	Levees	Channels	Flood Control Structures	Description
Annual Inspection Report of the Central Valley State-Federal Flood Protection System	✓	✓	✓	Annual report prepared by DWR based on DWR's fall levee, channel, and flood control structure inspections.
AB 156 Local Agency Annual Report	✓			Annual report prepared by DWR and submitted to the Board by December 31 of each year, based on information submitted to DWR by maintaining agencies by September 30 of each year.
Levee Mile Report	✓			Reports generated by DWR from inspections detailing maintenance issues found during inspections. One report is generated for each unit and includes photos of issues noted.
Annual Supplemental Erosion Survey of the San Joaquin River Flood Control System	✓			Annual report prepared by DWR based on supplemental inspections conducted by DWR personnel. These surveys are summarized in the Annual Inspection Report of the Central Valley State-Federal Flood Protection System.
Annual Hydraulic Structure Inspection Report			✓	Report generated by DWR from annual inspection of hydraulic structures maintained by DWR in accordance with the California Water Code.
Annual Bridge Inspection Report			✓	Report generated from annual inspection of bridges maintained by DWR in accordance with the California Water Code.

Source: DWR, 2015
Key:
AB = Assembly Bill
Board = Central Valley Flood Protection Board
DWR = California Department of Water Resources

Since 2008, a field computer interface inspection tool and georeferenced database have been used during DWR inspections that allow DWR to efficiently capture and compile inspection data and results. Specific criteria and rating descriptions used for inspection items are appended to the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood

Protection System (DWR, 2015b), are described in Sections 4.0 through 6.0 of this 2017 FSSR, and are in Appendix A. These criteria provide the bases for inspection results contained in DWR maintenance inspection reports (Table 2-1) and elsewhere in this 2017 FSSR.

Each inspection item (e.g., obstructive tree, erosion site, encroachment site) receives one of three possible ratings from DWR based on its condition as follows:

- **Acceptable (A) –** No immediate work required, other than routine maintenance. The flood protection project will function as designed and intended, with a high degree of reliability, and necessary cyclic maintenance is being adequately performed.
- **Minimally Acceptable (M)** – One or more deficient conditions exist in the flood protection project that needs to be improved or corrected. However, the project will essentially function as designed except with a lesser degree of reliability than the project could provide.
- **Unacceptable (U)** – One or more deficient conditions exist that may prevent the project from functioning as designed, intended, or required.

The Minimally Acceptable and Unacceptable ratings generally highlight where minor and serious maintenance issues have been observed. Only Minimally Acceptable and Unacceptable ratings are presented in this 2017 FSSR.

Assembly Bill 156 Local Agency Annual Report

In addition to regular DWR levee, channel and flood control structure inspections, California Assembly Bill 156 (Laird, 2007) amended California Water Code Section 9141, and requires local agencies to submit information to DWR for the levees they maintain by September 30 each year. In turn, DWR is required to summarize this information in an annual report to the Board by December 31 each year. DWR prepared the first (Assembly Bill 156) *Local Agency Annual Report* in 2008 and continues to update the report annually (DWR, 2009a). The report is now a combined report with the Local Maintaining Agency Reporting Program, the Utility Crossing Inventory Program, and various other programs. The title of the combined report is: *Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System* (DWR, 2015b).

Monthly Reports to the Board

DWR provides monthly reports to the Board, as requested by the Board. Monthly reports are verbal, and outline recent inspection activities.

Levee Mile Report

DWR prepares a Levee Mile Report for each levee unit inspected by DWR and maintaining agencies during spring, summer, and fall inspections. A Levee Mile Report details maintenance conditions found during an inspection, and includes photos of some problems noted. Maintaining agencies use Levee Mile Reports to plan and conduct maintenance activities, and emergency response agencies use data from the reports to evaluate planned actions during future floods.

Annual Erosion Survey of the San Joaquin River Flood Control System

The San Joaquin River Flood Control System Erosion Survey monitors and documents the condition of erosion sites annually. The erosion surveys include land-based and waterside surveys during the summer. These findings are contained in the Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b). Additional details on this survey are described in Appendix A in Section A-5.

Annual Hydraulic Structure Inspection Report

Annual maintenance inspections are conducted for hydraulic structures (including pumping plants) maintained by DWR. DWR operates and maintains hydraulic structures specified in Section 8361 of the California Water Code and hydraulic structures within State maintenance areas. These inspections identify any repairs, improvements, and/or replacements needed to comply with USACE operations and maintenance requirements and other guidelines. Formalized checklists and inspection criteria are used during each inspection and photographs are taken. The Annual Hydraulic Structure Inspection Report (DWR, 2015d) contains detailed descriptions of the structural integrity of each structure, a prioritized list of repairs (if any), a map illustrating the location of the structures, and a copy of each inspection checklist with updated photographs (DWR, 2015).

Annual Bridge Inspection Report

In 2008, DWR initiated the Bridge Inspection Program to standardize inspection and evaluation of bridges maintained by DWR in accordance with Section 8361 of the California Water Code. Before 2008, inspection and reporting of these bridges was conducted based on Title 33 Code of Federal Regulations, Section 208.10 requirements. The DWR program was initiated to assess in more detail the condition of bridges for conveyance capacity because of their age. The goals of the program are to provide for safe passage for floodfight operations, and to meet local transportation and inspection needs. The Annual Bridge Inspection Report (DWR, 2015a) includes detailed descriptions of each bridge’s condition, inspection ratings, photographs, and recommendations for repair, improvement and/or replacement (if any).

DWR Inspection Data in the Flood System Status Report

DWR inspection data are presented in FSSR Sections 4 through 6 according to status factors described in Section 3.0. Inspection data are also contained in Appendix A as supplemental information for factors evaluated more comprehensively in systemwide evaluations.

Inspection data are based on results of the 2015 inspections, and are located in this 2017 FSSR and Appendix A as follows:

- Levee Seepage (Appendix A, Section A-3)
- Levee Structural Instability (Appendix A, Section A-4)
- Levee Erosion (Appendix A, Section A-5)
- Levee Settlement (Crown Surface/Depressions/Ruttings) (Section 4.5)
- Levee Vegetation (Section 4.7)
- Levee Rodent Damage (Appendix A, Section A-7)
- Levee Encroachments (Section 4.9)
- Channel Vegetation (Section 5.2)
- Channel Sedimentation (Section 5.3)

- Hydraulic Structures (Section 6.1)
- Pumping Plants (Section 6.2)
- Bridges (Section 6.3)

2.1.2 USACE Inspections and Reporting

The primary purpose of USACE inspections is to determine whether federal and nonfederal flood protection facilities meet federal maintenance requirements. This determination has a major bearing on the eligibility for federal rehabilitation assistance under Public Law (PL) 84-99. All USACE inspections incorporate instructions from the most recent USACE inspection checklist, in the Flood Damage Reduction Segment/System Inspection Report (2015).

Linking USACE inspection results to eligibility for PL 84-99 rehabilitation assistance has increased the significance of USACE inspections in recent years. A levee system[5] must maintain an Acceptable or Minimally Acceptable rating to retain "Active Status" in the USACE Rehabilitation and Inspection Program. Levees with Active Status before a flood event are eligible for federal assistance after a flood event to repair damages caused by a flood (as authorized by PL 84-99).

There are three types of USACE inspections:

1. **Initial Eligibility Inspections**, which are conducted at the request of a local sponsor for initial inclusion into the USACE Rehabilitation and Inspection Program.
2. **Continuing Eligibility Inspections**, or routine inspections, which are conducted annually or biannually.
3. **Periodic Inspections**, which are conducted on a 5-year interval and include collecting existing historical documents (e.g., manuals, as-built drawings, previous reports) and conducting field inspections (USACE, 2015).

Initial eligibility inspections are performed to establish acceptable and minimum performance levels for nonfederal flood control works to gain an Active Status rating in the USACE Rehabilitation and Inspection Program.

For SPFC facilities, USACE Continuing Eligibility Inspections have been based on DWR annual inspection findings. Based on DWR inspection information, USACE may conduct follow-up inspections with site visits in certain areas before determining its inspection ratings. These follow-up inspection ratings take precedence over DWR inspection results in determining PL 84-99 eligibility. USACE has identified several levee systems as inactive in the PL 84-99 Rehabilitation Assistance program because of issues that USACE inspections have shown could negatively impact levee performance in a high water event. Maintaining agencies for these levee systems are encouraged to implement any corrective actions noted by USACE inspections so that their levees can be reinstated in the PL 84-99 Rehabilitation Assistance Program.

[5] In this context, a levee system or flood damage reduction system is a complete and independent unit made up of one or more flood damage reduction segments that collectively provide flood damage reduction to a defined area. Failure of one segment within a system constitutes failure of the entire system.

USACE began conducting Periodic Inspections for SPFC facilities in summer 2009. When conducted, Periodic Inspection ratings have precedence over Continuing Eligibility Inspection ratings, and are used to determine the status of facilities in the PL 84-99 Rehabilitation Assistance Program. USACE Periodic Inspection report cards for 10 SPFC levee systems are provided in Appendix A, Section A-1. These report cards summarize findings of USACE Periodic Inspections.

USACE provides inspection results to project sponsors and FEMA. When a levee system previously certified by USACE undergoes a Periodic Inspection, USACE reviews the FEMA certification according to inspection results. USACE procedures for levee system evaluations in support of FEMA certification have been consolidated in the document, Engineer Circular (EC) 1110-2-6067, USACE Process for the National Flood Insurance Program Levee System Evaluation (USACE, 2010a).

2.1.3 Joint DWR, Board, and USACE Inspections and Reporting

DWR, the Board, and USACE cooperate on project-specific inspections such as the Sacramento River Bank Protection Project erosion surveys. USACE, with the Board's sponsorship, has contracted for waterside erosion surveys of the Sacramento River Flood Control Project since 1998. Each year, DWR, the Board, and the USACE Sacramento District conduct a field reconnaissance review of levee erosion sites for the Sacramento River Flood Control Project.

In 2015, USACE provided their Sacramento Erosion Inspection Report in draft format. After some consideration, it was accepted and used in draft form for the 2015 reporting. The findings of this report are included in the DWR Levee Mile Reports and Annual Inspection Report, and are included in Section 4.4 of this 2017 FSSR.

2.2 Evaluation of SPFC Facilities

This section describes DWR and USACE evaluation activities for SPFC facilities. As mentioned, landside inspection data are limited to what is visible from the crown of a levee. Several other characteristics that impact the integrity of the SPFC require additional evaluations.

Inherent characteristics of SPFC facilities that cannot be observed in visual inspections include the following:

- Subsurface soil conditions
- Underwater levee structure
- Levee geometry
- Compliance with geotechnical design criteria for levees
- Channel conveyance capacity

These characteristics are assessed through evaluation activities as described below.

2.2.1 DWR Evaluations

DWR conducted site-specific geotechnical evaluations of levees through the Levee Evaluations Program. DWR conducted hydraulic evaluations of channel conveyance capacity through the channel capacity evaluation effort for the Sacramento and San Joaquin river systems. Similar detailed evaluations of flood control structures are not being conducted because information from visual inspections provides sufficiently detailed status information.

Geotechnical Evaluations

As part of developing the CVFPP, DWR evaluated geotechnical hazards associated with levee failure in areas where levees protect urban and nonurban areas, as generally defined by Proposition 1E. The DWR Levee Evaluations Program is evaluating approximately 2,000 miles of SPFC levees and appurtenant non-SPFC levees in the Central Valley (approximately 1,580 miles of SPFC levees and 420 miles of non-SPFC levees). The program is divided into ULE and NULE, each of which is further divided into multiple study areas.

ULE evaluated approximately 350 miles of SPFC levees and approximately 120 miles of appurtenant non-SPFC levees protecting areas with populations exceeding 10,000. NULE evaluated approximately 1,230 miles of SPFC levees and approximately 300 miles of appurtenant non-SPFC levees in the Central Valley in areas with a population of less than 10,000. Levees evaluated by ULE and NULE are shown in Figure 2-1. Appurtenant non-SPFC levees are defined as those that abut SPFC levees, whose performance may affect the performance of SPFC levees, or that provide flood risk reduction benefits to areas also being protected by SPFC features.

The goals of ULE and NULE were to determine whether levees meet defined geotechnical criteria and, where needed, to identify repair and improvement measures, including cost estimates, to meet desired geotechnical criteria. The methodology, criteria and results from ULE and NULE are described in more detail in Section 3.3.

Tables 2-2 and 2-3 summarize key deliverables of ULE and NULE, respectively.

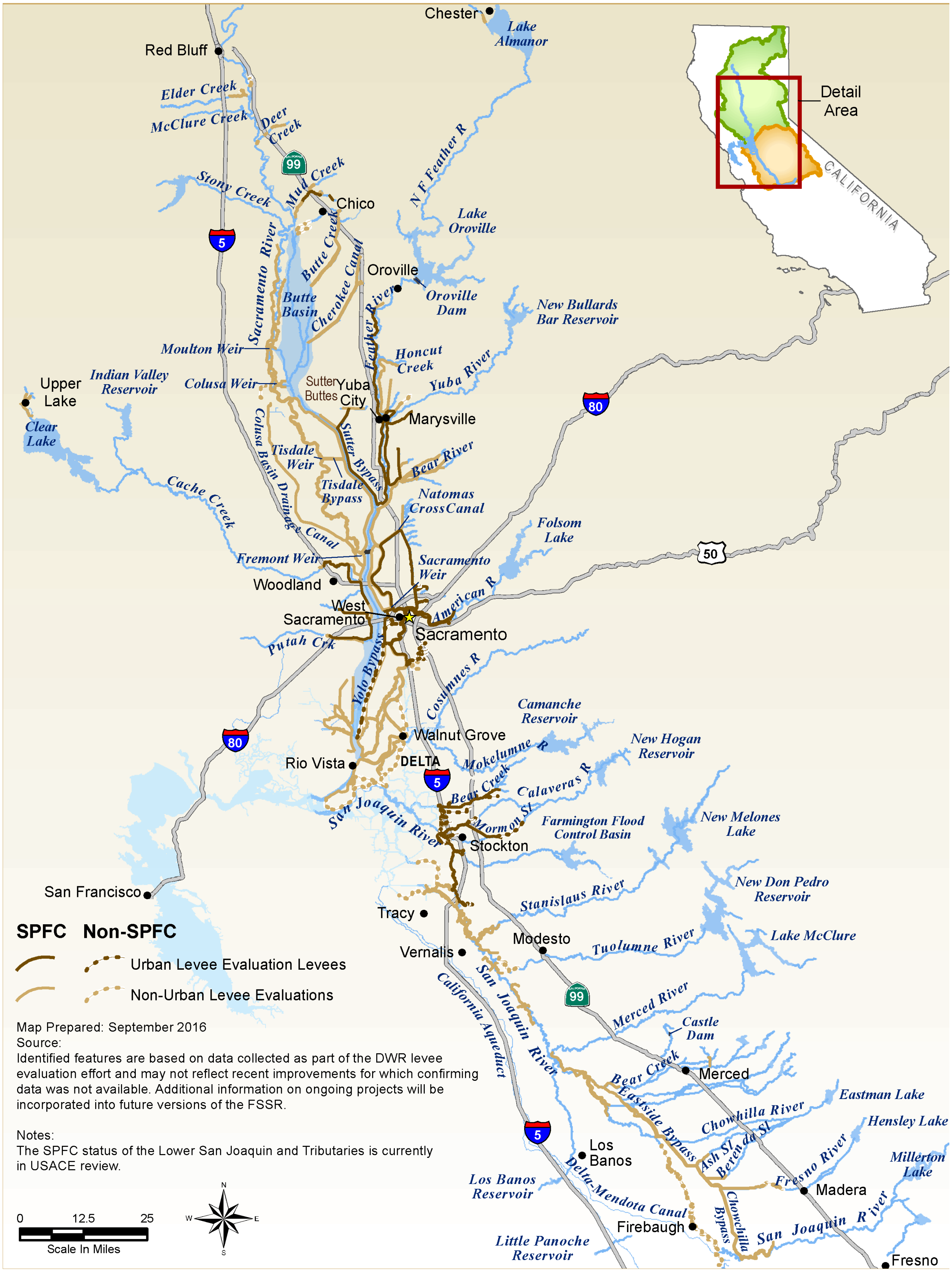

Figure 2-1. Levees Evaluated by ULE and NULE

Table 2-2. ULE Deliverables

Project Deliverable	Description
Data Technical Review Memorandum	Assesses known and unknown geotechnical conditions in a study area and documents levee performance during past flood events
Preliminary Geotechnical Data Report	Presents results of initial field exploration and laboratory testing programs
Preliminary Geotechnical Evaluation Report	Identifies locations for supplemental evaluation through preliminary geotechnical analyses of seepage and stability conditions
Supplemental Geotechnical Data Report	Presents results of the supplemental field and laboratory exploration program that addresses any significant data gaps
Final Geotechnical Evaluation Report	Presents additional analysis to evaluate levee conditions based on available data and to provide conceptual remediation and costs

Table 2-3. NULE Deliverables

Project Deliverable	Description
Data Technical Review Memorandum	Assesses known and unknown geotechnical conditions in a study area and documents levee performance during past flood events
Geotechnical Assessment Report	Presents results of comprehensive data collection and preliminary levee assessment
Remedial Alternatives and Cost Estimating Report	Identifies conceptual repair and improvement alternatives and cost estimates to correct identified problems
Geotechnical Data Report	Presents results of field and laboratory exploration and testing
Geotechnical Overview Report	Presents additional analysis to evaluate levee conditions based on available data and provides conceptual repair and improvement costs

Levee Penetrations Evaluation

A levee penetration is typically a conduit to allow storm water drainage, sewer, water (such as irrigation, drinking water, or waste), gas, electric, petroleum, chemicals or other utilities crossing through or under the levee without affecting its primary function of flood control. There are more than 7,500 levee penetrations crossing SPFC levees. Most of these penetrations were installed when the levees were built and more were added as encroachments for over many years. Most of these penetrations have outlasted their design life of 35 to 50 years. These aging penetrations pose a considerable hazard to the levee integrity. DWR, under its Utility Crossings Inspection Program (UCIP) has inventoried these penetrations using available databases from the Board for encroachment permits, as-built plans for SPFC levees, O&M manuals, levee logs, and data from USACE's periodic inspections.

Based on the flood risk associated with the levee penetrations, there is a need to prioritize and evaluate the levee penetrations. DWR, under the Flood System Repair Project (FSRP), is planning to evaluate levee penetrations using video inspection to prioritize rehabilitation needs.

Penetrations that fall into the critical category will be considered for repair/replacement in partnership with the maintaining agencies under FSRP. The list of critical penetrations will be used to determine funding priorities; the updated list of critical penetrations is also shared with the DWR Flood Operations Center to assist in flood preparedness activities.

Hydraulic Evaluations

Hydraulic evaluations help identify and evaluate SPFC channel conveyance capacity conditions. As mentioned, DWR conducted hydraulic evaluations through the CVFED Program and continues to through the DWR Maintenance Program. Recently, DWR completed hydraulic evaluations through the channel capacity evaluation effort for the Sacramento and San Joaquin river systems, which is the main source of informational updates in the 2017 FSSR.

The channel capacity evaluation effort for the Sacramento and San Joaquin river systems provided the primary source of SPFC channel conveyance capacity data. The analysis program included gathering updated topographic, hydrologic, and hydraulic data, which was used to develop mathematical models to understand flood risk and evaluate channel conveyance capacity in the Central Valley on a systemwide level. Systemwide modeling generally characterizes impedance to flow, but is not designed to evaluate subtle changes in channels as a result of sediment deposition, in-channel vegetation, and/or other obstruction in channels. Once complete, these models will support evaluation and design of potential actions and projects to help manage flood risk. The information gathered during the channel capacity evaluation effort for the Sacramento and San Joaquin river systems was used to evaluate channel status in Section 5.1 of this 2017 FSSR.

The models were supported by additional physical data, analytical tools, and work products, including the following:

- Detailed aerial photographs and topographic data for a major portion of the Central Valley
- Detailed light detection and ranging (LiDAR) topographic data for the majority of SPFC levees
- Bathymetry surveys and surveys of bridges and structures for major rivers and tributaries in the Central Valley
- Supplemental field surveys of structures, stream gages, and channel cross sections for major rivers and tributaries in the Central Valley

Project-specific modeling conducted by the DWR Maintenance Program provided a second source of channel conveyance capacity data in the Sacramento River watershed, and is presented in Section 5.1. DWR is responsible for maintaining channel flow capacity for Sacramento River Flood Control Project channels, and for performing channel-specific maintenance activities identified in the USACE O&M manuals, including channel clearance, if required to maintain design flow capacity. The goal of the DWR Maintenance Program is to accurately characterize Sacramento River Flood Control Project channel hydraulics, and to identify needed maintenance activities for each of the Sacramento River Flood Control Project channels and bypasses prescribed in California Water Code Section 8361. Project-specific models help systematically prioritize channel vegetation management and sediment management activities by determining whether a channel capacity inadequacy is driven by sedimentation, channel vegetation, subsidence, flow constrictions caused by bridge crossings, or other factors. Where available, project-specific hydraulic modeling results from projects conducted by other agencies were used as the source of channel conveyance capacity data.

For systemwide and project-specific modeling, characterization of a channel's current conveyance capacity and identification of channels requiring maintenance are also derived from a hydraulic investigation that includes development of a one-dimensional HEC-RAS hydraulic model. Inadequacies in a channel's conveyance capacity are determined based on design flows and stages depicted in the 1957 USACE Levee and Channel Profiles, File Number 50-10-334 (1957 Design Profile). For channels not covered in the Sacramento River watershed by the 1957 Design Profile and those in the San Joaquin River watershed, the as-constructed plans were used to determine the design stage.

The DWR Maintenance Program is developing Channel Evaluation Reports for each of the Sacramento River Flood Control Project channels and bypasses prescribed in California Water Code Section 8361. The reports present an evaluated channel's current conveyance capacity, identify locations needing maintenance, and develop channel management plans to safely convey the design flow without encroaching on specified stage and level of freeboard.

Note that there are some differences between how DWR is currently evaluating existing channel conveyance capacities as part of both the channel capacity evaluation effort for the Sacramento and San Joaquin river systems, the Program and its Maintenance Program, and how USACE evaluates channel conveyance capacities for planning studies. DWR defines the maximum safe channel capacity using a deterministic approach to delineate floodplains along the Sacramento and San Joaquin rivers, and evaluating specific maintenance projects. This approach considers remaining freeboard and levee stability with respect to geotechnical conditions. USACE uses a risk-based approach that assigns a probability of failure based on defined levee stability parameters and estimated frequency of river stages.

To evaluate baseline hydraulic conditions for the 2017 CVFPP Update, DWR used a risk-based approach more similar to USACE's approach. Risk-based approaches are better for evaluating flood risk at a systemwide scale, but their accuracy depends on having sufficient geotechnical and hydrologic data to support the analysis. Some supporting efforts such as the Sacramento and San Joaquin River Basin-Wide Feasibility Studies (BWFSs) used a deterministic approach to evaluate hydraulic performance along with a robust multi-benefit analysis.

2.2.2 USACE Evaluations

USACE is also conducting numerous site-specific evaluations in support of flood control civil works projects in the Central Valley. Examples of recent projects include the following:

- American River Watershed Common Features Project
- Marysville Ring Levee Project
- South Sacramento County Streams Project
- West Sacramento Levee Improvement Program
- Natomas Levee Improvement Program
- Lower San Joaquin Feasibility Study
- Water Resources Development Act 1996/1999 Levee Improvement Sites

In addition to site-specific evaluation studies, USACE (in sponsorship with the Board) has conducted a comprehensive system evaluation for the Sacramento River Flood Control Project. Contents of the technical studies conducted for each phase of the system evaluation are summarized in Table 2-4.

Table 2-4. Sacramento River Flood Control System Evaluation Technical Studies

Technical Study	Description
Historical Levee Embankment Problem Areas	Locations of levee breaks, seepage, boils, sinkholes, slope failures, erosion damage
Levee Crown Surveys	Levee crown elevations
Cross Section Surveys	Comparison of existing cross sections with original design and construction cross sections
Design Water Surface Profiles	Comparison of levee crown elevations with design water surface profiles
February 1986 High Water Mark Profiles	Comparison of February 1986 high water mark profile with design water-surface profile
Hydrology	Discharge-frequency relationships, rating curves, assessment of ability of channels to convey design flow within design water surface elevation
Geotechnical	Soil sample analysis, review of soil maps and aerial photographs, slope stability analysis, and assessment of potential for damage due to seepage and piping
Design Freeboard	Levee reaches with inadequate design freeboard
Design Flow	Locations of design flow inadequacies
Level of Flood Protection	Recurrence intervals for February 1986 peak flood stages based on engineering and geotechnical considerations
Economics	Flooded areas (floodplains), and estimated flood damages

The Sacramento River Flood Control System Evaluation was conducted by USACE from 1988 to 1995; resulting evaluation reports are listed in Table 2-5.

Table 2-5. Sacramento River Flood Control System Evaluation Reports

Phase	Report Title	Month/Year
1	Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Sacramento Urban Area	May 1988
2	Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Marysville/Yuba City Area	January 1990
3	Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Mid-Valley Area	December 1991
4	Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Lower Sacramento Area	September 1993
5	Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Upper Sacramento Area	May 1995

Following the evaluations listed in Table 2-5, USACE and the Board constructed projects for each of the five areas to remediate identified problem locations and restore levees to design standards, while addressing seepage. Where levees did not meet design standards and problems did not result from lack of maintenance, levee remediation projects were proposed after evaluation. Remediation that could be economically justified was conducted, but some identified problem locations were left unremediated if remediation could not be economically justified. Also, work was performed according to design criteria at the time, which, in some cases, were less stringent than current design criteria.

Additional information on levee conditions after the Sacramento Flood Control System Evaluation is included in Section 4.0.

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3.0 Flood Risk in Sacramento and San Joaquin River Watersheds

SPFC levees along the Sacramento and San Joaquin rivers and their tributaries reduce the frequency of flooding on lands along these rivers. Since their construction, these levees and associated facilities have helped promote public safety and prevent billions of dollars of flood-related damages. However, portions of these levees have failed occasionally, resulting in significant property damage and loss of life. In addition, new development behind the levees places more lives and property in areas that face flood hazards, leading to higher flood risk.

Opposite sides of a river reach can have different flood risks because of different consequences of failure

This section presents a general overview of flood risk within the Sacramento and San Joaquin river watersheds. For the CVFPP, flood risk is defined as the long-term average consequences of flood inundation within an identified area given a specified climate condition, land use condition, and flood management system (existing or planned) in place. The consequences may be direct or indirect economic cost, loss of life, environmental impact, or other specified measures of flood effect. Flood risk is a function of flood hazard,[6] loading,[7] exposure,[8] and consequences. Elements of flood hazard, loading, exposure, and consequences include hydrology, hydraulics, levee performance (or fragility) curves, and economic and life safety consequences, which are discussed in the CVFPP and supporting documentation. As described in this 2017 FSSR, "hazard" refers specifically to geotechnical hazard when discussed in relation to the hazard assessments performed by ULE and NULE. The geotechnical hazard data presented are used to meet the FSSR legislative requirement related to the risk of levee failure (Section 1.1) and to develop levee performance curves for evaluating exposure for the baseline condition in the CVFPP. Therefore, ULE and NULE data related to risk of levee failure in this 2017 FSSR do not reflect the complete definition of flood risk, which, as mentioned, includes hydrology, hydraulics, levee performance curves, and economic or life safety consequences of flooding.

Levee performance for ULE was evaluated against hazard classifications relative to established levee design criteria. Levee performance for NULE was evaluated as hazard categories, which

[6] Flood hazard is defined by FEMA as any flood event or condition with the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, environmental damage, business interruption, or other loss. Flood hazard is a function of hydrology and hydraulics (e.g., rising or rapidly flowing water in a channel).

[7] In the context of flood risk, loading describes the frequency and magnitude of flooding. It is commonly described with a discharge-frequency function that identifies the probability that discharge at a specified location will exceed a specified value.

[8] Exposure is a description or measure of the relationship between inherent flood hazard and the consequences of flooding. Exposure is related to the performance of levees.

are qualitative indicators of the potential for levee failure. ULE and NULE assessments contained in this 2017 FSSR represent the completed analysis of levee conditions as of May 2016.

3.1 Flood Risk

Many Californians, especially those in deep floodplains in the Central Valley, face a significant risk of harm and damage caused by floods. Facilities of the SPFC play an important role in public safety and protection of property. This FSSR is one of several ways DWR in which improving the understanding of the severity of flood risks among those who live and work in areas protected by SPFC facilities.

Levees with the highest likelihood of failure do not necessarily present the greatest risks to the public. The consequences that could occur if a levee fails are an important component of flood risk. Therefore, floods in urban areas typically pose the greatest risks because of the large number of people that could be harmed and the value of the properties that could be damaged. Areas with greater populations will generally also have greater economic consequences.

Regardless of how well flood facilities are designed, constructed, maintained, and operated, there is always a residual chance of failure. Improvements to existing flood facilities can reduce the probability of flooding, but not eliminate it.

Figures 3-1 and 3-2 show FEMA floodplains in the Sacramento River watershed and San Joaquin River watershed that have a 0.2 percent (or 1 in 500) chance or greater of flooding in any year (FEMA, 1996). Although larger areas can be inundated during more extreme floods, the maps indicate areas that are vulnerable to floods.

Levee stability concerns

For the 2017 CVFPP Update, basin-wide life safety and flood damage estimates have been updated based on current physical conditions and model refinements. It is expected that annual life loss in the Sacramento River basin may average approximately 66 people per year. In the San Joaquin River basin, annual life loss are expected to average nearly 149 people per year.

Estimates of basin-wide flood economic damages in the Central Valley were developed and documented for the first time in the December 2002 Sacramento and San Joaquin River Basins California Comprehensive Study Interim Report (USACE and DWR, 2002). These damages included estimated losses to structures, their contents, agricultural crops, and several other damage categories. They were presented as expected annual damages which represents long-term average annual flood damage for a given area under all possible flood events. DWR updated and adapted the systemwide economic damage model to estimate sytemwide life safety as part of the 2012 CVFPP.

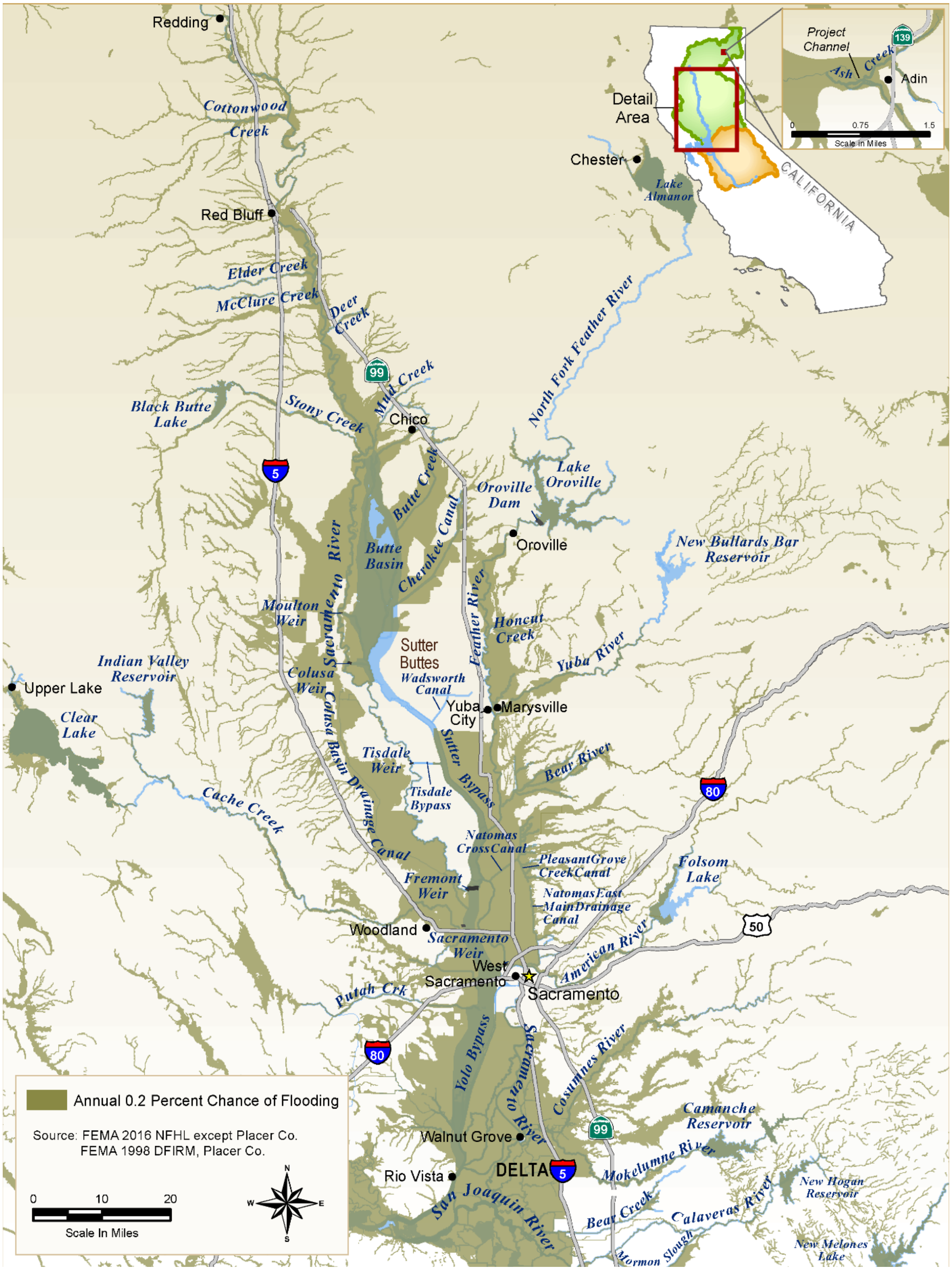


Figure 3-1. FEMA Floodplains with Annual 0.2 Percent Chance of Flooding in the Sacramento River Watershed

Figure 3-2. FEMA Floodplains with Annual 0.2 Percent Chance of Flooding in the San Joaquin River Watershed

3.2 Factors That Influence Flood Risk

Uses of SPFC facilities have changed since the first federal project authorization. Originally, flood management in the Sacramento River watershed was closely tied to management and transport of mining debris generated in upstream mountain and foothill areas. Channels were designed to flush out and move mining debris downstream to keep the channels open for navigation and to convey floodwater. While this legacy system has generally worked well to prevent flooding, it was never intended to serve the multiple purposes the public expects now, such as flood protection for rapidly developing floodplains, long-term sustainability, natural resource preservation, water supply, and recreational use.

Factors related to the physical condition of SPFC facilities are described in three broad categories: levee status factors, channel status factors, and flood control structure status factors.

3.2.1 Levee Status Factors

Levee problems are evaluated in the FSSR according to the following status factors:

- **Inadequate Levee Geometry (Levee Geometry Check)** – Levee crown elevations that are too low, crown widths that are too narrow, and levee side slopes that are too steep can reduce levee stability and lead to failure.

- **Seepage** – Seepage under a levee foundation or through a levee can reduce levee stability and lead to failure.

- **Structural Instability** – Slides, sloughs, slope depressions or bulges can reduce levee stability and lead to failure.

- **Erosion** – Levee and bank erosion can directly reduce levee cross sections and shorten seepage paths, leading to failure.

- **Settlement** – Levee settlement or land subsidence over years can result in levee crown elevations lower than designed, reducing freeboard or causing water to overtop a levee.

- **Penetrations** – Irrigation and drainage pipes, utilities, and other structures through levees may create seepage paths. Seepage along the penetrations, or through deteriorating penetrations, could wash away levee material and lead to failure. Lack of positive closure devices on pipes penetrating levees can also lead to localized flooding.

- **Levee Vegetation** – Vegetation on levees can interfere with floodfighting efforts and maintenance by reducing visibility and accessibility. The extent that levee vegetation impacts levee integrity is the subject of ongoing research.

- **Rodent Damage** – Burrowing animals can create holes in levees that can create seepage paths and lead to levee failure.

- **Encroachments** – Encroachments (such as debris, fences, and structures) on SPFC facilities can interfere with floodfighting efforts and maintenance and, in some cases, reduce levee stability, which can lead to levee failure.

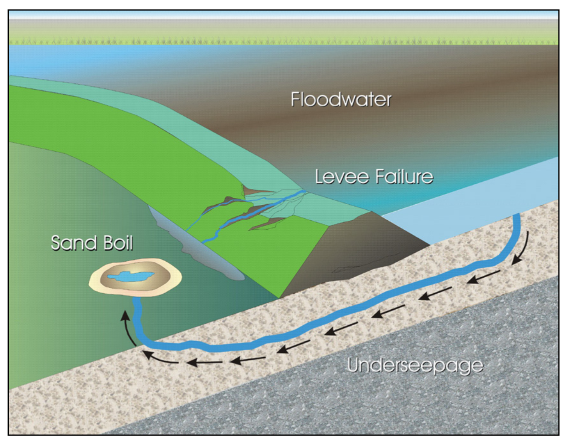
3.2.2 Channel Status Factors

Some SPFC channels may have insufficient capacities to safely convey design flood flows because of the following factors:

- **Inadequate Channel Conveyance Capacity** – Channels can have lower than designed flow capacity because of insufficient levee height or obstructions. Insufficient levee height can reduce the effective cross-sectional flow area. Similarly, obstructions such as bridges, sediment deposits, pilings, docks, marinas, and increased channel roughness from vegetation can also reduce the effective cross-sectional flow area and increase water levels, leading to levee overtopping.

- **Channel Vegetation** – Vegetation can decrease channel capacity, and vegetative debris can collect at bridges and other in-channel structures, restricting and redirecting flow and lead to levee overtopping.

- **Channel Sedimentation** – Deposits of sediment carried by floodwaters can reduce the cross-sectional areas of flood channels, leading to levee overtopping.



Levee underseepage

3.2.3 Flood Control Structure Status Factors

The SPFC relies on successful operation of the following flood control structures:

- **Hydraulic Structures** – Weirs, drainage structures, control structures, diversion structures, drop structures, outlet or outflow structures, and siphons/intakes must be maintained so that they serve their design purpose.

- **Pumping Plants** – Pumping plants must be maintained so that they serve their design purpose.

- **Bridges** – Bridges must be maintained so that they serve their design purpose and do not restrict flows through channels.

3.3 Risk of Levee Failure

As mentioned, the DWR Levee Evaluations Program evaluated approximately 1,700 miles of SPFC levees and appurtenant non-SPFC levees in the Central Valley (approximately 1,400 miles of SPFC levees and 300 miles of appurtenant non-SPFC levees). The goals of ULE and NULE are to determine whether levees meet defined geotechnical criteria and, where needed, to identify repair and improvement measures, including cost estimates, to meet desired geotechnical criteria. Therefore, ULE and NULE assess hazards related to levee performance but do not provide a complete analysis of exposure or evaluate consequences of levee failure. The remaining elements of risk of levee failure for urban and nonurban levees, particularly levee performance curves and life safety and economic consequences, are being analyzed in the CVFPP.

As mentioned, levee performance for ULE was evaluated as hazard classifications relative to established levee design criteria. For NULE, levee performance was evaluated as hazard categories that show potential for levee failure. This approach was selected because the extent of the NULE study area was considerably greater than that of ULE, making it difficult to conduct the same level of field explorations and geotechnical data collection performed for ULE levees.

The following subsections provide more detailed information about the methodologies used to assess levee conditions under ULE and NULE, descriptions of the criteria that define hazard, and a summary of overall hazard of levee segments based on those criteria. This information is used in Section 4.0 to discuss levee conditions in more detail, based on individual status factors.

3.3.1 Urban Levee Evaluations – Methodology and Results

ULE evaluated approximately 320 miles of SPFC and 110 miles of appurtenant non-SPFC urban levees, protecting populations greater than 10,000. SPFC levees evaluated by ULE are shown in Figure 2-1.

ULE Approach

The overall strategy for DWR urban levee evaluations was impacted by two legislative and executive actions. New California Government Code sections added by Senate Bill 5 in 2007 required cities and counties within the Sacramento-San Joaquin Valley to provide, require, or demonstrate an urban level of flood protection for areas located within a FEMA floodplain that are urban or urbanizing before making certain land use decisions. An urban level of flood protection is defined as the level of protection necessary to withstand a flood event that has a 1 in 200 chance of occurring in any given year. In addition, the Governor's 2006 Emergency Order S-18-06 fast-tracked ULE, with the goal of quickly identifying significant levee deficiencies that required repair.

ULE study areas were generally based on urban areas identified by Proposition 1E. [9] Proposition 1E defined an urban area as "any contiguous area in which more than 10,000 residents are

[9] The definition of urban area in Proposition 1E differs from the definition provided in new California Government Code sections added by Senate Bill 5 in 2007. California Government Code Section 65007 defines an urban area as a "developed area in the Sacramento-San Joaquin Valley in which there are 10,000 residents or more." Therefore, ULE study areas may include a mix of urban and nonurban areas, as defined by California Government Code Section 65007, because some urban levees protect adjacent nonurban areas. Furthermore, some urbanizing areas protected by levees are being evaluated under NULE. An urbanizing area is defined in California Government

protected by Project Levees." This means that a project levee failure could flood the residences of more than 10,000 people in a single area. Levees providing protection to areas meeting this definition of an existing urban area were considered urban levees under ULE.

ULE evaluations were implemented in five major steps:

1. **Historical Data Collection** – Available levee data were collected, and State, USACE, and local experts were interviewed. Geomorphology studies were also conducted. For each study area, results were documented in a Technical Review Memorandum, which generally assessed known conditions and potential conditions suggested by available data, as well as levee performance during past flood events. Based on the results of historical data collection, Steps 2 and 3 may not have been performed in study areas that underwent significant investigation by USACE and/or local stakeholders; in this case, screening efforts proceeded to Steps 4 and 5.
2. **Initial Field Investigation** – Initial field exploration (limited to the levee crown) and laboratory testing programs were conducted and documented in a Phase 1 Geotechnical Data Report.
3. **Preliminary Analysis** – Each ULE study area was then broken into separate segments based on similar geologic and geotechnical conditions identified in the Technical Review Memorandums and Phase 1 Geotechnical Data Reports; preliminary geotechnical analyses of seepage and stability were conducted; and areas for supplemental evaluation were identified based on those analyses.
4. **Supplemental Investigation** – Based on the results of analyses performed during Step 3, and particularly its correlation with past performance, a supplemental field and laboratory exploration program was developed and implemented to address any significant data gaps. This work was documented in a Supplemental Geotechnical Data Report.
5. **Final Screening** – Additional analyses were conducted to evaluate levee conditions based on available data. As necessary, conceptual remediation and corresponding costs were identified on a segment-by-segment basis for each study area. Analyses and conceptual remediation were documented in a Geotechnical Evaluation Report.

During the preliminary analysis phase and the final screening phase, analyses were conducted to assess the performance of each ULE levee segment against performance criteria for the following four failure modes:

- Freeboard
- Levee geometry
- Steady-state seepage (reported as seepage)
- Steady-state stability (reported as structural instability)

Code Section 65007 as a "developed area or an area outside a developed area in the Sacramento-San Joaquin Valley that is planned or anticipated to have 10,000 residents or more within the next 10 years. For more information, also see California Government Code Sections 65007, 65302.9, 65860.1, 65865.5, 65962, and 66474.5.

The performance criteria for categories used in these assessments are based on the USACE Engineer Manual (EM) 1110-2-1913, Design and Construction of Levees (USACE, 2000) and DWR's Urban Levee Design Criteria (ULDC) (DWR, 2012a). Although freeboard is not technically a failure mode, it was a performance criterion identified in the above documents and, therefore, the ULE approach considered freeboard in assessing overall hazard classifications.

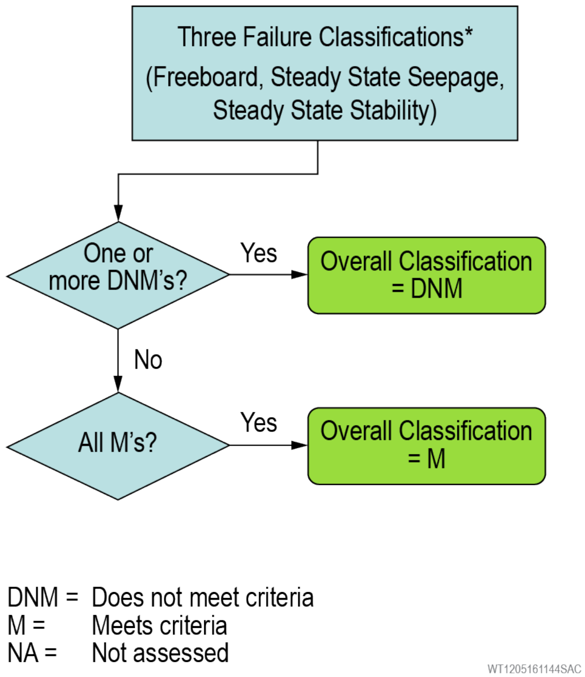
Based on these analyses, each ULE levee segment was assigned one of the following hazard classifications for each potential failure mode:

- **Meets Criteria (M)** – Levees in this classification met or exceeded criteria.
- **Does Not Meet Criteria (DNM)** – Levees in this classification did not meet criteria. These levees required the most immediate attention (i.e., repair or replacement).
- **Not Assessed (NA)** – There was no evaluation completed for a given levee segment or the information obtained was not sufficient to complete a determination of "Meets Criteria," or "Does Not Meet Criteria."

ULE results were developed in two phases. The first phase presented preliminary criteria-based results for freeboard, levee geometry, seepage, and stability for the 1955 and 1957 design water surfaces as presented in this 2017 FSSR (USACE, 1955b; USACE, 1957a; 1957b). In December 2012, the second phase presented criteria-based results for the 200-year surface water profile, and final results for the 1955 and 1957 design water surfaces.

ULE hazard classifications for levee geometry, seepage, and stability are discussed in detail in Section 4.0. ULE freeboard classifications are described in Appendix A, Section A-2.

An overall classification was assigned to each ULE levee segment based on the collective performance for freeboard, steady state seepage, and steady-state stability, as shown in Figure 3-3. For example, each ULE levee segment was assigned a hazard classification for each of the failure modes. If any of the hazard classifications was DNM, then the overall hazard classification was DNM. If all of the hazard classifications were M, then the overall hazard classification was M. Levee geometry classification was not included in the overall classification because the ULE geometry check was performed as a first step in an evaluation of erosion hazard that is not yet complete. It should be noted that an NA rating was used to classify freeboard (levee geometry) for a small amout of levees which did not have sufficient data to determine an M or DNM rating.



Note:
* Levee geometry classification was not included in the overall classification because the ULE geometry check was performed as a first step in an evaluation of erosion hazards that is not yet complete.
Key:
DNM = Does Not Meet Criteria
M = Meets Criteria

Figure 3-3. ULE Overall Levee Segment Hazard Classification Decision Tree

Levee geometry, burrowing animal damage, penetrations, settlement, encroachments, and levee vegetation data were not considered in the assignment of ULE overall hazard classifications.

The following section describes the overall hazard classifications for various levee segments in ULE study areas.

Summary of Overall Hazard Classification

The preliminary analysis phase is complete, and hazard classifications were assigned to ULE levee segments, segregated into the following 14 study areas (north to south):

- Sutter
- Marysville
- Reclamation District 784
- Woodland
- Davis
- Natomas
- Natomas East Main Drainage Canal
- West Sacramento
- American River
- Sacramento River (east levee Sacramento River from American River to Freeport)
- Bear Creek (San Joaquin County)

- Calaveras River
- Reclamation District 404
- Reclamation District 17

Geotechnical Evaluation Reports were prepared for all 14 study areas. Table 3-1 summarizes the overall hazard classifications for 317 miles of ULE SPFC levees. As described above, ULE non-SPFC levee data were not available for inclusion in this 2017 FSSR.

Table 3-1. Summary of ULE Overall Hazard Classification

	Overall Hazard Classification		
	Meets Criteria (M)	**Does Not Meet Criteria (DNM)**	**Total**
ULE Levees in the Sacramento River and San Joaquin River Watersheds			
ULE SPFC Levee Miles Evaluated	131	186	317
Percent of ULE SPFC Levees Evaluated	41%	59%	100%

Key:
SPFC = State Plan of Flood Control
ULE = Urban Levee Evaluations

Overall, almost half of ULE SPFC levees met criteria (hazard classification M) at the design water surface elevation. In some urban areas, substantial segments of levees met criteria, but also have substantial segments of levees that did not meet criteria (hazard classification DNM). For example, portions of the urban levees surrounding the Natomas area of Sacramento have been recently improved to meet criteria. Other portions of the Natomas urban levees are planned for improvement but currently do not meet criteria. Approximately half of ULE SPFC levees do not meet criteria at the design water surface elevation. These levees require the most immediate attention for repair or replacement. Levees in Yuba City, Marysville, Davis/Woodland, and Lathrop mostly do not meet criteria. Although the evaluations did not take into account improvements for the Marysville ring levee that are currently under construction, once these improvements are complete and data are available, results will be incorporated into future updates to this 2017 FSSR.

Overall hazard classifications of SPFC ULE levee segments in the Sacramento and San Joaquin river watersheds are shown in Figure 3-4.

3.3.2 Nonurban Levee Evaluations – Methodology and Results

NULE encompassed approximately 1,100 miles of SPFC nonurban levees and 190 miles of appurtenant non-SPFC nonurban levees. Nonurban SPFC and non-SPFC levees included in the evaluations are shown in Figure 2-1.

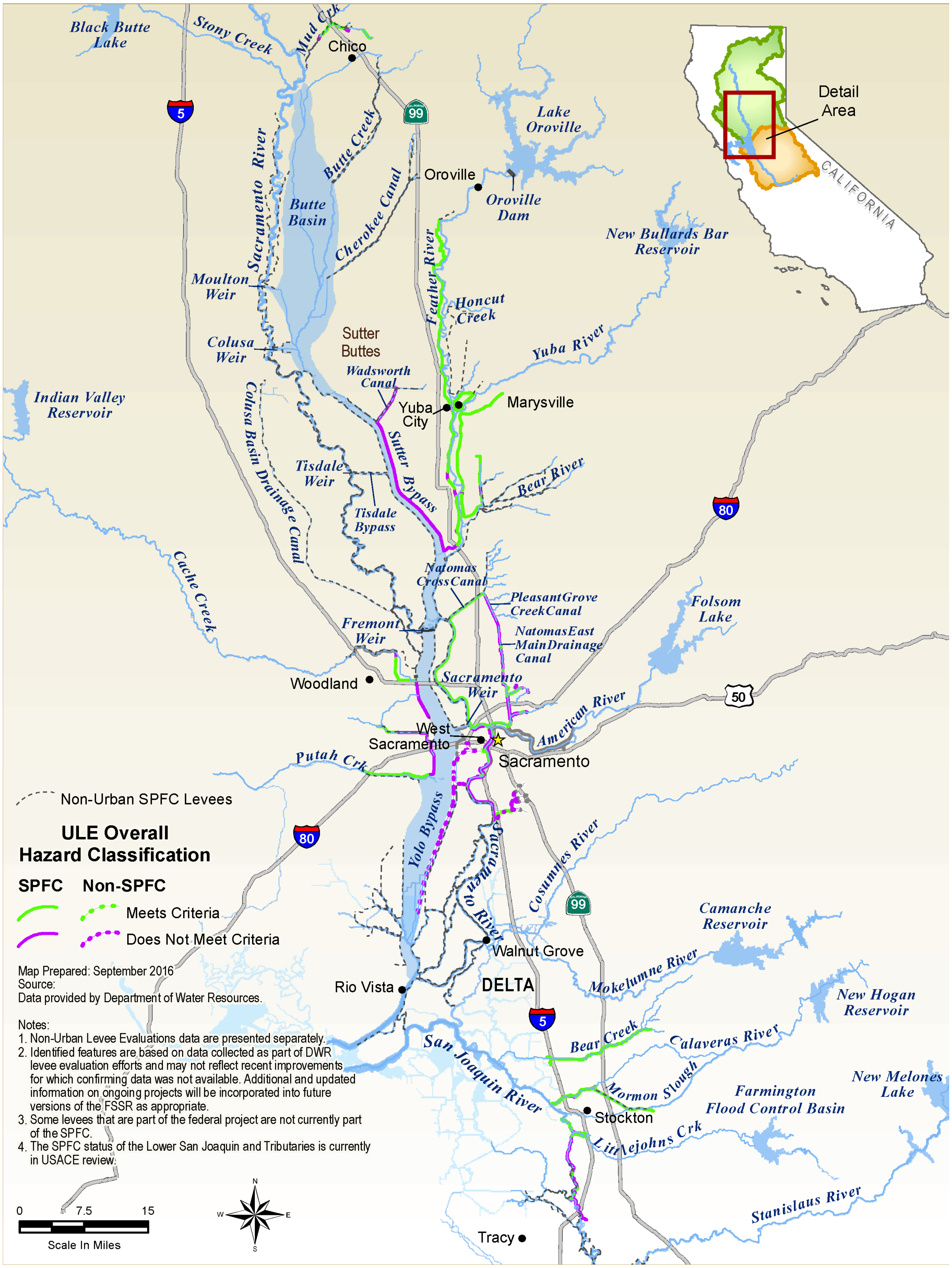


Figure 3-4. ULE Overall Hazard Classifications in the Sacramento and San Joaquin River Watersheds

NULE Approach

NULE levees were evaluated using a two-phase approach. Phase 1 consisted of nonintrusive studies for SPFC and appurtenant non-SPFC nonurban levees using readily available data supported by surface geomorphology studies. NULE levees were evaluated via systematic, consistent, repeatable analysis that correlated geotechnical data with levee performance history, and were not relative to any design criteria. Phase 2 consisted of supplemental studies, which were performed for selected nonurban levees, and involved field investigations combined with more detailed geotechnical analyses. To facilitate evaluation, NULE levees were divided into segments along reclamation district, levee district, and maintenance area boundaries; key physical features (e.g., bypasses, tributaries); and channel sides (i.e., left bank/right bank). NULE Phase 1 included evaluating the following different types of data:

- Existing subsurface information
- Historical performance
- Historical records from the National Archives in San Bruno, California, and selected local sources such as university libraries
- Records available at State agencies and data contained in the California Levee Database
- Data (including interviews) obtained from maintaining agencies and other local levee agencies
- Geologic and geomorphic conditions (including existing Quaternary geologic mapping)
- Surface mapping
- Vintage aerial photography (stereo-paired imagery collected in 1937)
- Vintage topographic maps (1907 through 1915)
- LiDAR topographic surveys
- Assessment water surface elevations (where available, the 1955/1957 design water surface profiles were used for Phase 1 assessments)
- Animal burrow persistence data
- Levee penetrations logs
- Maintenance ratings

These data were managed by DWR in a project-specific electronic database to systematically catalog project data and provide quick and efficient access during levee hazard assessments. The data were used to develop levee construction and performance histories, evaluate levee geometry and other features potentially impacting geotechnical performance, evaluate levees and levee foundation composition and associated conditions, and assess geotechnical levee hazard indicators.

To facilitate a consistent assessment approach, NULE developed a Levee Assessment Tool. The Levee Assessment Tool is a systematic, repeatable process for assessing levee hazard indicators and past levee performance. Details about Levee Assessment Tool development and implementation are in the technical memorandum, Levee Assessment Tool (URS, 2010). The assessment teams used geometric, geologic, and historical performance data from GIS to select a cross section for analysis within each NULE levee segment. The Levee Assessment Tool was used at this cross section to assess the entire segment. Each NULE levee segment was evaluated at the assessment water surface elevation. Where available, the 1955/57 design water surface elevations, as defined by the 1953 Memorandum of Understanding (USACE and Board, 1953), were used as the assessment water surface elevation. In the absence of 1955/57 design water surface elevations, the assessment water surface elevation was based on freeboard requirements for each levee segment (i.e., generally 3 feet below the levee crown).

In addition to the geotechnical hazard assessments, other assessments were performed based on levee geometry and water surface elevation. These included a freeboard check and a geometry check comparison to the levee design prism. Collected data also were reviewed to identify occurrences of levee overtopping.

Four geotechnical failure modes were evaluated by NULE. Note that NULE geotechnical failure modes differ from ULE's four failure modes because of different methodology. NULE geotechnical failure modes include the following:

- Underseepage
- Through seepage
- Slope stability (reported as structural instability)
- Erosion

Based on Phase 1 evaluations, each levee segment was assigned one of the following categories for each geotechnical failure mode:

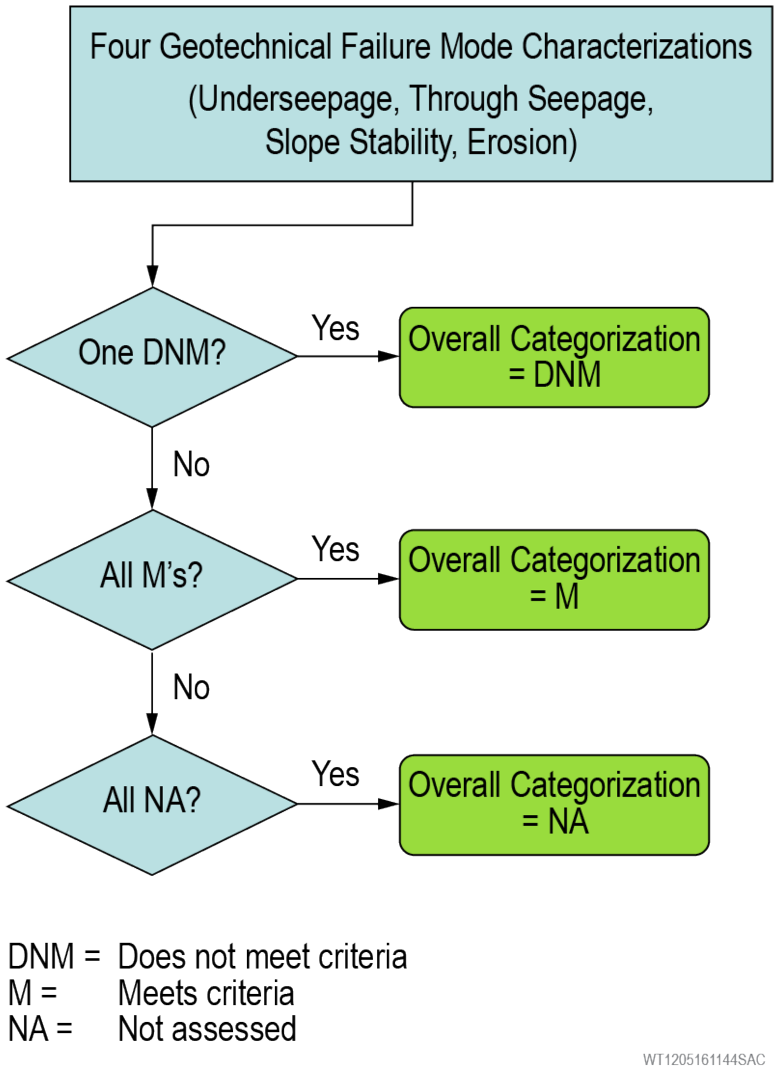
- **Meets Criteria (M)** – When water reaches the assessment water surface elevation, the performance criteria for the geotechnical failure modes is met.

- **Does Not Meet (DNM)** – When water reaches the assessment water surface elevation, the performance criteria for the geotechnical failure modes is not met.

- **Not Assessed (NA)** – There was no evaluation completed for a given levee segment or the information obtained was not sufficient to complete a determination of "Meets Criteria," or "Does Not Meet Criteria."

An overall hazard category was assigned to each NULE levee segment, considering the collective performance for the geotechnical failure modes, including underseepage, through seepage, slope stability, and erosion, as shown in Figure 3-5.

For example, each NULE levee segment was assigned a hazard classification for each of the failure modes. If any of the hazard classifications was DNM, then the overall hazard classification was DNM. If all of the hazard classifications were M, then the overall hazard classification was M. If in any given project area, there was not sufficient data to warrant a determination with respect to the four geotechnical failure modes, then the overall hazard classification was NA.



Key:
LD = Lacking Sufficient Data

Figure 3-5. NULE Overall Levee Segment Hazard Categorization Decision Tree

Penetrations and burrowing animal damage data included in this 2017 FSSR were considered during assignment of through seepage hazard categories. Levee geometry check, settlement, encroachment, and levee vegetation data were not considered during assignment of NULE overall hazard categories, because NULE focused on geotechnical evaluations.

Summary of Overall Hazard Categorization

Table 3-2 summarizes NULE overall hazard categorizations for SPFC levees and non-SPFC levees. The total number of NULE levee miles assigned to each NULE hazard category (Meets Criteria, Does Not Meet Criteria, and Not Assessed) are summarized for the North NULE (Sacramento River watershed) and South NULE (San Joaquin River watershed) study areas, and both study areas combined, as described below.

The Geotechnical Assessment Report, North NULE Study Area (DWR, 2011a) documents study methodology and results for NULE levees in the Sacramento River watershed. The overall hazard categorizations for SPFC and non-SPFC levees in the North NULE Study Area are shown in Figure 3-6. The Geotechnical Assessment Report, South NULE Study Area (DWR, 2011b), documents study methodology and results for NULE levees in the San Joaquin River watershed. The overall hazard categorizations for SPFC and non-SPFC levees in the South NULE Study Area are shown in Figure 3-7.

Table 3-2. Summary of NULE Overall Hazard Categorization

NULE Study Area	Overall Hazard Category			Total
	Meets Criteria	Does Not Meet Criteria	Not Assessed	
North NULE Study Area (Sacramento River Watershed)				
North NULE SPFC Levee Miles Evaluated	376	406	33	816
Percentage of North NULE SPFC Levees Evaluated	46%	50%	4%	100%
North NULE Non-SPFC Levee Miles Evaluated	41	24	19	84
Percentage of North NULE Non-SPFC Levees Evaluated	49%	27%	24%	100%
South NULE Study Area (San Joaquin River Watershed)				
South NULE SPFC Levee Miles Evaluated	93	191	-	398
Percentage of South NULE SPFC Levees Evaluated	23%	48%	-	100%
South NULE Non-SPFC Levee Miles Evaluated	44	45	15	104
Percentage of South NULE Non-SPFC Levees Evaluated	42%	43%	15%	100%
Combined North and South NULE Study Areas				
NULE SPFC Levee Miles Evaluated	469	597	33	1,099
Percentage of NULE SPFC Levees Evaluated	43%	54%	3%	100%
NULE Non-SPFC Levee Miles Evaluated	85	69	34	188
Percentage of NULE Non-SPFC Levees Evaluated	45%	37%	18%	100%

Overall, just under three-fifths (54 percent) of NULE SPFC levees were categorized as “Does Not Meet Criteria” at the assessment water surface elevation. Just over two-fifths (43 percent) of NULE SPFC levees were categorized as “Meets Criteria”. In the Sacramento River watershed, NULE SPFC levees categorized as “Meets Criteria” are primarily along tributaries; none of the NULE SPFC levees along the Sacramento River were categorized as “Meets Criteria.” In the San Joaquin River watershed, NULE levees categorized as “Meets Criteria” were primarily along tributaries, with some short segments along the San Joaquin River.

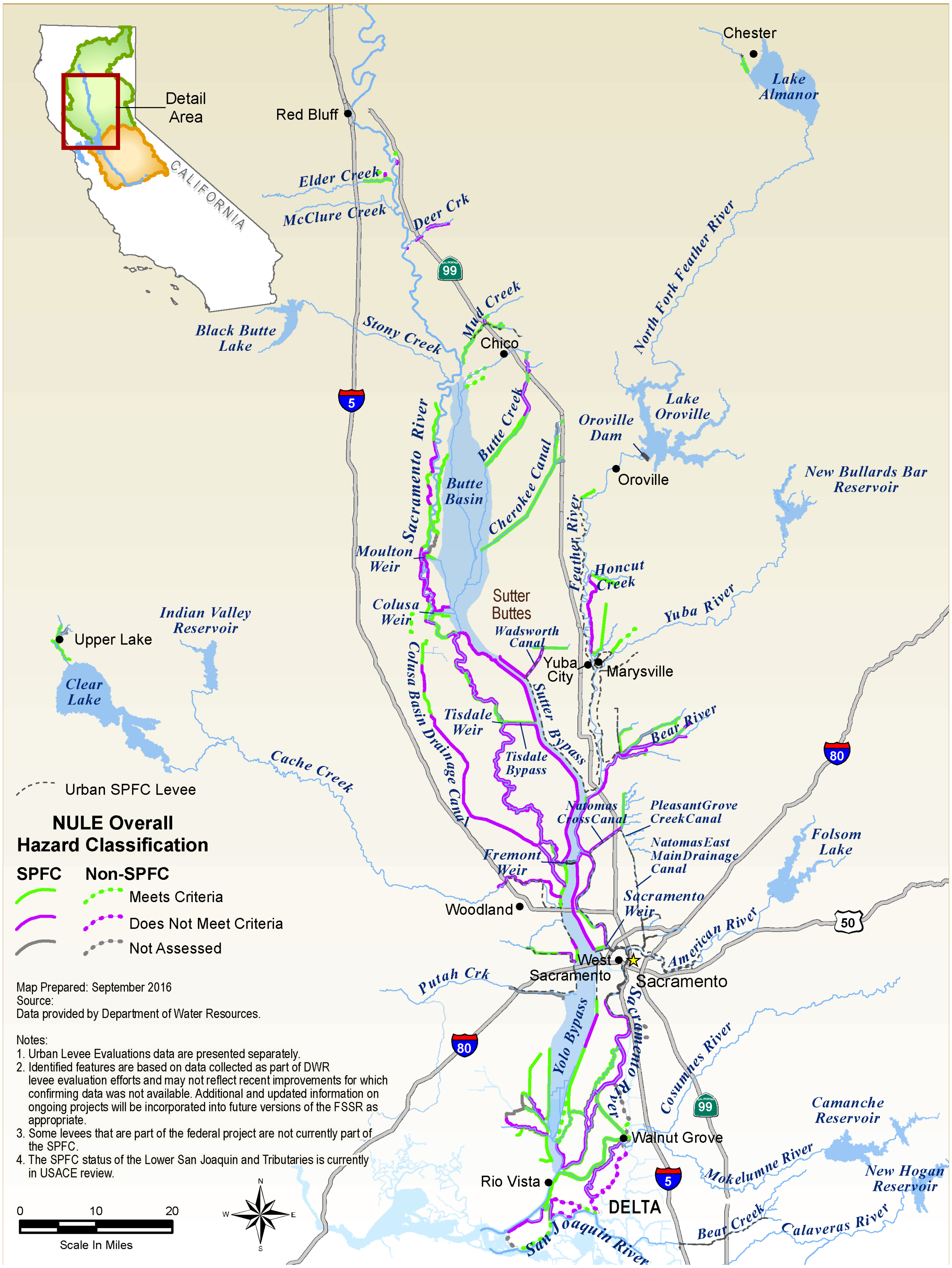


Figure 3-6. North NULE Study Area Overall Hazard Categorizations in the Sacramento River Watershed

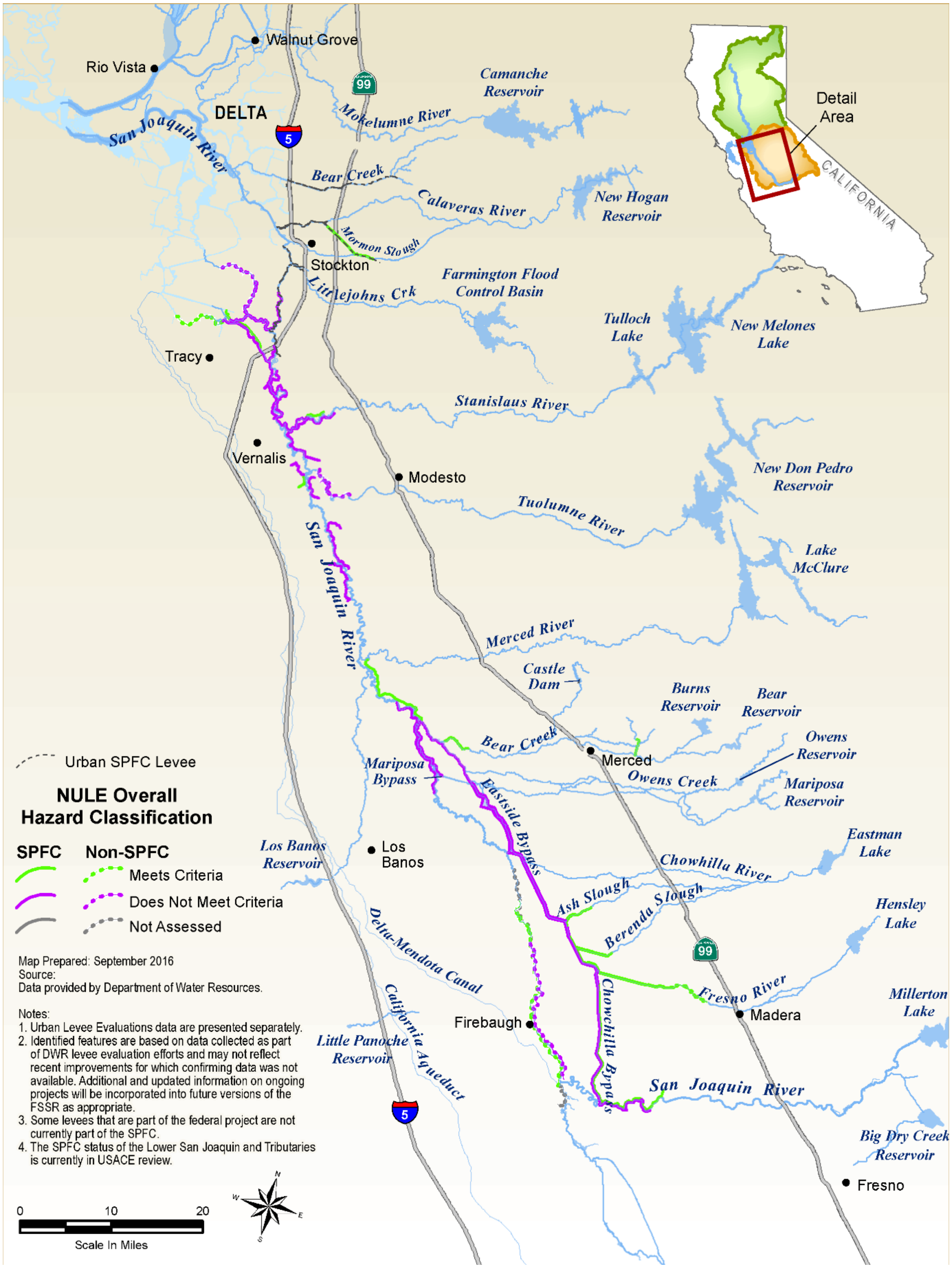


Figure 3-7. South NULE Study Area Overall Hazard Categorizations in the San Joaquin River Watershed

3.3.3 Urban and Nonurban Levee Evaluations Methodology Summary

Figure 3-8 summarizes the process for developing the ULE overall hazard classification and NULE overall hazard categorization.

ULE levee segments were evaluated for four failure modes (freeboard, levee geometry, steady state seepage, steady state stability) based on DWR and USACE design criteria. Results from three of the four failure modes (freeboard, steady state seepage, and steady state stability) were considered when assigning a ULE overall hazard classification using the ULE Overall Levee Segment Hazard Classification Decision Tree (see Figure 3-3). For NULE, levee segments were evaluated for four geotechnical failure modes (underseepage, through seepage, slope stability, and erosion) based on the potential for levee failure at the assessment water surface elevation. The results from all four geotechnical failure modes were considered when assigning a NULE overall hazard category using the NULE Overall Levee Segment Hazard Categorization Decision Tree (see Figure 3-5).

As mentioned, levee geometry was considered during the ULE overall hazard classifications as a proxy for assessing the erosion failure mode because ULE erosion analyses have been completed and the collected geometry data represents the initial step in that analysis. Freeboard was considered during ULE overall hazard classifications, but not during NULE overall hazard categorizations, because the ULE approach compared collected data against current design criteria, which included freeboard criteria. The NULE approach, however, was based on a qualitative assessment of the potential for levee failure.

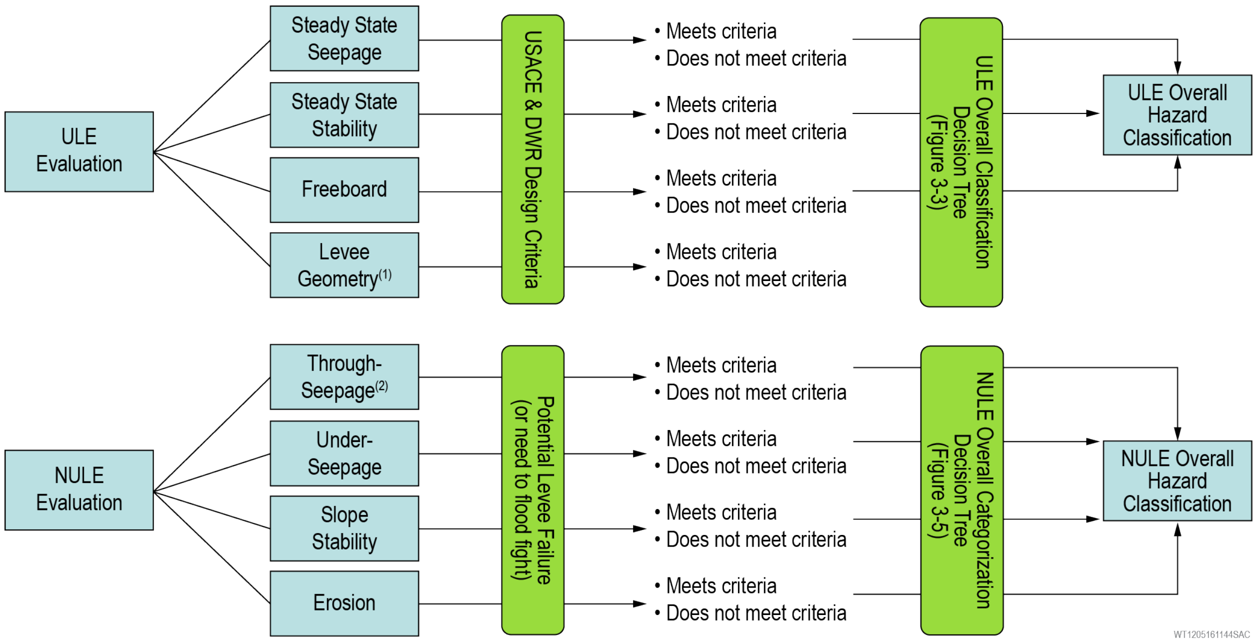


Figure 3-8. Process for ULE Overall Hazard Classifications and NULE Overall Hazard Categorizations

4.0 Levee Status

SPFC levees have provided tremendous benefits to public safety and protection of property in the Central Valley since facilities were originally constructed. However, the current physical condition of SPFC levees has been adversely affected by the following: pervious sandy and gravelly layers in levees or levee foundations, early twentieth-century construction practices, lack of modern design criteria at time of design, levee alignments that exacerbate erosion, facility obsolescence, deferred maintenance, and other items unrelated to flood management, such as groundwater extraction and land use.

Many levees were constructed by local interests before federal and State authorization of the flood control projects, using material dredged from adjacent rivers. These materials, which may be soft or contain coarse, permeable sediments subject to underseepage, were then placed on untreated ground in the late nineteenth and early twentieth centuries. Subsequently, some of these levees were improved while others remained as constructed by local interests, when adopted into the federal flood control project and SPFC in the mid-twentieth century.

Even with regular maintenance, and capital improvement projects that have been implemented through the late twentieth century and early twenty-first century, the foundations and core of many levees (some more than 100 years old) are of unknown integrity. Thousands of penetrations have been placed under and through levees over the years, many of which remain unpermitted and potentially threatening to levee integrity. Also, groundwater extraction and some land use practices have caused land subsidence that adversely affects levee foundations and crown elevations. In addition, insufficient SPFC property rights and easements for flood management adversely affect maintenance in some locations. Finally, funding limitations have placed further strain on SPFC levees by causing some maintenance to be deferred.

After the 1986 flood in the Central Valley, USACE Sacramento District was authorized to conduct a comprehensive analysis of the long-term integrity of the Sacramento River Flood Control Project in partnership with the Board; this analysis was called the Sacramento River Flood Control System Evaluation (USACE, 1988; USACE, 1990; USACE, 1991; USACE, 1993; USACE, 1995). USACE Sacramento District determined that some reaches of levee had structural problems which, if not remediated, would put thousands of people in the Central Valley at risk who rely on levees for their safety and protection of their property from floods. Key results of the Sacramento River Flood Control System Evaluation analysis were as follows:

- High flood flows in 1986 severely stressed levees to the point that a levee failure in Linda (and several other near failures) occurred, demonstrating that the SPFC facilities could not be assumed to be as reliable as previously thought.
- Investigations found that several reaches of levee had geotechnical problems, mostly relating to stability, seepage, and piping potential (described in Section 4.2). These conditions stemmed from the time of construction and were present when the facilities were turned over by USACE to the Board for O&M. Remedial levee reconstructions and improvements are required for the SPFC to function at its original intended design level.

- Levee maintenance evaluations found that, while there were some minor instances of poor maintenance, inadequate maintenance was not the primary cause of structural problems with the levees.

Since this analysis, USACE Sacramento District and the Board have reconstructed selected levee segments protecting urban and rural areas in locations where estimated benefits exceeded the estimated reconstruction costs, as summarized in Table 4-1. Capital improvement projects and extraordinary O&M have also been conducted by maintaining agencies.

Table 4-1. Approximate Length of Levees Reconstructed After Sacramento River Flood Control System Evaluation

Study Area	Approximate Total Length of Levees Reconstructed
Sacramento Urban Area	32 miles
Marysville/Yuba City Area	26.4 miles
Mid-Valley Area	18.3 miles
Lower Sacramento River Area	0.4 miles
Upper Sacramento River Area	3.8 miles
Total	**80.9 miles**

Flood events in 1995 and 1997 reemphasized that the levee system needed additional levee reconstructions and improvements to achieve the desired level of flood protection. As a result of poor performance with respect to levee underseepage during the 1997 flood, USACE Sacramento District convened a panel of experts that recommended modifications to USACE levee underseepage evaluations and design. The USACE Sacramento District adopted most of the panel's recommendations, and issued new guidance in Engineer Technical Letter (ETL) 1110-2-569, Design Guidance for Underseepage (USACE, 2005) and the Geotechnical Levee Practice Standard Operating Procedures for the USACE Sacramento District (USACE, 2008).

Per this new guidance, it became evident that a new USACE system evaluation was needed to evaluate levee underseepage according to new USACE criteria. As discussed in Section 3.3, DWR has been conducting levee evaluations of levee underseepage (and other failure modes) against current criteria in coordination with USACE and other partner agencies since 2007 for ULE. These efforts, building on the findings of previous analyses by USACE, have advanced additional levee improvement projects in several areasand supported development of the CVFPP and the 2017 CVFPP Update.

This section describes current SPFC levee conditions using a combination of data from the DWR Levee Evaluations Program, DWR inspection data, and a DWR Animal Burrowing Persistence Study (DWR, 2009b). As part of the systemwide analysis, information about appurtenant non-SPFC levees is also included in data provided by NULE. Table 4-2 lists levee status factors considered for this 2017 FSSR, data used, and location of the data in this 2017 FSSR. In addition to the ULE and NULE hazard assessments described in Sections 3 and 4, ULE and NULE collected and cataloged historical seepage, erosion, structural instability and settlement occurrences in a GIS database; much of this information is in Appendix A. For example, ULE/NULE hazard assessment data for seepage is included in Section 4.2, and historical seepage occurrences and annual inspection results for seepage are included in Appendix A, Section A-3.

Table 4-2. Levee Status Factors Data Summary

Levee Status Factor	Data in FSSR	Location of Data in FSSR	Considered in ULE Overall Hazard Classification (Section 3.0)	Considered in NULE Overall Hazard Categorization (Section 3.0)
Levee Geometry Check • Levee Geometry Check • Freeboard	ULE/NULE Geometry Check	Section 4.1	No	No
	ULE/NULE Freeboard Check	Appendix A, Section A-2	Yes	No
Seepage[1]	ULE/NULE Hazard Assessments	Section 4.2	Yes	Yes
	ULE/NULE Historical Seepage Occurrences	Appendix A, Section A-3	Yes	Yes
	DWR Annual Inspections	Appendix A, Section A-3	No	No
Structural Instability	ULE/NULE Hazard Assessments	Section 4.3	Yes	Yes
	ULE/NULE Historical Levee Slope Instability Occurrences	Appendix A, Section A-4	Yes	Yes
	DWR Annual Inspections	Appendix A, Section A-4	No	No
Erosion	NULE Hazard Assessment	Section 4.4	No	Yes
	ULE/NULE Historical Erosion Occurrences	Appendix A, Section A-5	No	Yes
	DWR Annual Inspections	Appendix A, Section A-5	No	No
Settlement	DWR Annual Inspections	Section 4.5	No	No
	ULE/NULE Historical Sinkhole and Subsidence Occurrences	Appendix A, Section A-6	No	No
Penetrations	UCIP Levee Penetration Locations	Section 4.6	No	Yes
Levee Vegetation	DWR Annual Inspections	Section 4.7	No	No
Rodent Damage	Animal Burrowing Persistence Study	Section 4.8	No	Yes
	DWR Annual Inspections	Appendix A, Section A-9	No	No
Encroachments	DWR Annual Inspections	Section 4.9	No	No

Notes:
[1] NULE hazard assessment includes underseepage and through seepage. ULE hazard assessment includes a steady state seepage analysis of both underseepage and through seepage.

Key:
DWR = California Department of Water Resources
FSSR = Flood System Status Report
NULE = Nonurban Levee Evaluations Project
ULE = Urban Levee Evaluations Project

Levee status factors considered in assignment of ULE overall hazard categories included freeboard, seepage, and slope stability. Levee status factors considered in assignment of NULE overall hazard categories included seepage (both underseepage and through seepage), slope stability, and erosion. ULE and NULE evaluated other factors, as described, but overall categorizations were based on evaluation of these factors.

Supporting information related to levee status is included in Appendix A, Section A-1, that encompasses multiple levee status factors:

- Historical levee breach and overtopping locations, to show where levees have failed in the past because of any combination of factors.
- Local projects under DWR's Early Implementation Program and USACE/Board projects locations, to show current projects in planning, design, or implementation phases. Early Implementation Program projects are projects that are proceeding in advance of the CVFPP. USACE/Board projects are projects underway that the Board participates in and cost-shares with USACE that reconstruct or improve SPFC facilities in the Sacramento and San Joaquin river watersheds.
- Description of other modifications to SPFC facilities for which the State has not provided nonfederal assurances of cooperation to the federal government, or that are not yet authorized by the Board for acceptance into the SPFC.

4.1 Levee Geometry Check

Although physical processes such as erosion may alter levee geometry, many SPFC levees do not comply with current minimum geometry criteria because levee geometry criteria used at the time of construction varied. Before congressional authorization of flood control projects in the Central Valley, levees were constructed to variable geometry criteria by local interests. After congressional authorization, USACE improved levee geometry in some locations before turning flood control projects over to the Board for O&M. Minimum levee geometry criteria have previously been specified by various USACE and State guidance documents, such as USACE's EM 1110-2-1913, Design and Construction of Levees (USACE, 2000), Title 23 Waters Division 1, of the Central Valley Flood Protection Board California Code of Regulations, the 1953 Memorandum of Understanding Respecting the Sacramento River Flood Control Project (USACE and Board, 1953) and USACE Sacramento District's Reference Paper 10LO, Geotechnical Levee Practice Standard Operating Procedures (USACE, 2008).

Not all existing SPFC levees have been constructed or improved to levee geometry design criteria as specified in USACE and State guidance documents. For example, the 1953 Memorandum of Understanding Respecting the Sacramento River Flood Control Project (only applicable for Sacramento River Flood Control Project improvements authorized by the Flood Control Acts of 1917, 1928, 1937, and 1941 – also known as the "Old Project") lists 55.6 miles of levees that were exempted from meeting levee geometry design criteria. In addition, the 1953 Memorandum of Understanding acknowledged that the levee design criteria were not fully implemented for the "Major and Minor Tributary Project" Sacramento River Flood Control Project improvements authorized by the Flood Control Acts of 1944 and 1950. The Standard O&M Manuals for both the Sacramento River Flood Control Project and Lower San Joaquin River and Tributaries Project state that "some bypass levees and some river levees do not have the standard slopes or crown widths" (USACE, 1955a; USACE, 1959). Updates or exceptions to minimum levee geometry criteria are noted in as-constructed drawings attached to unit-specific O&M manuals, where available.

Furthermore, after levee construction, repeated occurrences of erosion, settlement (both localized settlement and regional settlement from the consolidation of underlying strata), and seepage have contributed, and continue to contribute, to changes in levee geometry that cannot be addressed by routine levee maintenance activities.

The ULDC (DWR, 2012a) includes criteria for urban levee geometry.

4.1.1 Status Evaluation Methodology

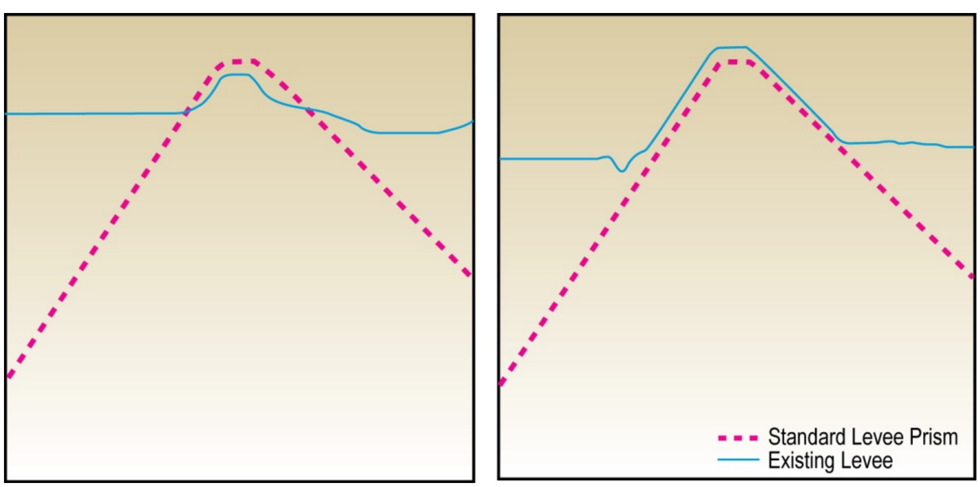
The DWR Levee Evaluations Program conducted a levee geometry check of ULE and NULE levees that compared existing levee geometry at regular cross section intervals with a standard levee design prism.

The standard levee design prism for the Sacramento River is based on the 1953 Memorandum of Understanding levee design criteria (USACE and Board, 1953). Unit-specific levee design geometry (levees exempted from the 1953 Memorandum of Understanding or constructed after 1951) was not accounted for as part of the evaluation. The standard levee design prism for the San Joaquin River is based on available design data, or a standard prism with a 12-foot wide crown, and waterside slopes with a 3 to 1 ratio, and landside slopes with a 2 to 1 ratio, when design data were unavailable.

The standard levee design prism was plotted using GIS; the GIS plot was then overlain on levee topography derived from LiDAR survey data.

The check was performed at a cross section spacing of 500-foot intervals and 100-foot intervals for the Sacramento and San Joaquin river watersheds, respectively. LiDAR survey data were collected for ULE and NULE levees in 2007.

Figure 4-1 demonstrates a levee cross section that deviates from the standard design prism and a levee cross section that conforms to the standard levee design prism.



Levee Cross Section That Deviates from Standard Levee Design Prism | **Levee Cross Section That Conforms to Standard Levee Design Prism**

Figure 4-1. Levee Cross Section Geometry Check Illustrations

Urban Levee Evaluations Project

As mentioned, levee performance for ULE was evaluated against hazard classifications relative to established levee design criteria. For ULE, levee segments were evaluated to determine if cross sections met the standard levee design prism geometry criteria, and were presented in the following hazard classifications:

- Meets Criteria (M)
- Does Not Meet Criteria (DNM)
- Not Assessed (NA)

ULE geometry check results were not considered in assignment of the ULE overall hazard classification shown in Figure 3-4.

Nonurban Levee Evaluations Project

For NULE, the percentage of a levee segment with an existing geometry smaller than the standard design prism was estimated and reported; this is the percentage of a levee that deviates from the standard design prism. For example, a levee with a 60 percent deviation from the standard levee design prism means that 60 percent of the levee segment was smaller than the standard levee design prism, meaning 60 percent of the levee segment did not meet levee geometry criteria.

The percent of levee deviating from the standard levee design prism was calculated through qualitative analysis on a cross section by cross section basis. The percentage of levee segment with existing geometry that did not fit within the standard levee design prism was estimated and reported. Levees with wide crowns could pass the levee geometry check even with slopes steeper than those indicated by the standard levee design prism. Analysts used engineering judgment to assess whether inadequacies indicated from GIS analysis were the result of true geometric inadequacy, misalignment of the design prism, and/or LiDAR-indicated levee centerline. For more information about the NULE geometry check, see the Geotechnical Assessment Reports for the North NULE Study Area and South NULE Study Area (DWR, 2011a and 2011b).

NULE geometry check results were not considered during the assignment of an NULE overall hazard categorization as shown in Figure 3-6 and Figure 3-7. Instead, other levee geometry parameters, such as the head-to-levee base-width ratio, levee height, and levee landside slope angle, were considered during assignment of NULE underseepage, through seepage and stability hazard categorizations. These categorizations in turn impacted NULE overall hazard categorizations as shown in Figure 3-6 and Figure 3-7.

4.1.2 Limitations of Status Evaluations

ULE levee geometry check results presented in this section represent findings of the first of a multitiered process being applied by DWR to assess levee geometry inadequacies and erosion hazards, the results of which have been incorporated into Geotechnical Evaluation Reports completed for individual ULE study areas (see Section 4.4.1 for more details). A levee geometry check was also completed which was intended to be used as an indicator of erosion. The results were noted as an imperfect indicator of erosion hazard. This imperfection was due to various factors in addition to erosion which could cause a levee to have inadequate levee geometry.

The levee geometry check presented in this 2017 FSSR was limited to a comparison between existing levee geometry and standard levee design prisms described in Section 4.1.1, and does not assess the cause of any deviations noted for ULE or NULE levees. While deviation from standard geometry may be caused by erosion, it also could reflect a levee that was not constructed to the standard levee design prism, or a levee that has degraded because of settlement or other post-construction events. The levee geometry check does not reflect any prior-approved deviations, such as updates or exceptions to minimum levee geometry standards noted in unit-specific O&M manuals. Unit-level evaluation of a levee's geometry based on its construction specifications was not part of this levee geometry check. Estimates of the extent of deviation from standards (depth or severity) are also not included in the FSSR for ULE or NULE levees. Because of the limitations above, ULE levee segments identified in Figure 4-2 as "Does Not Meet Criteria" warrant further assessment of potential erosion hazards and do not necessarily reflect the need for levee improvement.

4.1.3 Results of Status Evaluations

Results of the levee geometry check for ULE and NULE are summarized below. ULE and NULE levee freeboard check results, and additional information on recent levee remedial actions/improvements (including locations of levee raises, widening, and levee reconstructions), current and ongoing repairs/improvements, and ongoing actions to improve future evaluations of levee geometry are included in Appendix A, Section A-2.

Urban Levee Evaluations Project

Results of the geometry check for SPFC ULE levees are shown in Figure 4-2. The majority of SPFC ULE levees along the Feather River, American River, and Sacramento River north of the City of Sacramento were met standard levee design prism geometry criteria. Approximately one-third of SPFC ULE levees deviate from current standard levee design prism geometry. These levees were located along bypass features and associated tributaries to the west, and along the Sacramento River south of Sacramento. Geometry check results for SPFC ULE levees in the San Joaquin River watershed and elsewhere in the Sacramento River watershed varied.

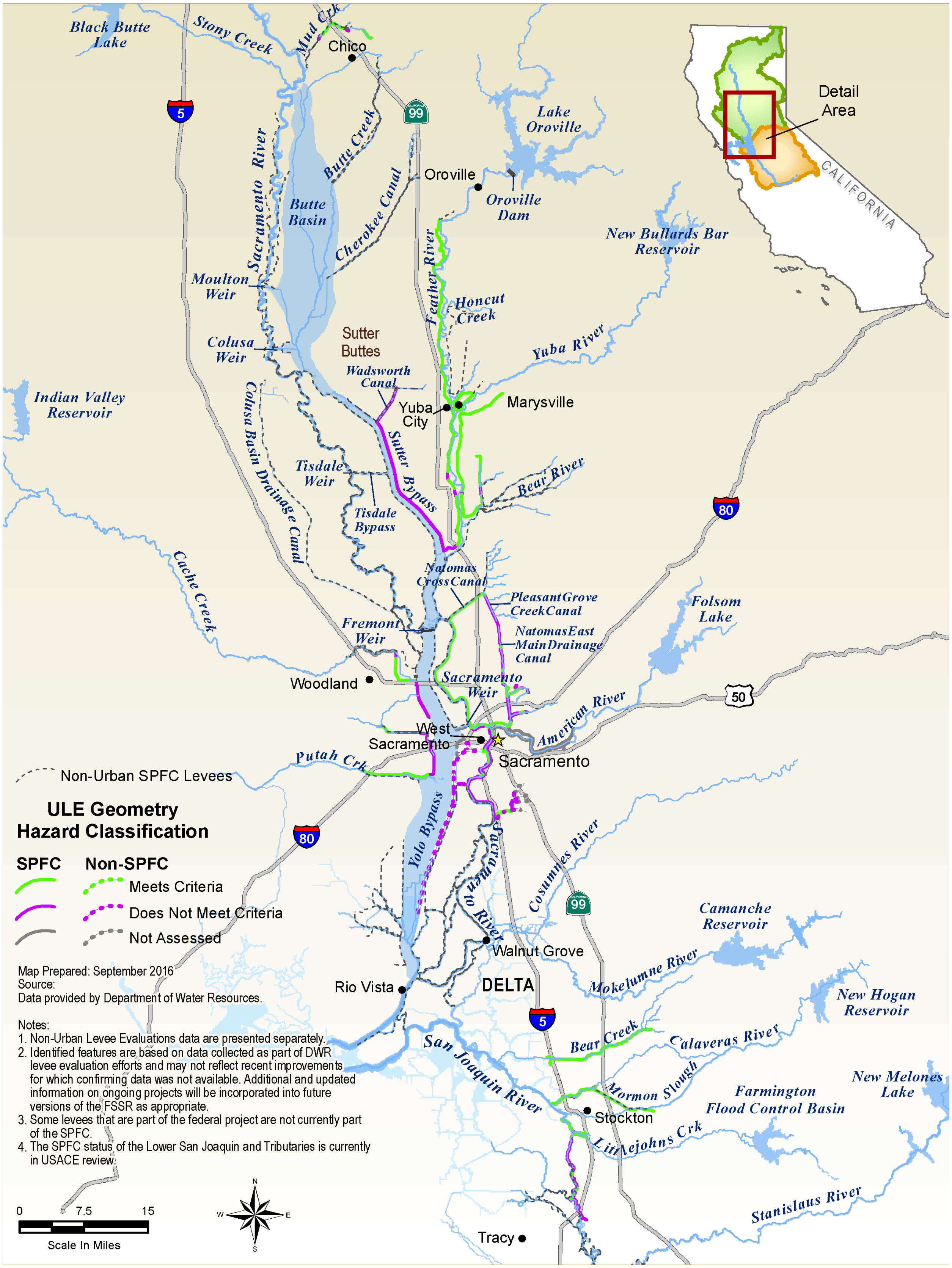


Figure 4-2. ULE Levee Geometry Check

Nonurban Levee Evaluations Project

Geometry check results for NULE levees are shown in Figures 4-3 and 4-4. The percentages mapped are the percentage of each NULE levee segment that deviated from standard levee design prism geometry. Compliance with minimum levee geometry criteria varied across the Sacramento and San Joaquin river watersheds. Results suggest that the San Joaquin river watershed and Sacramento River have the highest percentage of levees that conform to standard levee design prism geometry. Further, levees along the bypasses and along the tributary streams to the Sacramento River in the northern Sacramento River watershed have the lowest percentage of NULE levee segments that conform to standard levee design prism geometry. Results elsewhere along NULE levees were variable.

4.2 Seepage

Seepage problems for levee systems are commonly divided into two distinct categories: underseepage and through seepage. Underseepage occurs when permeable foundation material or native soils beneath the base of a levee present a pathway for water to move under a levee and exit at the surface near or beyond the landside levee toe. Through seepage occurs when water moves from a waterway through a levee. When water moving through or under the levee carries with it foundation soil or levee materials, piping action may result in settlement of the levee or erosion of the landside toe or slope and cause the levee to breach during high water.

Levee seepage is often associated with pervious sandy and gravelly layers in a levee or levee foundation, early twentieth-century construction practices, and lack of any seepage design criteria at the time of construction. Many SPFC levees were built by landowners and local entities in the late nineteenth century and early part of the twentieth century without benefit of current design criteria or construction practices. These levees were typically constructed without consideration for foundation stability, suitability of levee material, or placement procedures. Many levees were constructed using sandy materials and were placed on top of riverine deposits that often contained pervious sandy or gravelly layers. As a result, many SPFC levees are susceptible to underseepage or through seepage. A number of other factors may increase the potential for seepage, including the presence of erodible fill, animal burrows, or other penetrations that exit from the landside levee slope or foundation, potentially causing the levee to erode or degrade.

Engineering practices to address seepage have evolved significantly over time. USACE levee seepage design criteria and construction practices were originally developed to address through seepage only, but were revised after the 1950s to address growing concerns about underseepage. Therefore, many existing levees do not comply with current USACE levee underseepage criteria because the levees were constructed before the revised criteria were adopted. Conflicting guidance between old and new seepage design criteria has resulted in inconsistent levels of protection for different levee projects (USACE Sacramento District Levee Task Force, 2003).

Most recently, USACE has been updating seepage criteria in EM 1110-2-1913, Design and Construction of Levees (USACE, 2000); further updates to USACE seepage criteria are expected. DWR's ULDC (DWR, 2012a) contains more rigorous seepage design criteria than the current USACE guidance. This is because USACE guidance applies to all levees, and the DWR ULDC (DWR, 2012a) only apply to levees protecting urban and urbanizing areas.

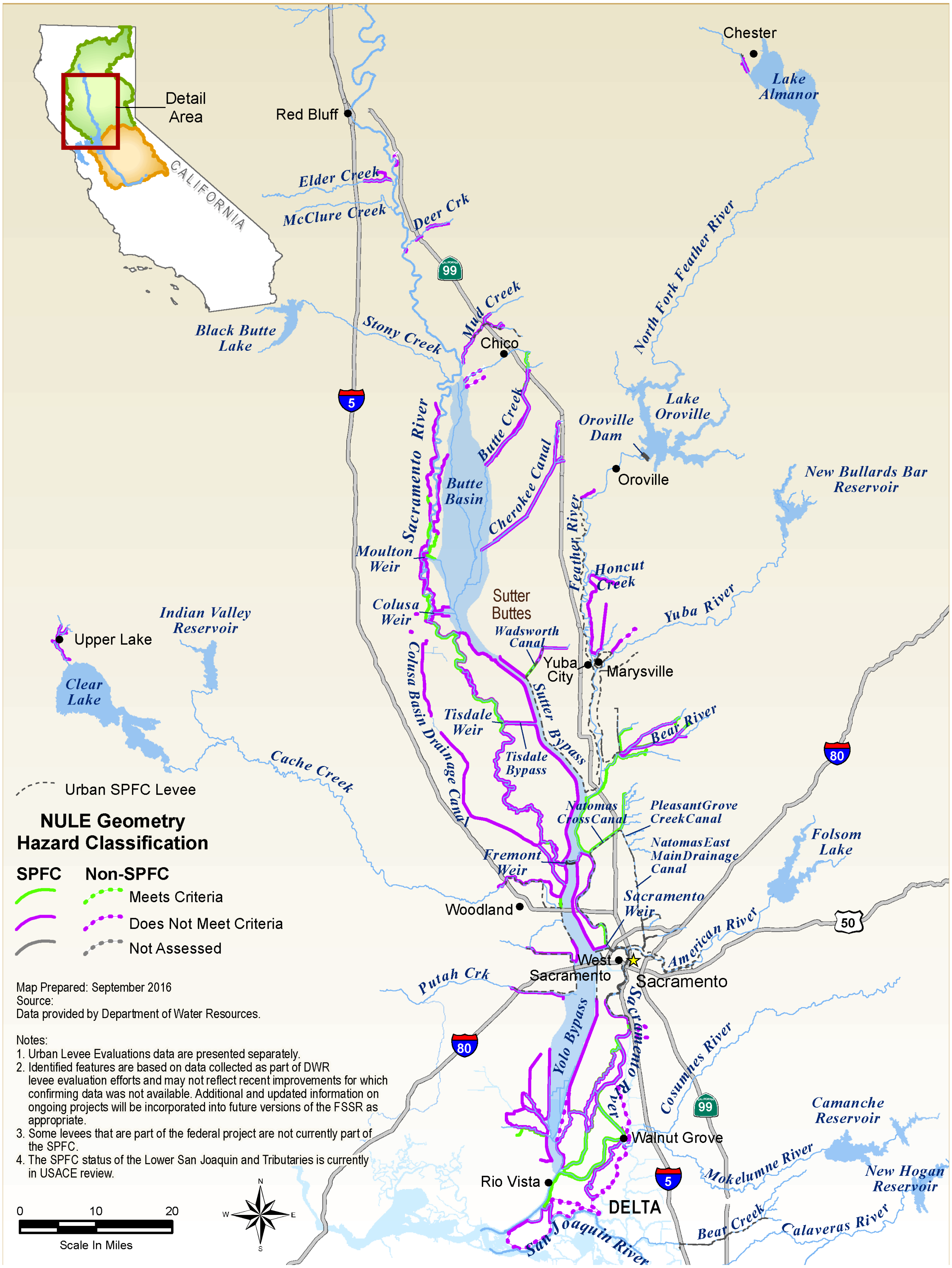


Figure 4-3. NULE Levee Geometry Check in the Sacramento River Watershed

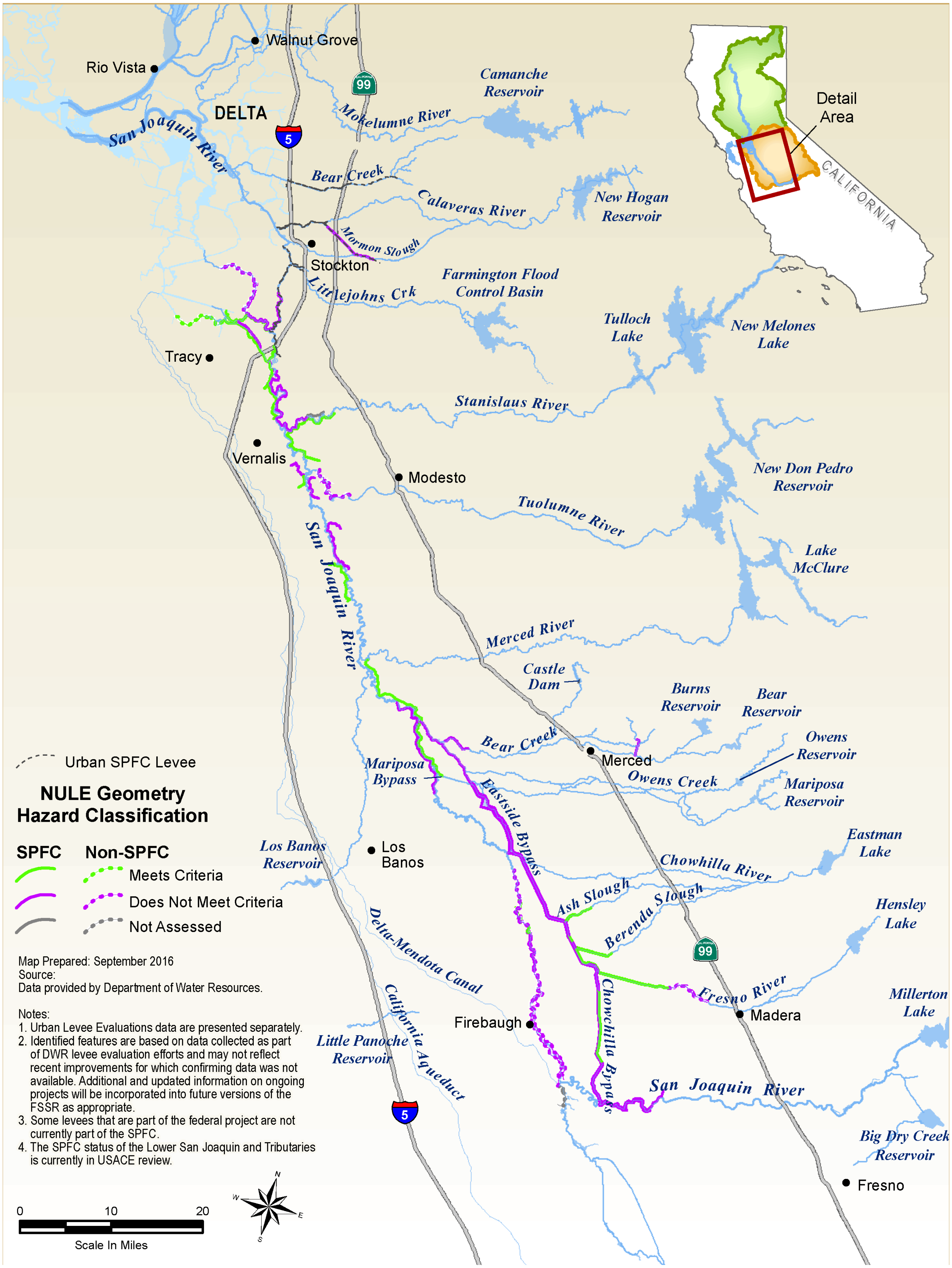


Figure 4-4. NULE Levee Geometry Check in the San Joaquin River Watershed

4.2.1 Status Evaluation Methodology

DWR used different methods to assess the potential for seepage for ULE and NULE, reflecting different scopes, objectives, and funding availability for the projects.

Urban Levee Evaluations Project

As mentioned, levee performance for ULE was evaluated against hazard classifications relative to established levee design criteria to assess seepage along ULE levees, DWR performed a quantitative analysis that assessed underseepage and through seepage concurrently. A steady state seepage computer model used for this effort (SEEP/W) incorporated existing and new geotechnical data and analyses from borings drilled at regular intervals along the entire urban levee system. The model estimates an exit gradient for underseepage at the design water surface elevation and allows assessment of potential through seepage conditions, which are then compared against accepted criteria, as specified in the USACE's EM 1110-2-1913, Design and Construction of Levees (USACE, 2000) and DWR's ULDC (DWR, 2012a).

ULE evaluations included assessing each ULE levee segment and assigning each segment to one of the following hazard classifications for steady state seepage:

- Meets Criteria (M)
- Does Not Meet Criteria (DNM)
- Not Assessed (NA)

Nonurban Levee Evaluations Project

For NULE, levee performance was evaluated as hazard categories that show potential for levee failure. As part of NULE Phase 1, levee assessments were performed for underseepage and through seepage based on comparing available geologic and geotechnical data and documented performance records. Detailed methodology and results are in the Geotechnical Assessment Reports for the North NULE Study Area and South NULE Study Area (DWR, 2011a and 2011b).

NULE Phase 1 studies included assessing each NULE levee segment and assigning each segment to one of the following hazard categories for through seepage and underseepage as two geotechnical failure modes:

- Meets Criteria (M)
- Does Not Meet Criteria (DNM)
- Not Assessed (NA)

4.2.2 Limitations of Status Evaluations

Limitations of seepage hazard assessments for ULE and NULE are summarized below.

Urban Levee Evaluations Project

The steady state seepage hazard classifications presented in this 2017 FSSR for ULE levees are based on analyses of data collected as part of ULE. The supplemental field explorations from 2009 and 2010 have been incorporated and considered in the hazard classifications. These supplemental explorations enhanced levee seepage analytical results because the efforts were focused on data gaps identified based on results of the initial data collection effort.

Although the analytical methodology used for this seepage hazard assessment (Section 4.2.1) is similar to that used for designing local levee improvement projects, its recommended use is limited to identifying potential geotechnical hazards in urban levees, and to guide future evaluations and levee improvements; it does not represent the level of effort that would be necessary to certify a levee under the FEMA National Flood Insurance Program, which would require geotechnical explorations and analyses at greater frequency.

Nonurban Levee Evaluations Project
NULE seepage hazard categories provided in the NULE Geotechnical Assessment Reports for the North NULE Study Area and South NULE Study Area (DWR, 2011a and DWR, 2011b) represent a preliminary analysis of levee seepage conditions. They are only sufficient to guide subsequent NULE field activities, and to prepare preliminary remedial alternatives (and associated cost estimates) necessary for levee repairs and improvements to attain acceptable levee performance. Results of an assessment are not meant to be used to determine how a levee or associated system may perform in a flood event. Because of the limitations identified above, seepage hazard categories for NULE levees were not used to evaluate compliance with current levee design criteria.

4.2.3 Results of Status Evaluations

ULE and NULE seepage hazard assessments results are summarized below. Additional information about levee inspection results, historical levee seepage occurrences, recent remedial actions, ongoing and planned repairs and improvements, and ongoing actions to improve future evaluations for seepage are included in Appendix A, Section A-3. Also, USACE periodic inspection results for seepage in 10 USACE levee systems are included in Appendix A, Section A-1.

Urban Levee Evaluations Project
ULE steady state seepage hazard classification results are shown in Figure 4-5. Based on these results, SPFC ULE levee segments that generally meet seepage criteria include the rehabilitated portions of the Reclamation District 784 levees in Yuba County, the American River levees, the Natomas East Main Drainage Canal and Cross Canal levees, and Bear Creek levees in San Joaquin County. The longest segments that do not meet seepage criteria are along the west side of the Feather River. Classification results elsewhere among ULE levees varied. Overall, approximately one-third of SPFC ULE levees evaluated did not meet current seepage design criteria. Figure 4-8 shows ULE through seepage hazard classifications.

Nonurban Levee Evaluations Project
NULE underseepage hazard categorization results are shown in Figures 4-6 and 4-7. These figures show that approximately one-third of SPFC NULE levees in the Sacramento River watershed and almost two-thirds in the San Joaquin River watershed have a high underseepage hazard. Figures 4-9 and 4-10 show through seepage hazard categorizations for NULE levees in the two watersheds. In general, through seepage is less prevalent than underseepage; approximately one-eighth of SPFC NULE levees in the Sacramento River watershed and approximately half in the San Joaquin River watershed have a high through seepage hazard.

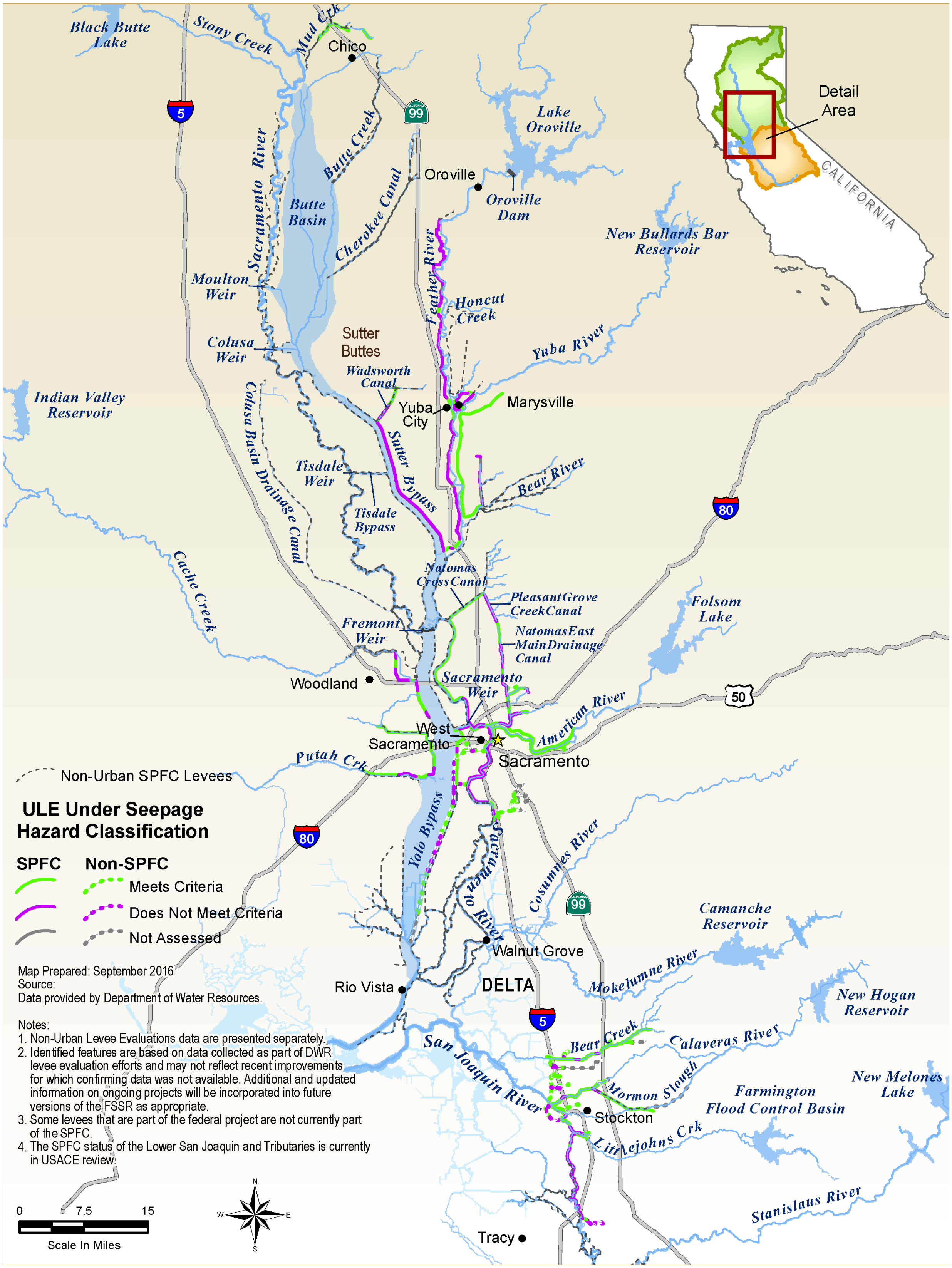


Figure 4-5. ULE Under Seepage Hazard Classification

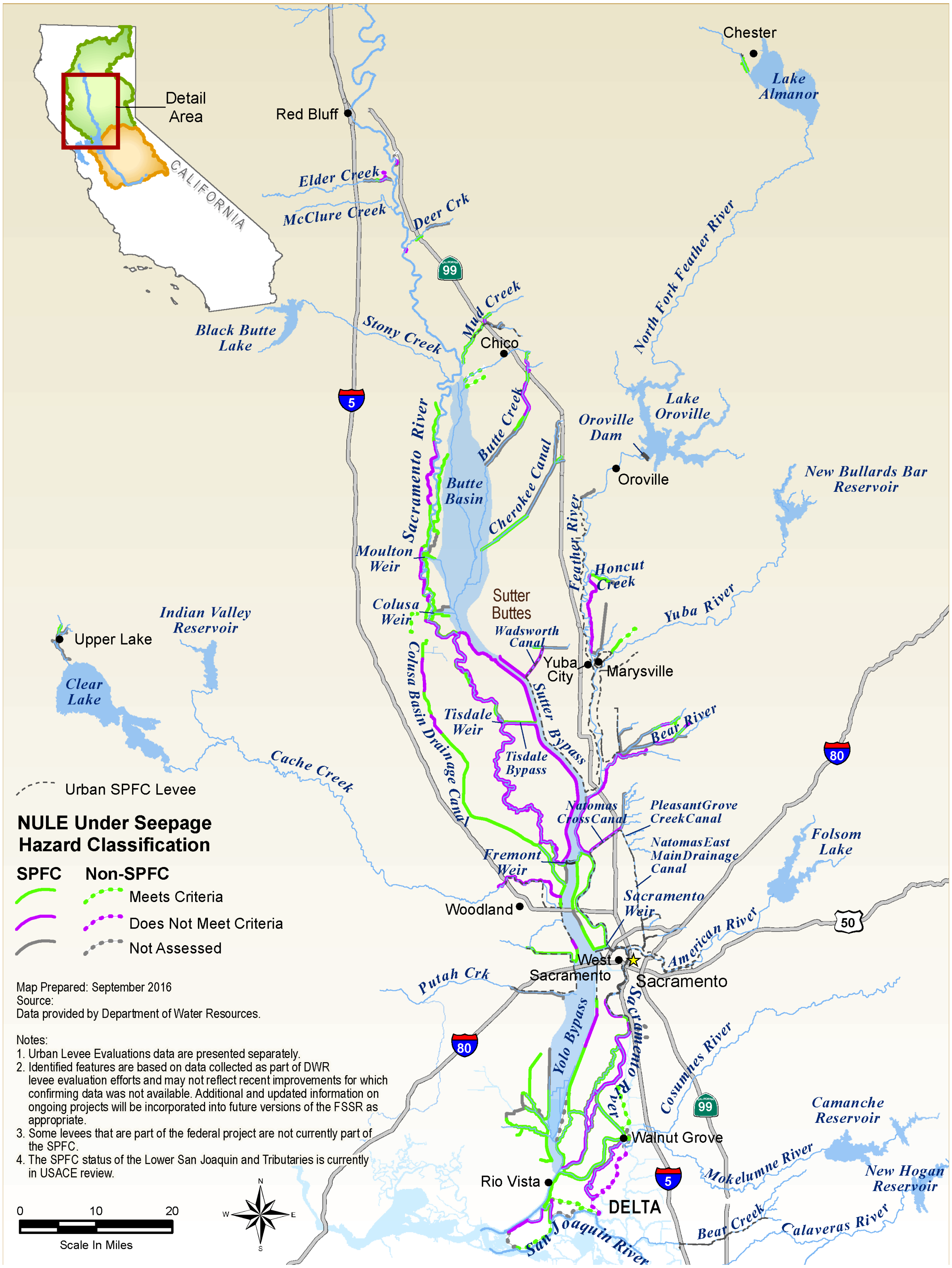


Figure 4-6. NULE Underseepage Hazard Categorizations in the Sacramento River Watershed

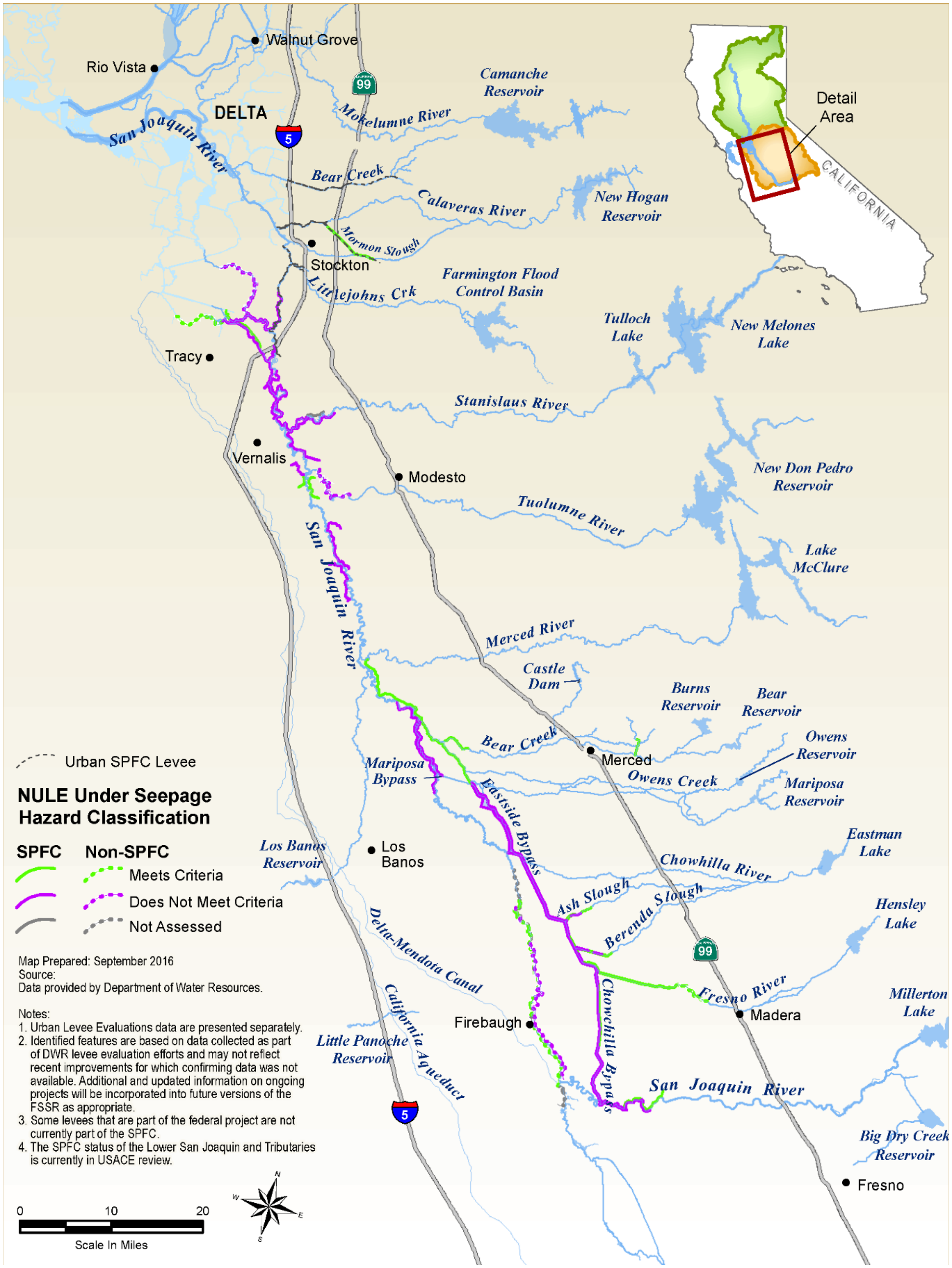


Figure 4-7. NULE Underseepage Hazard Categorizations in the San Joaquin River Watershed

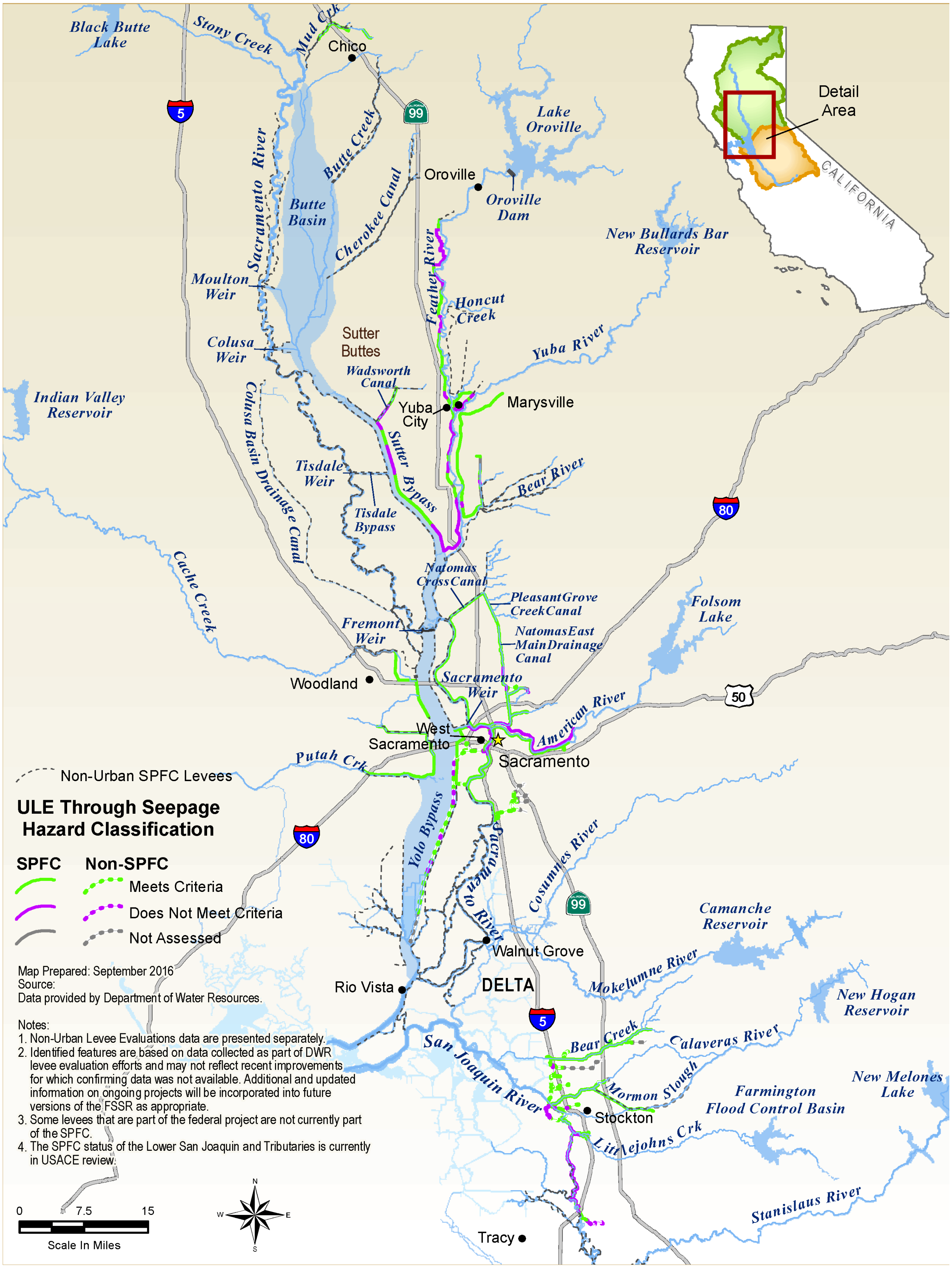


Figure 4-8. ULE Through Seepage Hazard Classification

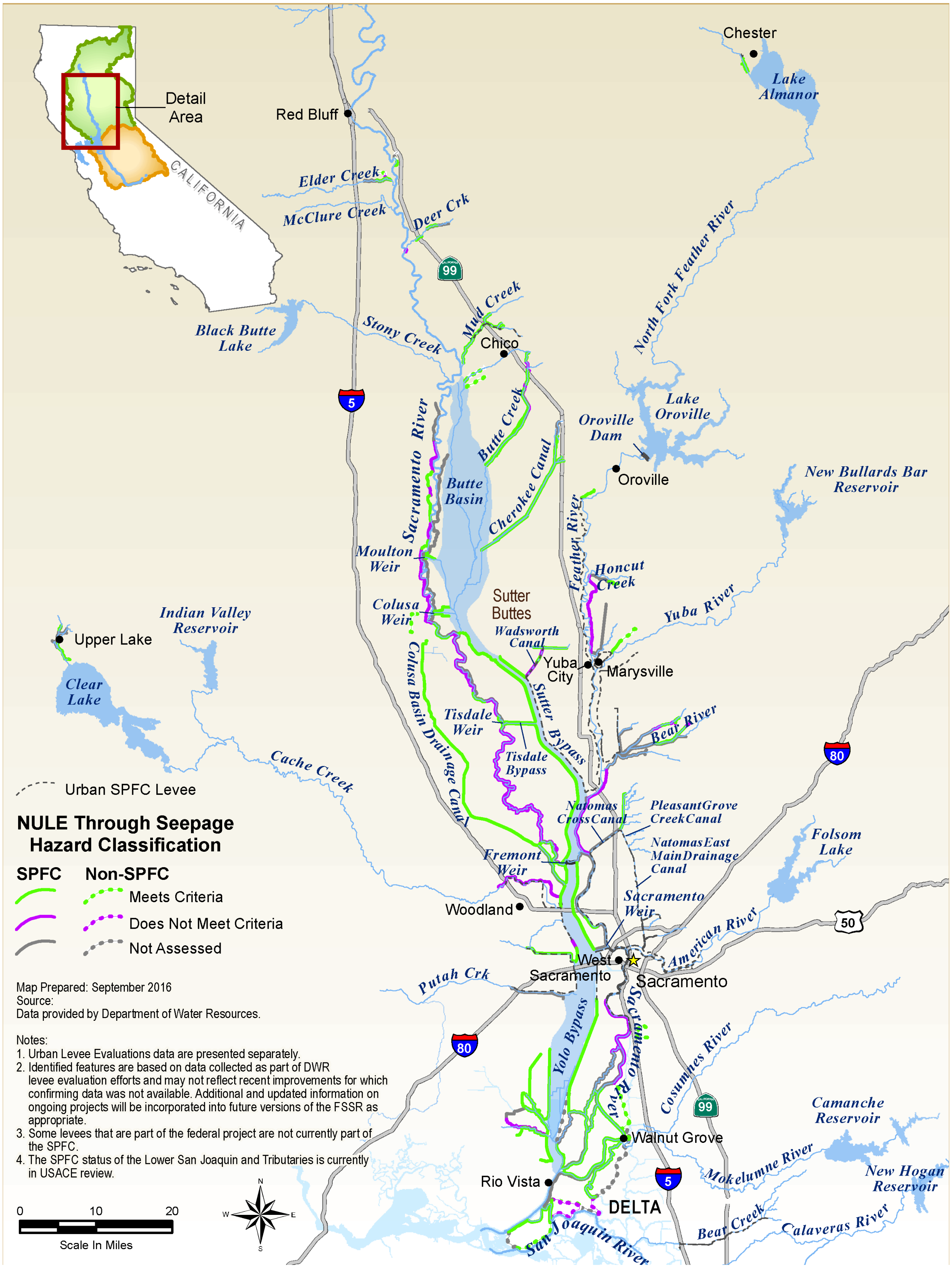


Figure 4-9. NULE Through Seepage Hazard Categorizations in the Sacramento River Watershed

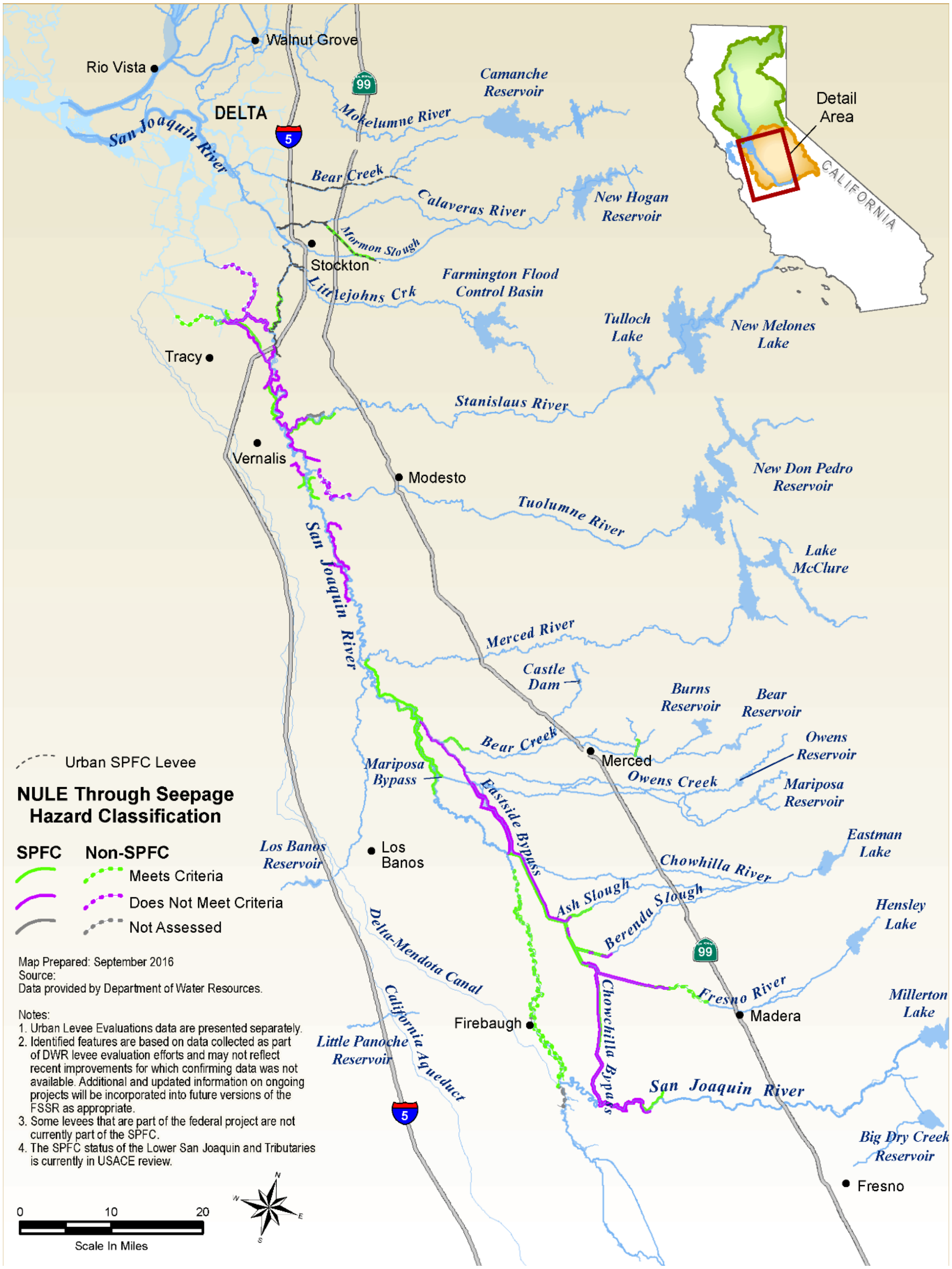


Figure 4-10. NULE Through Seepage Hazard Categorizations in the San Joaquin River Watershed

4.3 Structural Instability

Structural instability is characterized by slides, sloughs, cracking, slope depressions, or bulges that could pose a threat to levee integrity. Structural instability is often associated with soft or dispersive soils in a levee or its foundation, or with design and construction practices used for the construction of levees in the late nineteenth and early twentieth centuries. Deferred maintenance may also influence structural instability, but to a much lesser extent. As indicated previously, many SPFC levees were built by landowners and local entities without benefit of current design or construction practices. New stability analyses may be necessary for existing levees, particularly for older levees constructed before adoption of current criteria.

4.3.1 Status Evaluation Methodology

DWR used different methods to assess the potential for structural instability for ULE and NULE, reflecting different scopes, objectives, and funding availability for the projects.

Urban Levee Evaluations Project

To assess structural instability along SPFC ULE levees, DWR performed a quantitative analysis of steady state slope stability that produced hazard classifications relative to established design criteria. Analytical models used for this effort incorporated topography from LiDAR surveys of the urban levee system, and existing and new geotechnical data from explorations conducted at regular intervals along the urban levee system. The models were used to calculate a factor of safety at the design water surface elevation, which was then compared against accepted geotechnical criteria, as specified in USACE's EM 1110-2-1913, Design and Construction of Levees (USACE, 2000) and DWR's ULDC (DWR, 2012a). As part of ULE, levee assessments were performed for steady state slope stability to determine if the levees met geotechnical criteria at the design water surface elevation. Similar to hazard assessments for seepage, DWR assessed each ULE levee segment and assigned each segment to one of the following hazard classifications:

- Meets Criteria (M)
- Does Not Meet Criteria (DNM)
- Not Assessed (NA)

Nonurban Levee Evaluations Project

For NULE, levee performance was evaluated as hazard categories, which show potential for levee failure. As part of NULE Phase 1, levee hazard assessments were performed for slope stability based on a comparison of available geologic and geotechnical data and documented performance records. Similar to assessments for seepage, the slope stability hazard categorization identified during NULE Phase 1 included assessing each NULE levee segment and assigning each segment to one of the following hazard categories:

- Meets Criteria (M)
- Does Not Meet Criteria (DNM)
- Not Assessed (NA)

4.3.2 Limitations of Status Evaluations

The limitations of structural instability hazard assessments for ULE and NULE are summarized below.

Urban Levee Evaluations Project

The hazard classifications presented in this 2017 FSSR for ULE levees are based on analyses of data collected as part of ULE, and also include data collected from the supplemental field explorations performed in 2009 and 2010. Data from the supplemental explorations enhance levee slope stability analytical results because the efforts were focused on data gaps identified based on results of the initial data collection effort, as presented in this 2017 FSSR.

Although the analytical methodology used for this slope stability hazard assessment (Section 4.3.1) is similar to that used in designing local levee improvement projects, its recommend use is limited to identifying potential geotechnical hazards to urban levees and to guide future evaluations and levee improvements; it does not represent the level of effort that would be necessary to certify a levee under the FEMA National Flood Insurance Program, which would require geotechnical explorations and analyses at greater frequency.

Nonurban Levee Evaluations Project

As mentioned, the hazard categories provided in the NULE Geotechnical Assessment Reports for the North NULE Study Area and South NULE Study Area (DWR, 2011a; DWR, 2011b) represent a preliminary analysis of levee conditions, and are only sufficient to guide subsequent NULE field activities and prepare preliminary remedial alternatives (and associated cost estimates) necessary for levee repairs and improvements to attain acceptable levee performance. Assessment results are not meant to be used to determine how a levee or associated system may perform during a flood event. Because of the limitations identified above, slope stability hazard categories for NULE levees were not used to evaluate compliance with current levee design criteria.

4.3.3 Results of Status Evaluations

Results of structural instability hazard assessments for ULE and NULE are summarized below. For additional information on inspection results, historical levee slope instability locations, recent remedial actions, ongoing and planned remedial actions/improvements, and ongoing actions to improve future evaluations, see Appendix A, Section A-4. Also, USACE periodic inspection results for slope stability in 10 USACE levee systems are included in Appendix A, Section A-1.

Urban Levee Evaluations Project

ULE steady state stability hazard classification results are shown in Figure 4-11. Based on these results, an estimated one-fifth of SPFC ULE levees do not meet geotechnical criteria for slope stability at the design water surface elevation. In general, SPFC ULE levees in the San Joaquin River watershed, along the American River, and along rehabilitated reaches of the Natomas basin and east of the Feather River meet slope stability criteria. Results along the remaining SPFC ULE levees vary.

Nonurban Levee Evaluations Project

NULE slope stability hazard categories are shown in Figures 4-12 and 4-13. As shown, there is generally a higher slope stability hazard for levees in the Sacramento River watershed compared to the San Joaquin River watershed.

Approximately one-eighth of SPFC NULE levees in the Sacramento River watershed and 1 percent in the San Joaquin River watershed have a high slope stability hazard.

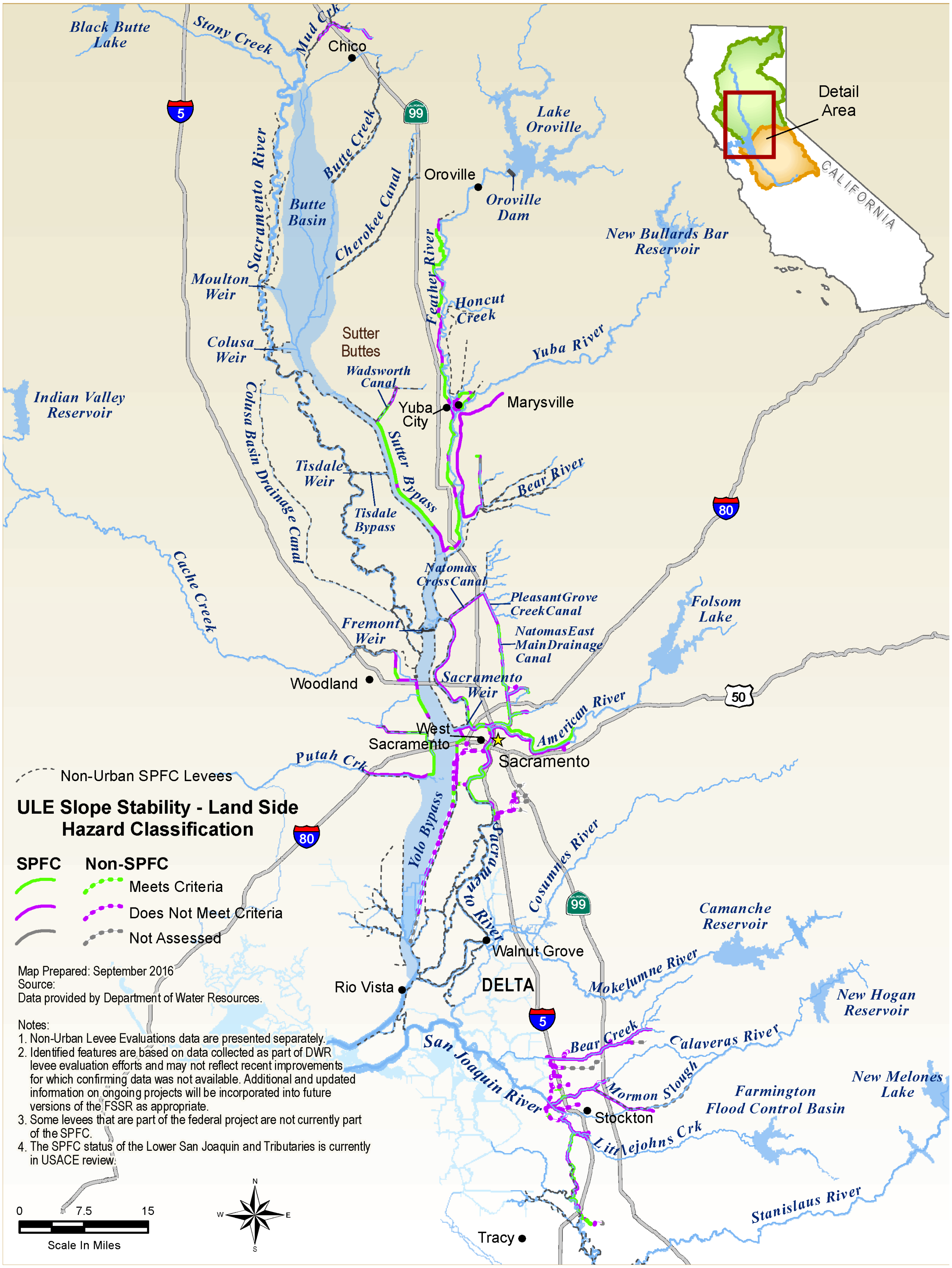


Figure 4-11. ULE Steady State Stability Hazard Classifications

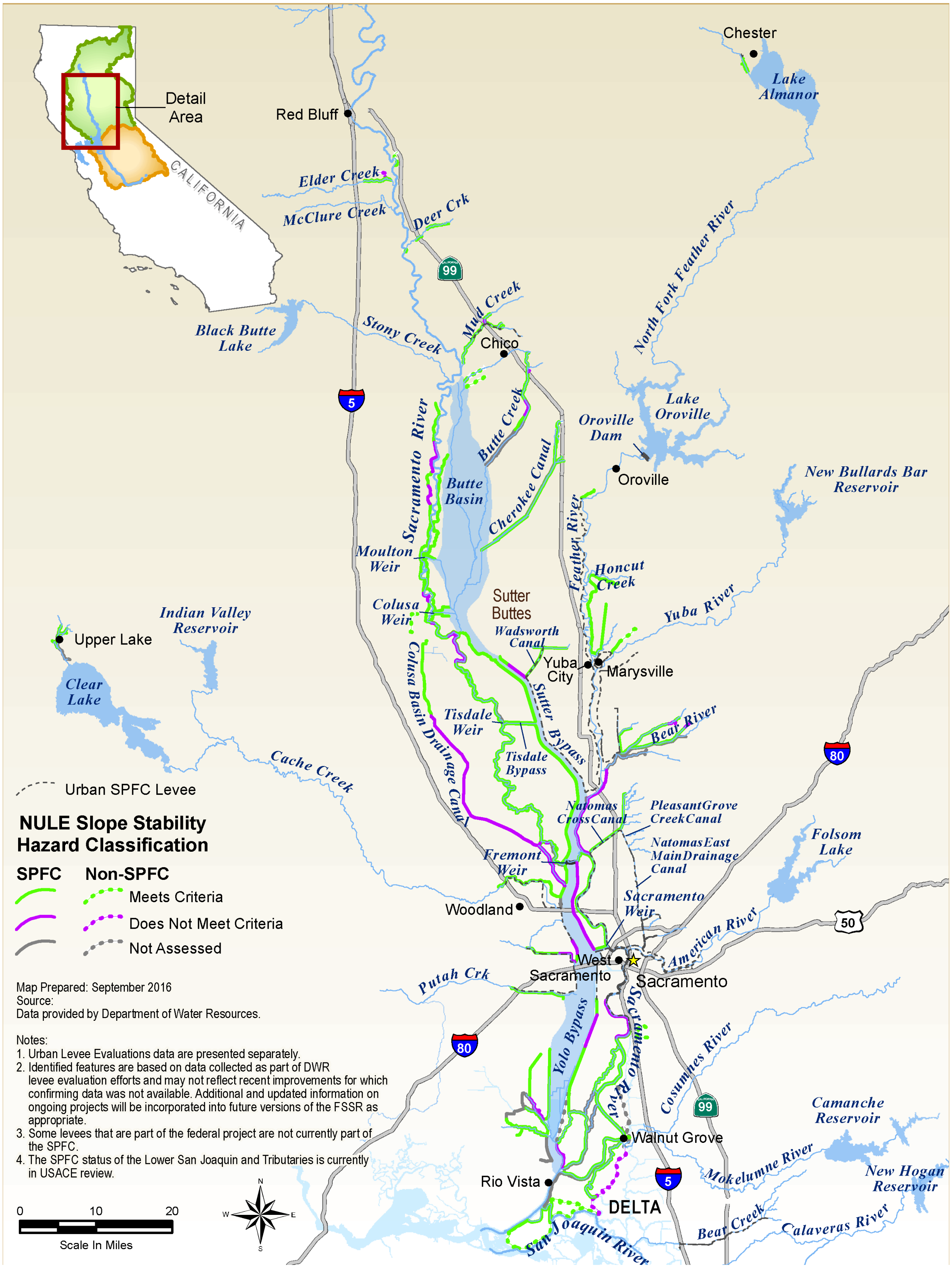


Figure 4-12. NULE Slope Stability Hazard Categorizations in the Sacramento River Watershed

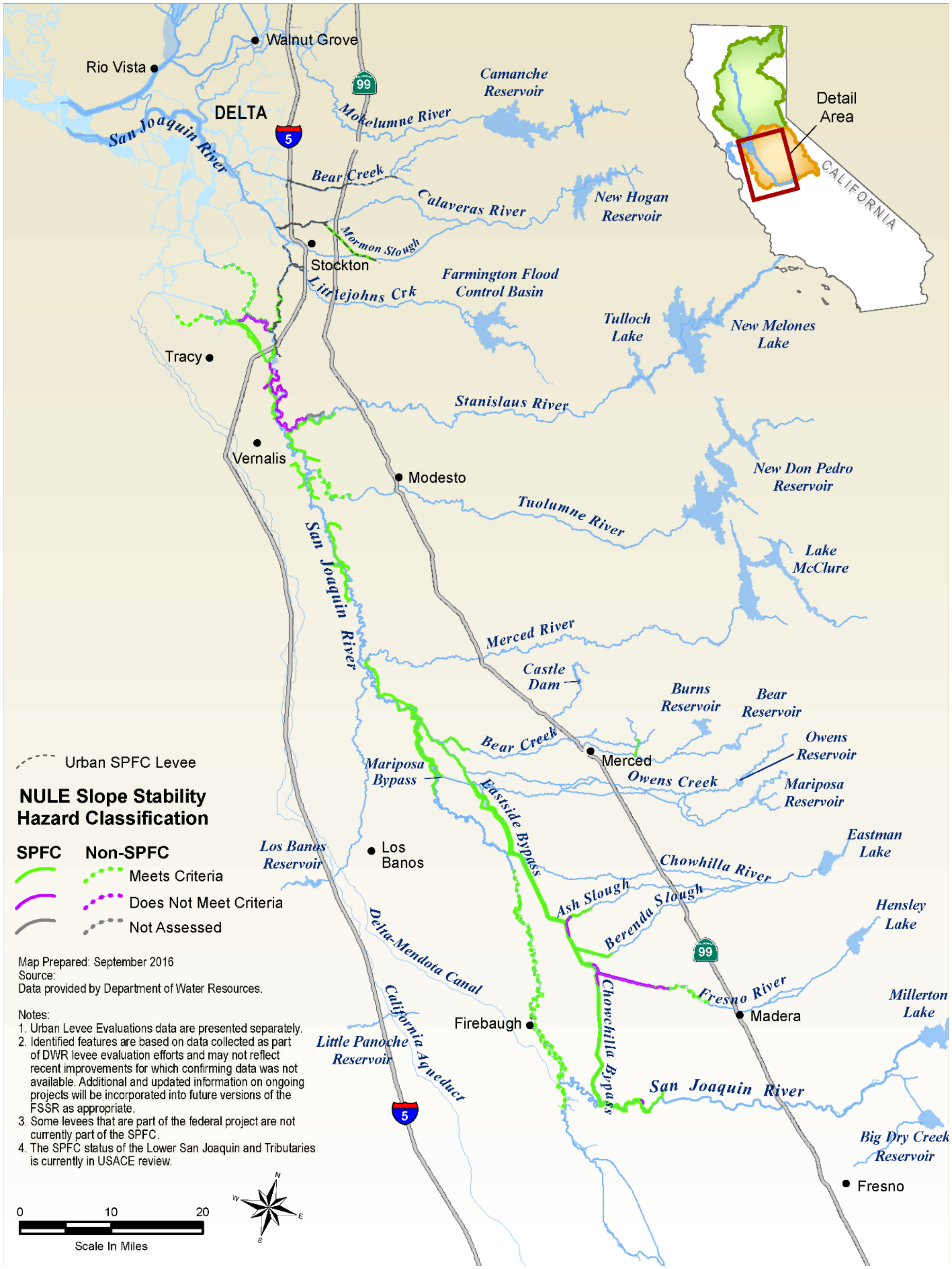


Figure 4-13. NULE Slope Stability Hazard Categorizations in the San Joaquin River Watershed

4.4 Erosion

Levee erosion problems are primarily the result of a lack of modern engineering criteria and construction standards for levees at the time of construction, resulting in unsuitable levee materials and narrow levee alignments in many locations. Deferred maintenance also contributes to erosion problems in some locations. Many early levees were not engineered to meet modern criteria and were constructed with readily available materials dredged from an adjacent river.

In many levee reaches of the Sacramento River system, levee alignments were designed and constructed close to the natural bank to flush out sediments that had accumulated in the system from hydraulic mining activities in the late 1800s. Decisions to construct levees close to channels more than 100 years ago shaped the location and alignment of SPFC levees today. By about 1912, an estimated 87 percent of the 494 miles of river levees in what is now the Sacramento River Flood Control Project had already been constructed on the valley floor. This effectively fixed the location and alignment of these levees for construction of the Sacramento River Flood Control Project. For instance, on the mainstem Feather River, existing levees controlled the location and alignment of approximately 77 percent of the Sacramento River Flood Control Project levees. In addition, some reclamation levees had already been built by 1912, which fixed the location and alignment of some of the bypass levees (Kochis, 1969).

By the mid-twentieth century, high velocity flows had largely scoured hydraulic mining sediment from the system, and erosion was recognized as a problem. As a result, many levees have been critically damaged and many more will continue to erode. Weakened levee geometry, poor soil materials, leaking pipes that penetrate levees, high flow velocity, and wave action have further exacerbated erosion problems.

Deferred maintenance can also contribute to erosion problems. Erosion repair and bank protection need to be conducted in a timely manner to prevent further erosion and possible levee failure. Some erosion can be attributed to rainfall on the levee, causing rounding off of the shoulders and movement of the toe, and should be addressed through maintenance activities; other erosion is attributable to the river’s erosive forces, and should be addressed by bank protection or levee setback or removal projects.

4.4.1 Status Evaluation Methodology

DWR used different methods to assess the potential for erosion for ULE and NULE, reflecting different scopes, objectives, and funding availability for the projects.

Urban Levee Evaluations Project

For this 2017 FSSR, the levee geometry check described in Section 4.1 serves as an indicator for levee erosion problems. Following the completion of ULE, a multitiered erosion evaluation process will be included in the the various GERs and the associated information will be compiled in this 2017 FSSR. The evaluation process will consider levee geometry, potential for wind-wave action, and past erosion history as part of the the first tier analysis. This finalized information will be summarized predominantly through the figures in Section 4.4.3.

ULE levee segments that had potentially moderate or high erosion hazard based on first-tier analysis were assessed under second-tier analyses. During second-tier analyses, levee surface materials and river flow velocities were compared, wave shear stress were evaluated, and field reconnaissance was conducted to verify past performance. ULE levee segments had potentially moderate or high erosion hazard based on the second-tier analyses were assessed under third-tier analysis, which classified levees as having a low, moderate, or high erosion hazard.

As a summation of the ULE analysis, ULE Erosion Hazard categorizations were characterized as:

- Low
- Medium
- High
- Not Assessed

Nonurban Levee Evaluations Project

For NULE, levee performance was evaluated as hazard categories that show potential for levee failure. NULE performed hazard assessments for levee erosion using past performance information from previous annual erosion studies prepared by DWR and USACE, information compiled from other reports, interviews with levee maintenance officials, and field reconnaissance. In addition to these documented occurrences of erosion, evidence of erosion was researched through review of topographic contours of levee waterside slopes. Results are documented in the Geotechnical Assessment Reports for the North NULE Study Area and South NULE Study Area (DWR, 2011a and DWR 2011b). NULE Phase 1 included assessing each NULE levee segment and assigning each segment to one of the following hazard categories:

- Meets Criteria (M)
- Does Not Meet Criteria (DNM)
- Not Assessed (NA)

4.4.2 Limitations of Status Evaluations

The limitations of erosion hazard assessments for ULE and NULE are summarized below.

Urban Levee Evaluations Project

ULE has completed evaluations specifically for erosion. However, because the levee geometry evaluation performed for ULE (described in Section 4.1.3) may indicate potential erosion hazard, it may be considered a proxy for erosion hazards, as mentioned.

Inadequate levee geometry may occur from a variety of conditions, including erosion. The results of that geometry check should be considered a conservative evaluation of the potential hazards associated with erosion. A more specific evaluation of erosion hazard, as described in Section 4.4.1, was provided in the Geotechnical Evaluation Reports prepared by DWR for each ULE study area.

Nonurban Levee Evaluations Project

As mentioned, the hazard categories provided in the NULE Geotechnical Assessment Reports for the North NULE Study Area and South NULE Study Area (DWR, 2011a and DWR, 2011b) represent a preliminary analysis of levee conditions. They are sufficient only to guide subsequent NULE field activities and prepare preliminary remedial alternatives (and associated cost estimates) necessary for repairs and improvements to achieve acceptable levee performance. NULE levee erosion hazard assessment results are not meant to be used to determine how a levee or associated system may perform during a flood event, or whether levees comply with current levee design criteria.

4.4.3 Results of Status Evaluations

ULE and NULE levee erosion hazard assessment results are summarized below. For additional information about levee inspection results, historical erosion occurrences, recent remedial actions, ongoing and planned repairs and improvements, and other actions to improve future evaluations, see Appendix A, Section A-6. Also, USACE periodic inspection results about levee erosion/bank caving for 10 USACE levee systems are included in Appendix A, Section A-1.

Urban Levee Evaluations Project

ULE has completed a hazard assessment specifically for levee erosion susceptibility; this is summarized in Figure 4-14.

Nonurban Levee Evaluations Project

Estimates of NULE levee erosion hazard categorizations for the Sacramento River and San Joaquin river watersheds are shown in Figures 4-15 and 4-16, respectively. Approximately one-seventh of SPFC NULE levees in the Sacramento River watershed were categorized as having a high erosion hazard. NULE levee segments with high erosion hazard in the Sacramento River watershed are predominantly located in the area between the City of Sacramento and the Bear River in Yuba County.

The majority of NULE levees in the San Joaquin River watershed were categorized as having a low erosion hazard. The approximately one-eighth of SPFC NULE levee segments with high erosion hazard are predominantly located on the lower San Joaquin River (downstream from the Tuolumne River confluence), at Berenda Slough, and on the Fresno River.

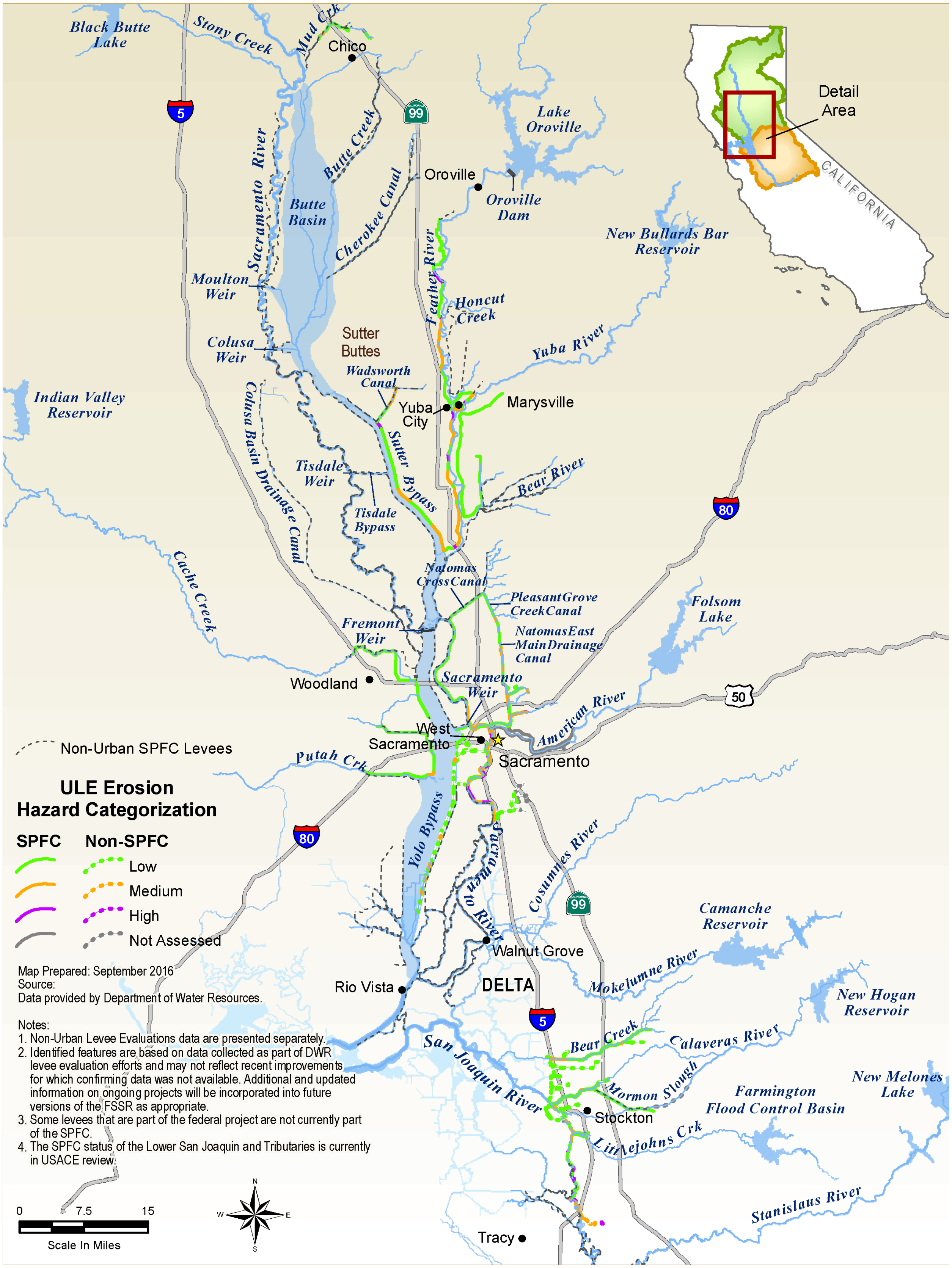


Figure 4-14. ULE Erosion Hazard Categorization

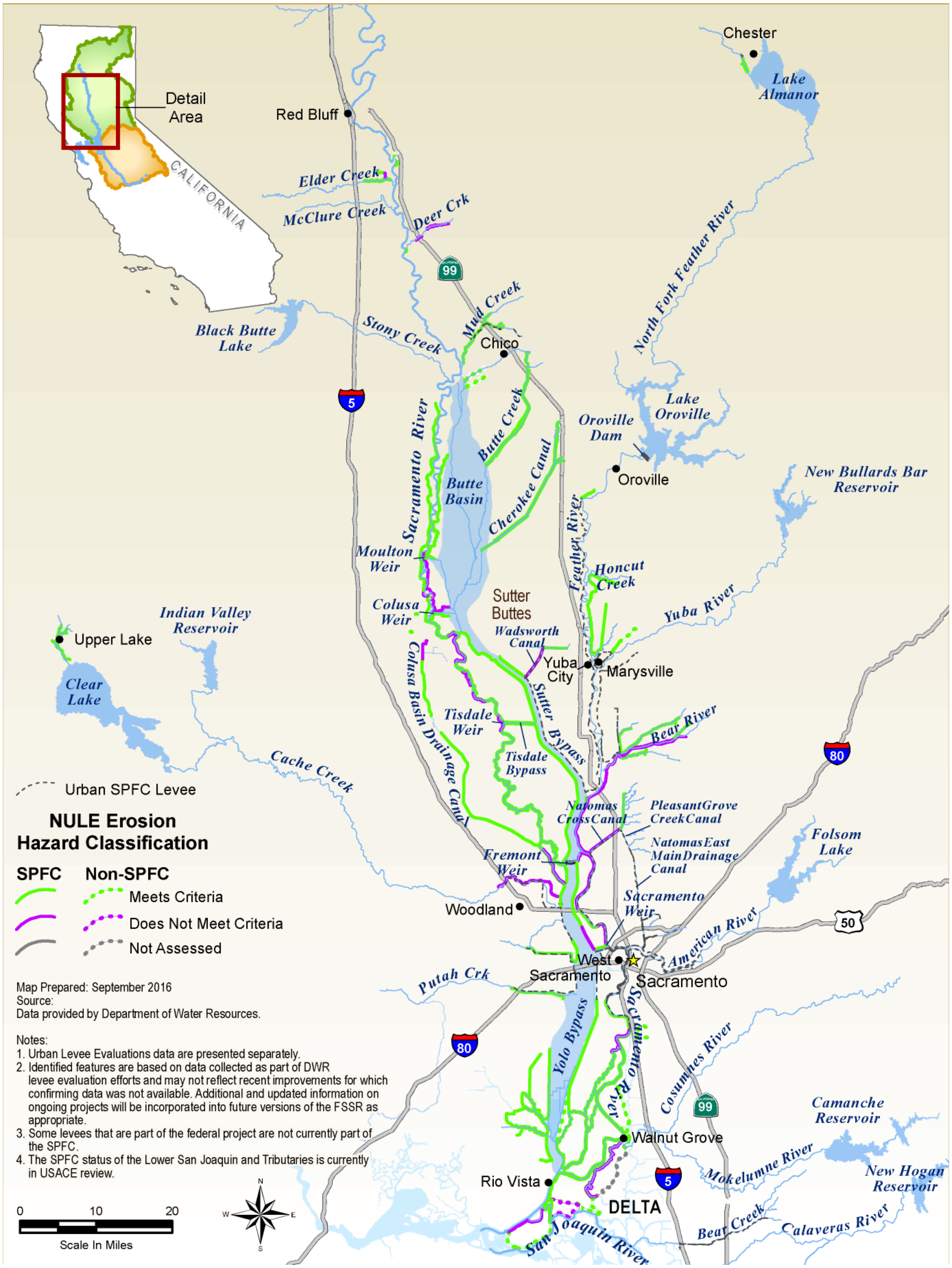


Figure 4-15. NULE Erosion Hazard Categorizations in the Sacramento River Watershed

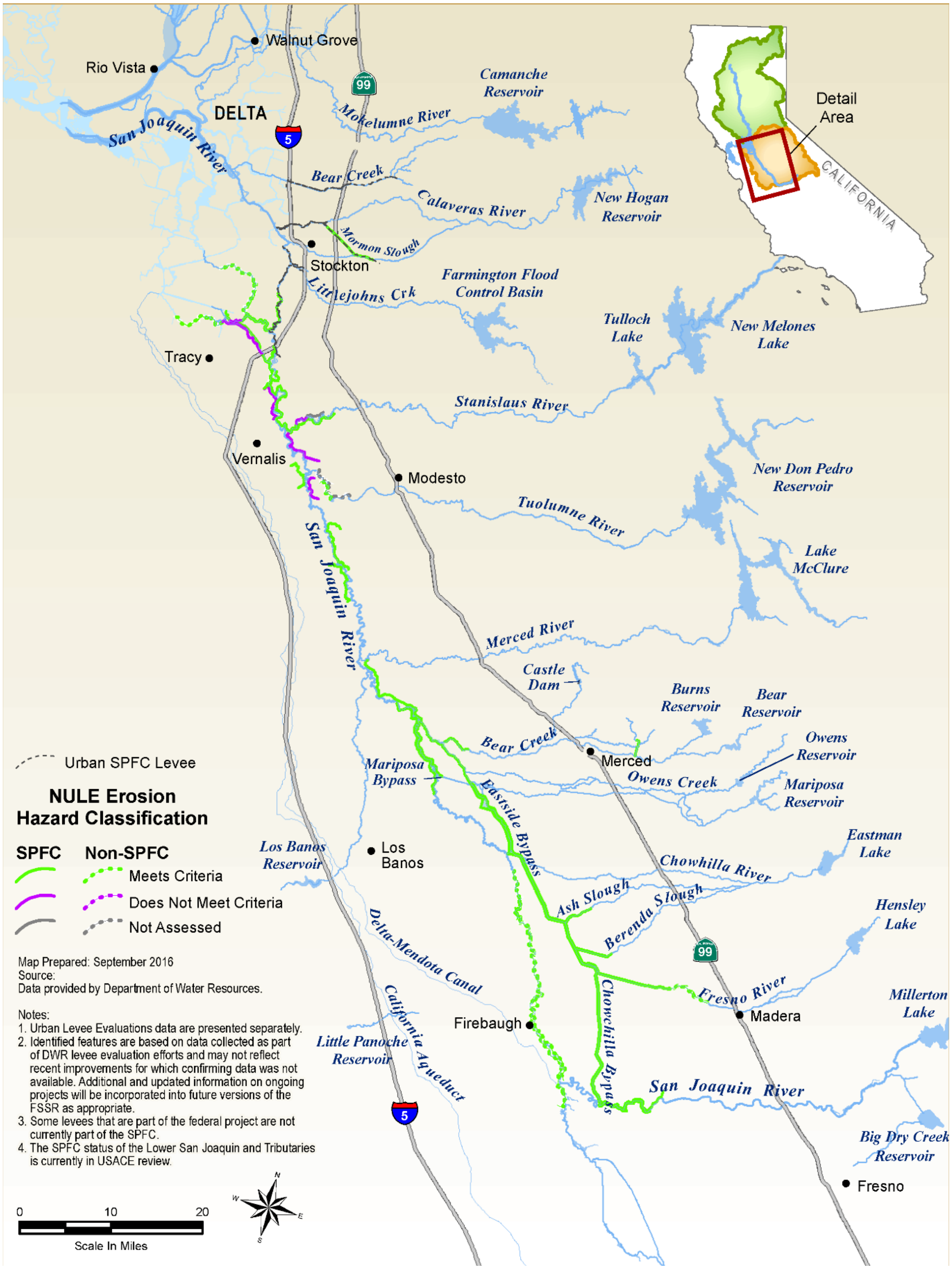


Figure 4-16. NULE Erosion Hazard Categorizations in the San Joaquin River Watershed

4.5 Settlement

Settlement problems exist where areas along the crown of a levee are lower than the design elevation. Three types of settlement problems affect SPFC levees: land subsidence, consolidation settlements, and localized depressions. Each settlement type is caused by different factors.

Land subsidence occurs in some regions from factors outside flood management, including groundwater extraction, natural gas, and peat oxidation, that have occurred over large areal extents rather than in localized places. Regional land subsidence contributes to settlement of levee foundations.

Consolidation settlement results from consolidation of underlying strata during and after levee construction because of the weight of the overlying levee structure. Consolidation settlement is generally applicable to levee embankments or levee raises soon after they have been constructed. Because most SPFC levees have been in place for nearly 100 years, it is likely that most primary consolidation settlement has already occurred; additional consolidation settlement in these locations is not expected. However, settlement of levees constructed on peat or other soft soils can occur gradually over time.

Localized depressions are surface manifestations of an underlying problem in a levee embankment, and are most often the result of internal voids and cavities. Such depressions and sinkholes are more hazardous to levees than long-term consolidation settlements because the collapse of voids present within a levee or its foundation can pose immediate threats to the levee embankment. Presence of localized depressions can be affected by soft, dispersive soils in a levee or levee foundation, early twentieth-century design and construction practices, and lack of any levee settlement criteria at the time of construction. In addition, many existing levees do not comply with current USACE levee settlement criteria because the levees were constructed before adoption of these criteria. Deferred maintenance problems from animal burrows or leaky pipes that penetrate a levee or levee foundation can also increase the vulnerability of a levee to localized depressions. In addition, localized depressions can be increased by erosion or seepage. Finally, localized depressions can result from vehicle travel on the levee during wet conditions, resulting in rutting and displacement of levee soils.

4.5.1 Status Evaluation Methodology

Settlement conditions described in this 2017 FSSR consider only localized depressions. DWR visually inspects SPFC levees for crown surface depressions and rutting at least two times per year, and reports results annually. Table 4-3 shows the DWR inspection rating descriptions for crown surface/depressions/rutting on earthen levees.

Table 4-3. Levee Inspection Rating Descriptions for Crown Surface/Depressions/Rutting on Earthen Levees

Inspection Rating	Rating Descriptions
Acceptable (A)	The road is in all-weather condition and drains properly without any ponded water. There are no ruts, pot holes, or other depressions on the levee crown or embankments. The levee crown and access roads are well established and drain properly without any ponded water. The crown is at or above the design elevation.
Minimally Acceptable (M)	The all-weather surface requires some maintenance but will not prevent access during the coming flood season. Some ruts, holes, settlement or other depressions on the levee less than 6 inches deep were observed or sections of the crown have settled below the design elevation for distances less than 100 feet.
Unacceptable (U)	The all-weather surface will not be usable during the coming flood season. Material should be added or the roadway regraded before the next flood season. There are depressions greater than 6 inches deep that will pond water or a large amount of additional road material is needed to ensure all-weather access. The levee may have settled below the design elevation for a distance greater than 100 feet.

Source: DWR, 2015

4.5.2 Limitations of Status Evaluations

ULE and NULE did not assess settlement hazard in detail. Results from DWR’s crown surface/depressions/rutting inspections presented here were not considered in assigning ULE and NULE overall hazard classifications and categorizations, respectively. However, levee settlement is included in this 2017 FSSR as a levee status factor because it can potentially reduce levee freeboard or compromise levee integrity.

As mentioned, DWR’s levee inspections focus on identifying localized depressions and do not identify settlement problems from land subsidence or consolidation settlement. A typical levee inspection occurs from the crown of a levee. Thick vegetation and wide berms can obstruct an inspector’s view of levee depressions. A more thorough evaluation of settlement conditions would include consideration of subsurface conditions to identify problems, and a systemwide review of existing levee crown elevation compared to levee design elevation.

4.5.3 Results of Status Evaluations

Minimally Acceptable and Unacceptable levee crown surface/depressions/rutting inspection ratings from the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b) are shown in Figures 4-17 and 4-18. DWR inspections identified five locations of localized levee settlement that affect the integrity of levees (i.e., ratings of Unacceptable).

For additional information about levee sinkhole and subsidence data collected by NULE, recent, ongoing, and planned repairs and improvements, and ongoing actions to improve future evaluations, see Appendix A, Section A-6. Also, USACE periodic inspection results for levee settlement and depressions/rutting for 110 USACE levee systems are included in Appendix A, Section A-1.

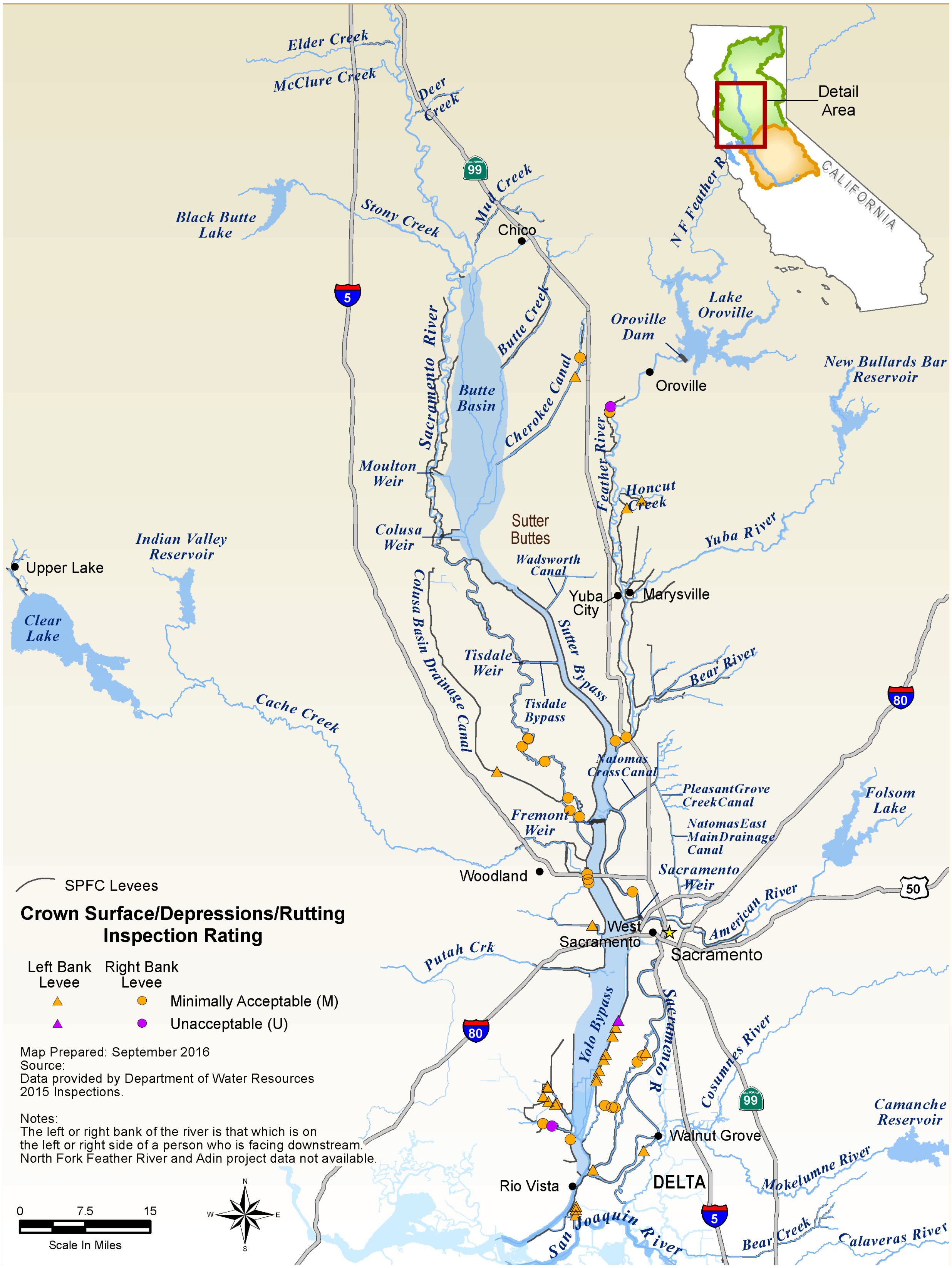


Figure 4-17. 2015 Crown Surface/Depressions/Rutting Inspection Ratings in the Sacramento River Watershed

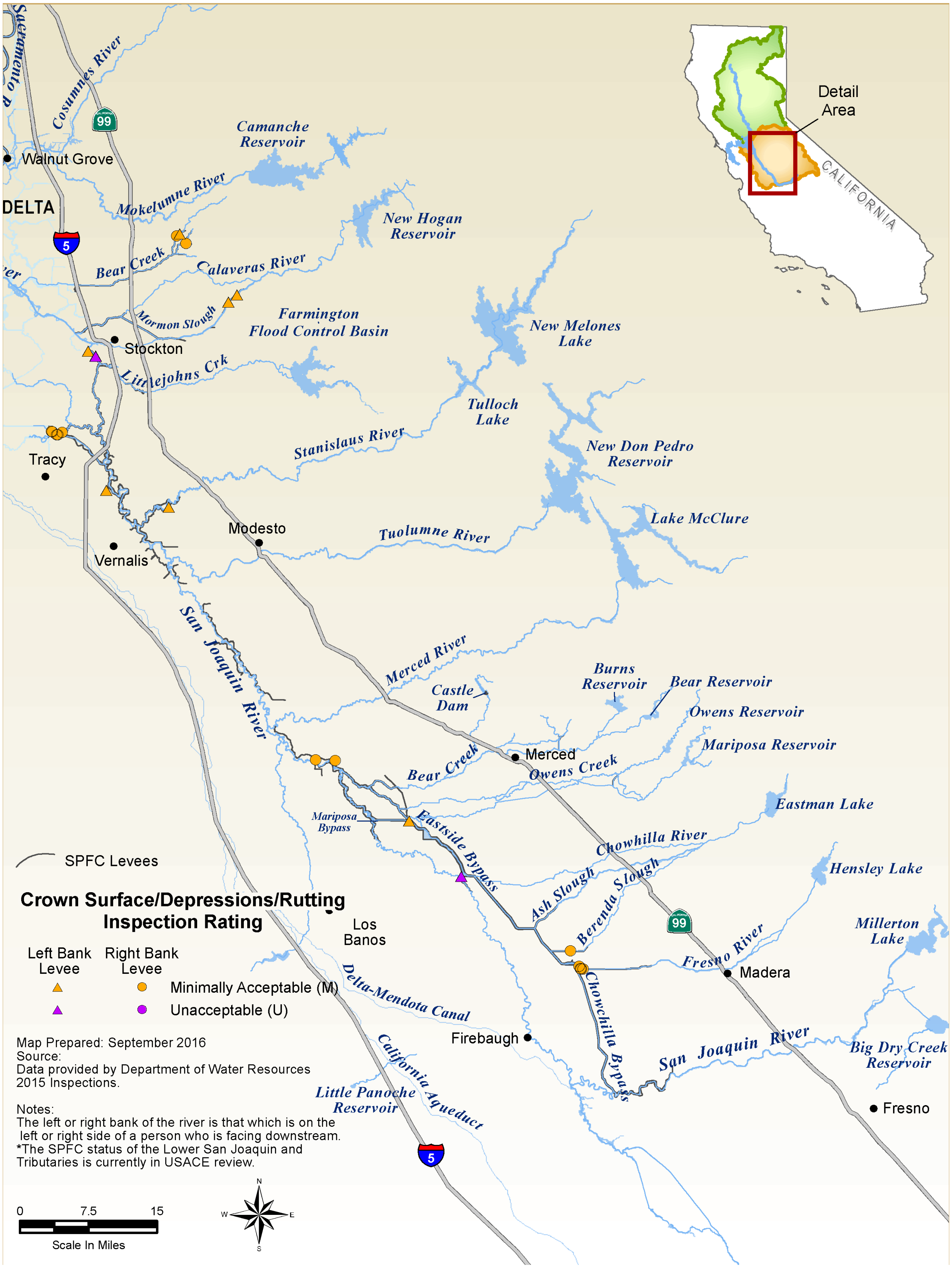


Figure 4-18. 2015 Crown Surface/Depressions/Rutting Inspection Ratings in the San Joaquin River Watershed

4.6 Penetrations

Penetrations include man-made objects that cross under or through a levee or floodwall and can create a preferential seepage path or hydraulic connection with the waterside. Typically, a penetration is a pipe or transportation structure, such as a roadway or rail line. Many penetrations are or were used for interior drainage and agricultural irrigation and are located in both urban and nonurban areas. Many penetrations were installed after levee construction and were therefore often not accounted for as part of original levee design. Other penetrations were constructed first and levees were built on top.

Penetrations can be potential pathways for seepage

Currently, penetrations through a levee must comply with criteria found in Title 23, Division 1, Chapter 1, Article 8, Section 123 of the California Code of Regulations. However, there are many cases where penetrations do not meet design criteria. In some instances, no modifications to the penetrations were made at the time the levee was constructed or when the levee was adopted as part of the SPFC. In addition, many old or abandoned penetrations were not installed using current criteria. Many penetrations were included as part of a particular flood control project and maintenance was turned over to maintaining agencies. DWR’s UCIP has identified over 7,600 penetrations through SPFC levees. However, there are still numerous penetrations that have not been located. Documentation of historical abandonment of penetrations is limited. As mentioned, penetrations can provide potential pathways for seepage, and may contribute to levee failure. In some instances, if backfill surrounding penetrations is more permeable than levee soils, a seepage pathway can develop. Susceptibility to seepage is particularly acute from older penetrations, which are prone to corrosion or collapse. Metal pipes can corrode, creating holes and leaks. These penetrations can induce the levee embankment to erode, creating areas of weakness or internal voids. This internal erosion often remains hidden until a surface expression develops, such as a sinkhole or localized depression (see Section 4.5 for a discussion of localized depressions).

In many instances, however, internal erosion has no surface expression and the threat to a levee remains undetected. Challenges to evaluating the threat to levee integrity from levee penetrations include the high number of penetrations in the Sacramento and San Joaquin river watersheds, limited existing documentation, and the significant time and expense required for invasive inspections.

Damage to levee embankments from penetrations can contribute to seepage, stability, and settlement problems. If the phreatic surface[10] intersects an internal levee embankment cavity during a high water event, internal erosion may accelerate, and potential for development of a levee breach will increase. Levee seepage, stability, and settlement problems are discussed in Sections 4.2, 4.3, and 4.5, respectively.

4.6.1 Status Evaluation Methodology

Through UCIP, DWR has identified, located, and visually inspected over 7,600 existing penetrations over the last 3 to 5 years. UCIP uses data from existing sources, including DWR levee logs, O&M manuals, permits, as-built drawings, and data from ULE and NULE. Each penetration is field verified and assigned a condition. As part of this effort, DWR has categorized existing penetrations into three maintenance categories: Urgent, Non-Urgent, and No Action Needed. Penetrations that appear well-maintained during a visual inspection are categorized as No Action Needed. Penetrations are categorized as Non-Urgent if there are maintenance deficiencies that do not immediately impact levee integrity during the next high water event. A penetration is categorized as Urgent if there are visible signs of damage or excessive wear and tear that could lead to levee integrity issues during the next high water event. DWR has plans to integrate these UCIP categories into the inspection ratings in the near future.

4.6.2 Limitations of Status Evaluations

DWR is continuing to catalog levee penetrations through SPFC levees. Due to ongoing maintenance activities and new permit applications, there is a need for continual updates and quality control of the utility crossing inventory database. As new information becomes available, revisiting previous records is necessary to make sure that the latest information is being used. Additional penetrations data, including data from remote sensing or electromagnetic surveys may be incorporated into future updates of this 2017 FSSR.

Efforts are also ongoing to develop criteria to evaluate risks associated with penetrations. Although records exist for many permitted penetrations, physical characteristics of the penetration (e.g., pipe dimension, material, use) were not documented consistently, and records stem from several different sources. The UCIP has been able to correct for many of the inconsistencies between the available data sources. However, there are a number of penetrations not found during field investigations that still may not have consistent records about the size, material, and use of the penetration. Efforts to sort out these inconsistencies are ongoing and updated as new information becomes available.

Penetrations data were some of the qualitative data inputs incorporated in assigning a NULE through seepage hazard category, and therefore were also considered during NULE overall hazard categorization. Penetrations data were not considered when assessing overall hazard classification for ULE levees because ULE seepage hazards were assessed using numerical computer models incorporating site-specific geotechnical data from soil borings.

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[10] The phreatic surface is the location where pore water pressure is under atmospheric conditions. The phreatic surface normally coincides with the water table.

4.6.3 Results of Status Evaluations

Figures 4-19 and 4-20 show documented levee penetrations for the Sacramento and San Joaquin river watersheds, respectively. Data show that penetrations are prevalent throughout the entire levee system. As mentioned, the current DWR UCIP database includes more than 7,600 penetrations through SPFC levees. In the Sacramento Valley, existing data include the greatest density of penetrations along the Sacramento River levees upstream from the Sutter Bypass and downstream from the City of Sacramento, with fewer penetrations documented along the Feather River levee system, along the smaller tributary stream levees, and along the bypass levees. In the San Joaquin Valley, penetrations have been identified throughout the San Joaquin River levees between Stockton and Fresno.

Tables 4-5 through 4-9 summarize information related to penetrations from the UCIP database. UCIP penetration status indicates whether or not a penetration was located during field verification. A penetration may have been found directly, may have been found via an indicator, or may not have been found. UCIP keeps track of penetration locations from a number of sources. However, some of these penetrations may not be located without subsurface investigation or remote sensing methods (see Table 4-4).

Table 4-4. UCIP Penetration Status by Watershed

Watershed	Found	Indicator Found	Not Found	Total
Sacramento River	2844	985	1419	5248
San Joaquin River	1627	222	512	2361
Grand Total	**4471**	**1207**	**1931**	**7609**

As part of the UCIP field investigation, penetrations were categorized as discussed in Section 4.4. The number of penetrations that have been categorized into each type are shown in Table 4-5. A total of 895 penetrations have not been rated at this time.

Table 4-5. UCIP Maintenance/Repair Category by Watershed

Watershed	No Action Needed	Non-Urgent	Urgent	None	Total
Sacramento River	2617	1612	259	760	5248
San Joaquin River	1252	873	101	135	2361
Grand Total	**3869**	**2485**	**360**	**895**	**7609**

A variety of materials have been used in the construction of penetrations inventoried under UCIP. Each material may have different costs, operations and maintenance procedures, and lifespans. Table 4-6 shows the number of penetrations constructed using a particular material.

Table 4-6. Type of Material Used for Penetrations by Watershed

Penetration Material By Watershed	Number of Penetrations
Sacramento River	**5248**
Corrugated Metal	730
Plastic Pipe (HDPE, PVC, etc.)	190
Galvanized Iron	140
Steel	2014
Reinforced Concrete	306
Other	75
Unknown	1793
San Joaquin River	**2361**
Corrugated Metal	717
Plastic Pipe (HDPE, PVC, etc.)	91
Galvanized Iron	52
Steel	713
Reinforced Concrete	208
Other	9
Unknown	571

HDPE = high density polyethylene
PVC = polyvinyl chloride

Penetrations have been installed for a number of different purposes including: irrigation, drainage, potable water supply, gas and oil transportation, and communications. Table 4-7 shows the number of penetrations that fall into each category as recorded in the UCIP database.

Table 4-7. UCIP Documented Penetration Type by Watershed

Penetration Type by Watershed	Penetrations
Sacramento River Total	**5248**
Communication/Electrical	612
Interior Drainage	1312
Drinking water, Reclaimed water, or Wastewater	333
Gas,Oil,Steam, Petroleum, or Chemical	427
Irrigation	1676
Unknown/Other	888
San Joaquin Total	**2361**
Communication/Electrical	178
Interior Drainage	1146
Drinking water, Reclaimed water, or Wastewater	122
Gas, Oil, Steam, Petroleum, or Chemical	69
Irrigation	599
Unknown/Other	247
Grand Total	**7609**

Age of a penetration can impact the integrity of the flood system. As a result, older penetrations tend to be at higher risk of developing issues, especially when not maintained. Table 4-8 shows penetrations age.

Table 4-8. Number of Penetrations by Age and Watershed (per UCIP)

Age in Years, Penetrations by Watershed	Penetrations
Sacramento River Total	**5248**
Less than 10	117
10 to 20	266
20 to 30	384
30 to 40	363
40 to 50	574
Greater than 50	3544
San Joaquin Total	**2361**
Less than 10	17
10 to 20	115
20 to 30	207
30 to 40	150
40 to 50	821
Greater than 50	1051
Grand Total	**7609**

Penetrations must be permitted via an encroachment permit issued by the Board and USACE. However, since many penetrations were installed prior to the construction of the levees, or before the levee was included in the flood control system, there are many penetrations that do not have encroachment permits. Penetrations referenced in the Flood Control System Operations and Maintenance manuals may have been issued an Automatic Board Order, but this was not done in many cases. As a result, there are numerous penetrations without an associated permit. Table 4-9 shows the current UCIP information regarding which penetrations encroachment permits.

Table 4-9. UCIP Penetration Permit Status by Watershed

Watershed	Permitted	Shown in O&M/ As-Builts	Unknown*
Sacramento River	3194	1136	918
San Joaquin	766	1064	531
Grand Total	**3960**	**2200**	**1449**

Note:
*Unknown penetrations do not currently have a permit referenced in UCIP records.

In addition, available information from maintaining agencies, permit records, and field inspections has been used to determine if a penetration is currently used, is abandoned, or has been removed. UCIP keeps track of current and former penetrations that could lead to levee integrity issues in the future. For additional information on recent levee remedial actions, ongoing and planned remedial actions, and ongoing actions to improve future evaluations, see Appendix A, Section A-7.

Figure 4-19. Levee Penetrations in the Sacramento River Watershed

Figure 4-20. Levee Penetrations in the San Joaquin River Watershed

4.7 Levee Vegetation

This section discusses vegetation management on levees (channel vegetation management is discussed in Section 5.2). Levee vegetation policy is described in greater detail in CVFPP.

State and federal agencies have differing perspectives on levee vegetation criteria and the extent to which levee vegetation policies have evolved over time. The following reflects DWR's perspective on levee vegetation criteria.

4.7.1 Vegetation Policy Development

When the Memorandum of Understanding between USACE and the Board was signed for the Sacramento River Flood Control Project in 1953, woody vegetation was already an integral component of the levees. For many decades, USACE's approach to vegetation on levees was to allow some vegetation, willows, and other suitable growth, where this vegetation could prevent erosion and wave wash. The Sacramento River Flood Control Project and Lower San Joaquin River and Tributaries Project Standard O&M manuals allow some vegetation to remain on levee waterside slopes to prevent erosion and wave wash (USACE, 1955a and USACE, 1959).

Over the last decade, USACE's enforcement of its policies regarding vegetation on levees has become more stringent. In April 2007, a Draft USACE White Paper provided specific guidance for USACE best management practices for vegetation management. In April 2009, USACE issued ETL 1110-2-571, Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures (USACE, 2009b). These guidelines limit growth (brush, weeds, or trees) to smaller than 2 inches in diameter.

However, implementation of USACE's guidelines would have resulted in large-scale removal of and extensive environmental damage to Central Valley's remaining riparian and shaded riverine aquatic habitat, the majority of which exists along levees. Furthermore, no scientific evidence was used to support that removal of vegetation from the levees would reduce flood risk and increase public safety.

In August 2007, DWR and the Board created the California Levees Roundtable, a partnership of maintaining agencies, USACE, FEMA, and resources agencies to generate procedures for vegetation management that are supported by the regulatory agencies and allow maintaining agencies to fulfill their public safety responsibilities. To address levee visibility and inspection issues presented by vegetation on levees, DWR adopted Interim Levee Vegetation Inspection Criteria in fall 2007 (DWR, 2007). These criteria were used temporarily while research on the impacts of vegetation on levees was conducted and the agencies worked to establish agreed upon criteria. On February 27, 2009, the California Levees Roundtable issued a joint collaborative document titled California Central Valley Flood System Improvement Framework (California Levee Roundtable, 2009), which provided interim guidance on best vegetation management practices. The California Central Valley Flood System Improvement Framework was later used as the basis for the comprehensive Vegetation Management Strategy (VMS) now in use. The VMS was also included in the 2012 CVFPP.

USACE continued to receive feedback on their levee vegetation management policies and conduct long-term program reviews and changes such as for PL 84-99 Rehabilitation Program. This program provides federal funds to repair levees after a flood event to local levee districts. On March 24, 2014, USACE issued new interim guidance to sponsors regarding the eligibility requirements for the PL 84-99 Rehabilitation Program. The new interim guidance states, “Vegetation on levees is no longer a criterion for determining Program eligibility.”

This revision carried over into other USACE guidelines. On April 30, 2014, USACE issued ETL 1110-2-583, an update to the Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures (USACE, 2014). In this ETL, USACE updated the applicability as follows: “…This ETL is not applicable to determinations for eligibility in the Rehabilitation Program (previously called the Rehabilitation and Inspection Program) under ER 500-1-1 and the provisions of Public Law 84-99.” All other provisions in the 2014 ETL are the same as the 2009 ETL.

DWR continues to conduct research and to move forward to refine vegetation management practices, such as developing the Levee Tree Assessment (DWR, 2015c) that is discussed further in the next section. Details about the VMS developed in 2012 are further developed in the 2017 CVFPP Update’s Conservation Strategy (Appendix D – Vegetation Management Strategy).

4.7.2 Levee Tree Assessment Process

The 2012 CVFPP VMS identified specific levee zones where existing vegetation would remain or be managed. The VMS also specified that remaining levee vegetation be evaluated to determine if it posed an unacceptable threat to levee integrity and removed, if determined to be such a threat. Although a key component of the VMS, the 2012 CVFPP did not specify how to identify vegetation that posed an unacceptable threat to levee integrity, and it did not describe management actions, other than tree removal, to address unacceptable threats.

In order to provide more specificity to the VMS, DWR has been developing the Levee Tree Assessment (DWR, 2015c). to identify levee vegetation (specifically trees) that may pose an unacceptable threat to levee integrity. The Levee Tree Assessment (DWR, 2015c) describes criteria where trees could threaten levee integrity, and may therefore require management to reduce or eliminate threats. These criteria reflect the best available scientific information regarding the mechanisms by which trees may threaten levee integrity, along with decades of on-the-ground experience managing levee vegetation.

The Levee Tree Assessment (DWR. 2015c) provides levee maintainers with more detailed guidance for implementing the VMS, and provides a more nuanced approach to managing trees on levees.

The VMS now in use allows Central Valley levees to retain acceptable maintenance ratings and PL 84-99 rehabilitation eligibility as long as levee trees and shrubs are properly trimmed and spaced to allow for visibility, inspection vehicles, and floodfight access.

The VMS discussed in the Conservation Strategy refined DWR's levee vegetation inspection criteria for visibility and accessibility, and forms the primary basis for identifying levee vegetation problems. This criteria along with the USACE ETL 1110-2-571, established the concept of the vegetation management zone (VMZ). The VMZ is the area on and near a levee in which vegetation is managed for visibility and accessibility; the VMZ also provides some habitat value over the life span of woody vegetation.

More specific details about managing vegetation under a variety of levee conditions can be found in the 2017 CVFPP Update's Conservation Strategy (Appendix D – Vegetation Management Strategy). Table 4-10 lists levee inspection rating descriptions for vegetation on earthen levees.

Table 4-10. Levee Inspection Rating Descriptions for Vegetation on Earthen Levees

Inspection Rating	Rating Descriptions
Acceptable (A)	The levee has no unwanted vegetation (brush, bushes, and undesirable weeds) blocking visibility or access; vegetation is maintained per DWR's Vegetation Criteria.
Minimally Acceptable (M)	Tall grass, weeds, brush or other vegetation partially block visibility of or access to the levee and/or 15 feet or the limit of the easement at the landside toe and 20 feet from shoulder down the waterside of the levee.Tall grass, weeds, or brush partially block visibility of or access to the levee and/or are within 10 feet of the landside toe.
Unacceptable (U)	Tall grass, weeds, brush or other vegetation completely block visibility of or access to the levee and/or to 15 feet or the limit of the easement at the landside toe and also 20 feet from shoulder down the waterside of the levee. Tall grass, weeds, or brush completely block visibility of or access to the levee and/or are within 10 feet of the landside toe.

Source: DWR, 2010b

Note:

See Appendix A-8, Figure A-31, for schematic showing *DWR Interim Vegetation Inspection Criteria for Standard Levees*, October 2007.

Table 4-11 lists the levee inspection rating descriptions for trimming or thinning trees on earthen levees.

Table 4-11. Levee Inspection Rating Descriptions for Trimming/Thinning Trees on Earthen Levees

Inspection Rating	Rating Descriptions
Acceptable (A)	Any trees on the levee or the landside easement are trimmed up at least 5 feet above the levee slope and spaced enough to allow visibility and flood fight access. All trees are maintained per DWR's Vegetation Criteria.
Minimally Acceptable (M)	Moderate density of limbs, leaves, or the trees themselves are partially obstructing visibility and flood fight access to the landside levee slope and/or within the landside easement, and and 20 feet from shoulder down the waterside of the levee.
Unacceptable (U)	Significant density of limbs, leaves, or the trees themselves are completely obstructing visibility and flood fight access to the landside levee slope and/or within the landside easement, and 20 feet from shoulder down the waterside of the levee.

Source: DWR, 2010b

Note:

See Appendix A-8, Figure A-31, for schematic showing *DWR Interim Vegetation Inspection Criteria for Standard Levees*, October 2007.

Levee vegetation data were not considered in the assignment of the ULE and NULE overall hazard classifications and categorizations, respectively. However, levee vegetation data are included in this 2017 FSSR because ongoing research is evaluating the potential impact of levee vegetation on levee integrity.

4.7.3 Limitations of Status Evaluations

Reported levee vegetation conditions are based on inspections and assessments relative to the 2015 DWR Annual Inspection Report (Appendix D, Vegetation Management Strategy).

4.7.4 Results of Status Evaluations

Inspection results reflect vegetation and trimming/thinning trees levee inspection ratings from the 2015 Annual Inspection Report (DWR, 2015a), updated by data collected from DWR's additional site visits in 2015. Unacceptable and Minimally Acceptable inspection ratings for vegetation and trimming/thinning trees maintenance issues are shown in Figures 4-21 through 4-24 for the Sacramento and San Joaquin river watersheds.

In 2015 there were 111 miles of unacceptable and nearly 200 miles of minimally acceptable vegetation and tree trimming/thinning issues in the Sacramento and San Joaquin river watersheds. These issues alone account for nearly 42 percent of all identified issues within the system. This is not uncommon and has consistently been the most pervasive issue that maintaining agencies have to deal with. Of the 1,571 identified vegetation and trimming/thinning trees related issues, only 1,034 were determined to be the responsibility of the LMA, and were therefore used to assess their overall performance as maintainers. The remaining 537 issues were identified as enforcement issues, meaning someone other than the LMA is responsible for addressing them. These enforcement issues are typically not high priority and are not addressed until other higher priority violations have been resolved. Due to limited resources, Board enforcement staff address violations in a worst-first manner. To address these relatively minor issues, the Board enforcement section would need to be funded for additional staff.

Because habitats for federal and State listed species can be located on the levees, managing vegetation on levees can be complex and challenging. Appropriate vegetation management often requires environmental permitting because of these habitat concerns. DWR continues to work with the regulatory agencies to provide permitting coverage for O&M activities to reduce impacts on federal and State listed species while maintaining the safety and integrity of the flood control system.

Additional information on recent, ongoing, and planned levee remedial actions, and ongoing actions to improve future evaluations of levee vegetation problems is included in Appendix A, Section A-8. Also, USACE periodic inspection results for levee vegetation growth (based on USACE levee vegetation inspection criteria) in 110 USACE levee systems are included in Appendix A, Section A-1.

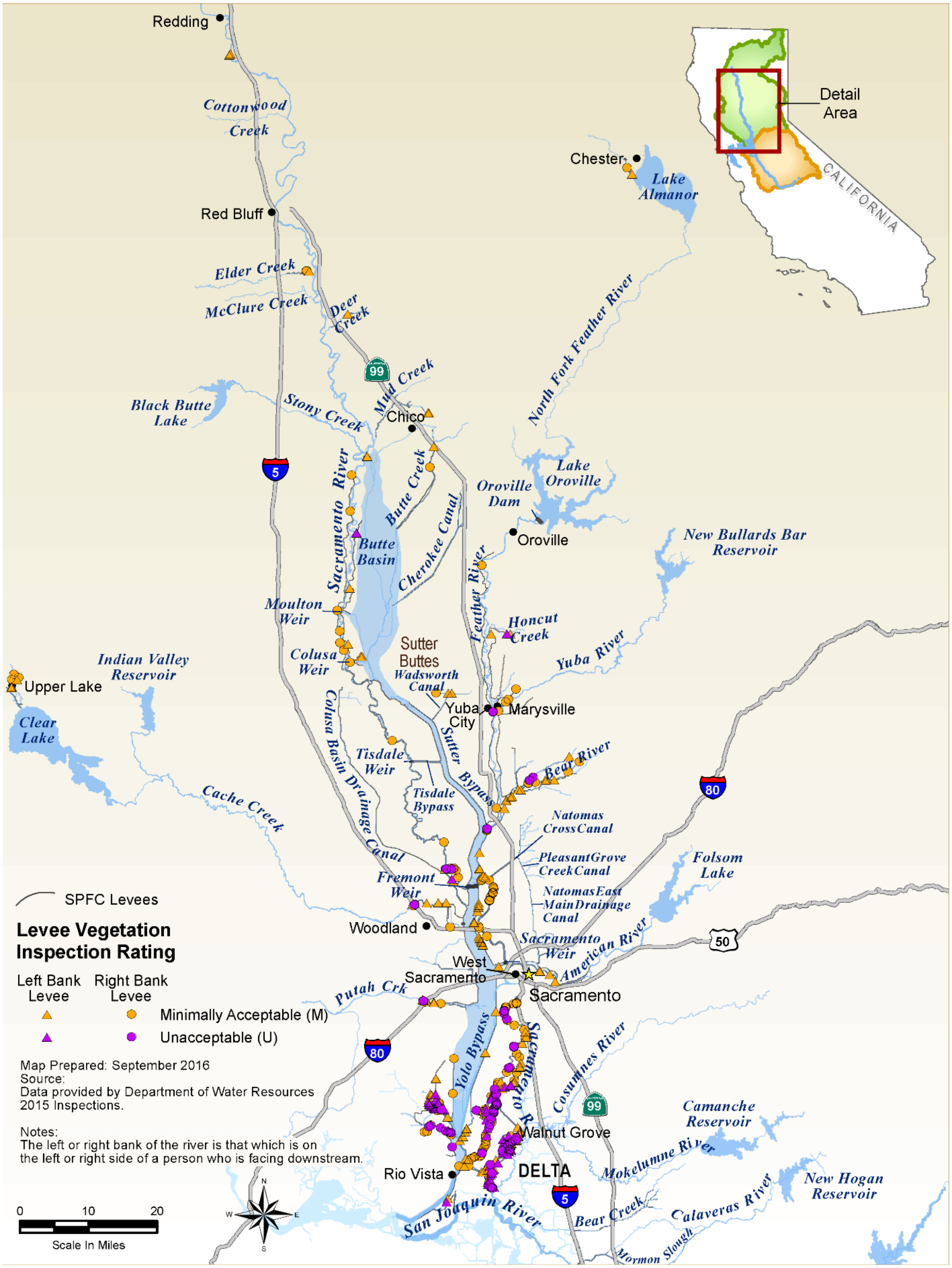

Figure 4-21. 2015 Levee Vegetation Inspection Ratings in the Sacramento River Watershed

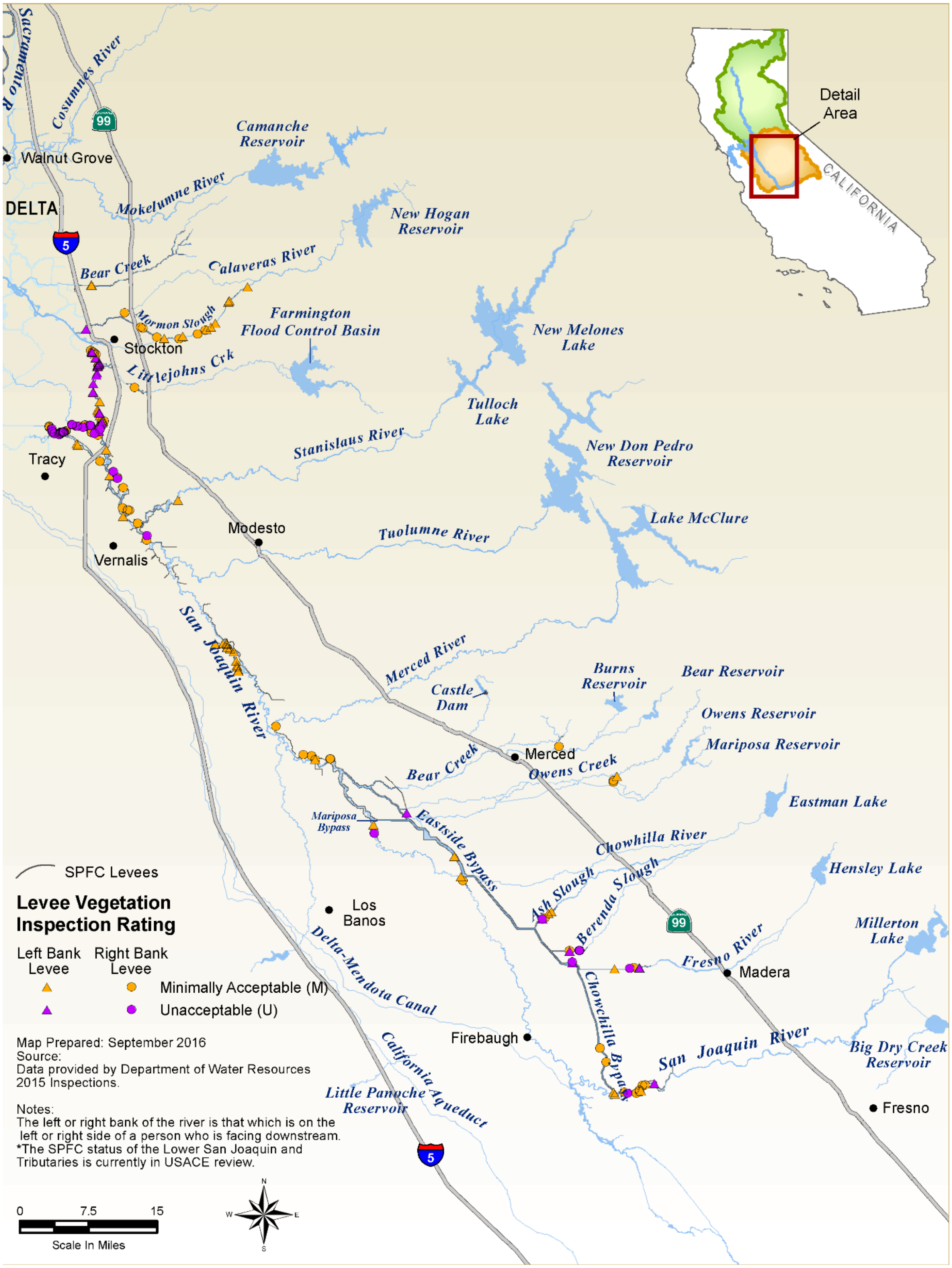

Figure 4-22. 2015 Levee Vegetation Inspection Ratings in the San Joaquin River Watershed

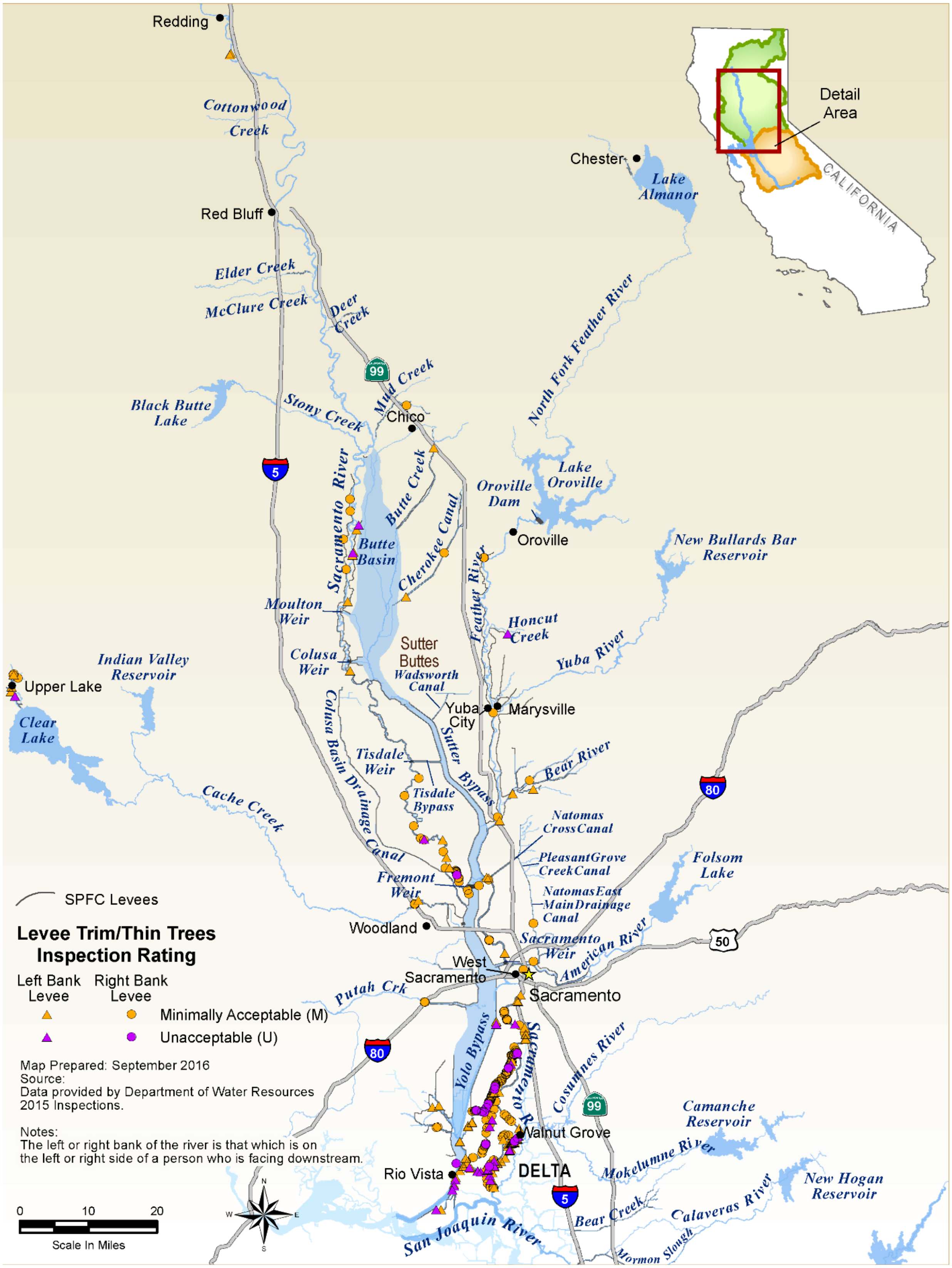

Figure 4-23. 2015 Trimming/Thinning Trees Inspection Ratings in the Sacramento River Watershed

Figure 4-24. 2015 Trimming/Thinning Trees Inspection Ratings in the San Joaquin River Watershed

4.8 Burrowing Animal Damage

SPFC levees may be damaged by animals creating burrows to form tunnels and galleries. These tunnels and galleries can be isolated or interconnected, depending on the animal species. The void spaces created by animal burrows can cause a preferential seepage path through a levee, promote surface and internal erosion, and reduce the strength of levee embankment and foundation materials by increasing pore water pressure. Large burrows and dens can also eventually collapse, inducing internal zones of low strength within a levee, reducing its stability and internal erosion resistance. Collapse of large void spaces creates sinkholes at the surface, which could lead to levee breaches if the collapse occurs during high water (see also Section 4.5, Settlement).

Animal burrows can increase seepage through a levee

Burrowing animal damage to SPFC levees can worsen because of deferred repairs or maintenance and other factors, such as land use adjacent to levees. While it is infeasible to eliminate all burrows from SPFC levees, maintaining agencies implement animal burrow control programs that reduce active burrowing and fill existing burrows. The specific type of control method used varies among maintaining agencies, and includes the following: grouting burrows, excavating and filling burrows, baiting, and others. Recent new scientific knowledge and expert opinion have recently highlighted that protected wildlife species may potentially use burrows in levees in certain situations. This will likely require additional environmental permitting that has not been required in the past (e.g., giant garter snake in the Sacramento Valley).

4.8.1 Status Evaluation Methodology

DWR conducted an Animal Burrow Hole Persistence Study on SPFC levees using data from biannual DWR inspections from 1984 to 2008 (DWR, 2009b). The metric used to assess animal activity in the study was cumulative occurrences of documented burrowing activity over time. Occurrences of documented burrowing activity include the presence of burrow holes on levee slopes or direct animal sighting. It was assumed that repeated documented animal burrows at a given location during a series of biannual inspections indicates animal activity persistence and, as a result, a higher degree of structural damage in embankments than at levee locations with lower numbers of documented burrows over time.

Statistical analysis was used to categorize levels of animal burrow hole persistence as the lower, middle, and upper third of the distribution (i.e., low, medium, and high persistence). Levels of persistence are described in Table 4-12. For more details about the study, refer to the Assessment of Animal Burrow Hole Persistence on Project Levees Technical Memorandum (DWR, 2009b).

Table 4-12. Animal Burrow Hole Persistence Levels

Animal Burrow Hole Persistence Levels[1]	Cumulative Occurrences of Documented Burrowing Activity per Levee Unit	Total Levee Miles
No Activity[2]	0	184
Low Persistence	1 – 3	350
Medium Persistence	4 – 7	382
High Persistence	8 or higher	543
No Data[3]	No data	108

Notes:

1 The Animal Burrow Hole Persistence Study included 42 biannual DWR inspection records spanning 21 years, from 1984 to 2008. Records for 1988, 1990, 1991, and 1993 inspections were not available (DWR, 2009b).

2 No Activity represents levee reaches for which no occurrences of documented burrowing activity were found in inspection reports, but for which documented occurrences were found elsewhere within the same levee unit.

3 No Data represents entire levee units for which there were no data in the inspection reports. It is unknown whether the lack of data along these levee units was an indication of absence of activity or a reflection of problems observing animal activity in these areas.

As described in Section 3.3, animal burrow persistence data were not considered when assigning ULE overall hazard classifications. However, burrow hole persistence data were considered in assigning NULE through seepage hazard categorizations.

4.8.2 Limitations of Status Evaluations

Levee inspections only document the presence (or absence) of animal burrows and do not measure burrow hole density, hole diameter, or structural damage to levees.

To facilitate analysis, data were grouped together by reach for levees with similar burrowing activity, land use, and physical features in and around the levee. However, this grouping may not capture variability in animal burrowing activity at small scales (i.e., 1 to 3 miles). Furthermore, more recent efforts of maintaining agencies may have changed conditions since the study was completed in 2009.

Some burrowing animals tend to be more damaging to levees (e.g., creating deeper, more penetrating burrows) than others; however, the type of burrowing animal in any particular area generally was not documented within the levee inspection reports. The study did not address burrows and dens associated with large rodents, such as muskrats and beavers. These species usually do not burrow directly into levee slopes, but prefer to construct the entrances to their dens under water, which may be within the levee prism with no visible sign of a burrow on the levee slope.

Records covering only 1,459 miles of approximately 1,600 total miles of SPFC levees contained information about burrowing activity. An additional 108 miles corresponded to entire levee units for which there were no data in the inspection reports (i.e., the “No Data” level). It is unknown whether the lack of data along these levee units was an indication of an absence of activity, a reflection of problems observing animal activity in these areas, or whether inspection data were not available for some other reason.

Animal persistence data were collected from levee inspections that are traditionally performed from a moving vehicle. For a variety of reasons, inspectors do not normally exit their vehicles to observe and document animal burrows. Visual inspection from a moving vehicle is not as effective for gathering information as foot surveys, and may lead to some underreporting of burrows. Certain maintenance measures, such as levee dragging and crown road grading, can also cover burrows on the surface, making underlying burrows difficult to observe during an inspection. Over time, this leads to levees that appear to lack any burrows on the surface, but instead may have internal burrows within the levee embankment.[11]

4.8.3 Results of Status Evaluations

Figures 4-25 and 4-26 show results for the DWR Animal Burrow Hole Persistence Study for the Sacramento and San Joaquin river watersheds, respectively (DWR, 2009b). More than one-third of the 1,459 miles of SPFC levees studied had high persistence (at least eight reported incidences of burrowing activity over the 21-year study span of inspection results).

Additional information on animal control inspection results, recent, ongoing, and planned levee remedial actions for burrowing animal damage, and ongoing actions to improve future evaluations is included in Appendix A, Section A-9. Also, USACE periodic inspection results on animal control for 10 USACE levee systems are included in Appendix A, Section A-1.

4.9 Encroachments

Encroachments are any obstruction or physical intrusion by construction of works or devices, planting or removal of vegetation, or caused by any other means, for any purpose, into a flood control project, waterway area of the flood control project, or area covered by an adopted plan of flood control (Title 23 of the California Code of Regulations, Chapter 1, Article 2, Section 4 (m)). Encroachments include boat docks, ramps, bridges, sand and gravel mining, placement of fill, fences, retaining walls, pump stations, residential structures, and irrigation and landscaping materials/facilities. Standard procedure is for the Board to obtain USACE approval before issuing an encroachment permit. More than 18,000 encroachment permits have been issued by the Board since its inception. A permit may be for a single encroachment or multiple encroachments. Many current encroachments are properly maintained. However, numerous permitted encroachments are not properly maintained, and numerous unpermitted encroachments exist on or within SPFC levee rights-of-way.

[11] This observation is verified by DWR's experience in grouting burrowing animal holes, such as on Cache Creek. In the first year of the grouting program, the grout takes were large because grout going into one burrow flowed to many other interconnected burrows. In subsequent years, grout take decreased because only the new burrows required grout.

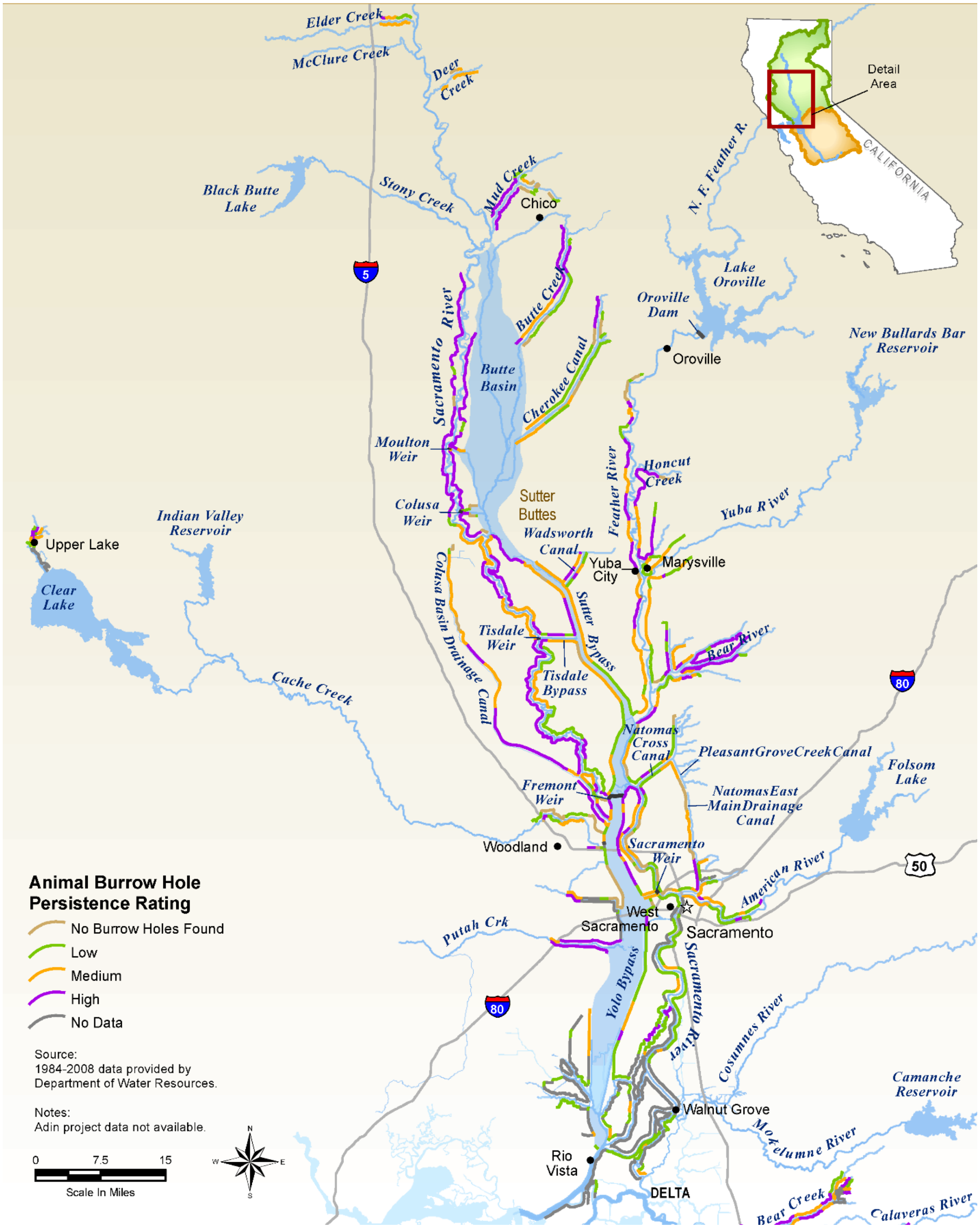

Figure 4-25. Animal Burrow Hole Persistence in the Sacramento River Watershed

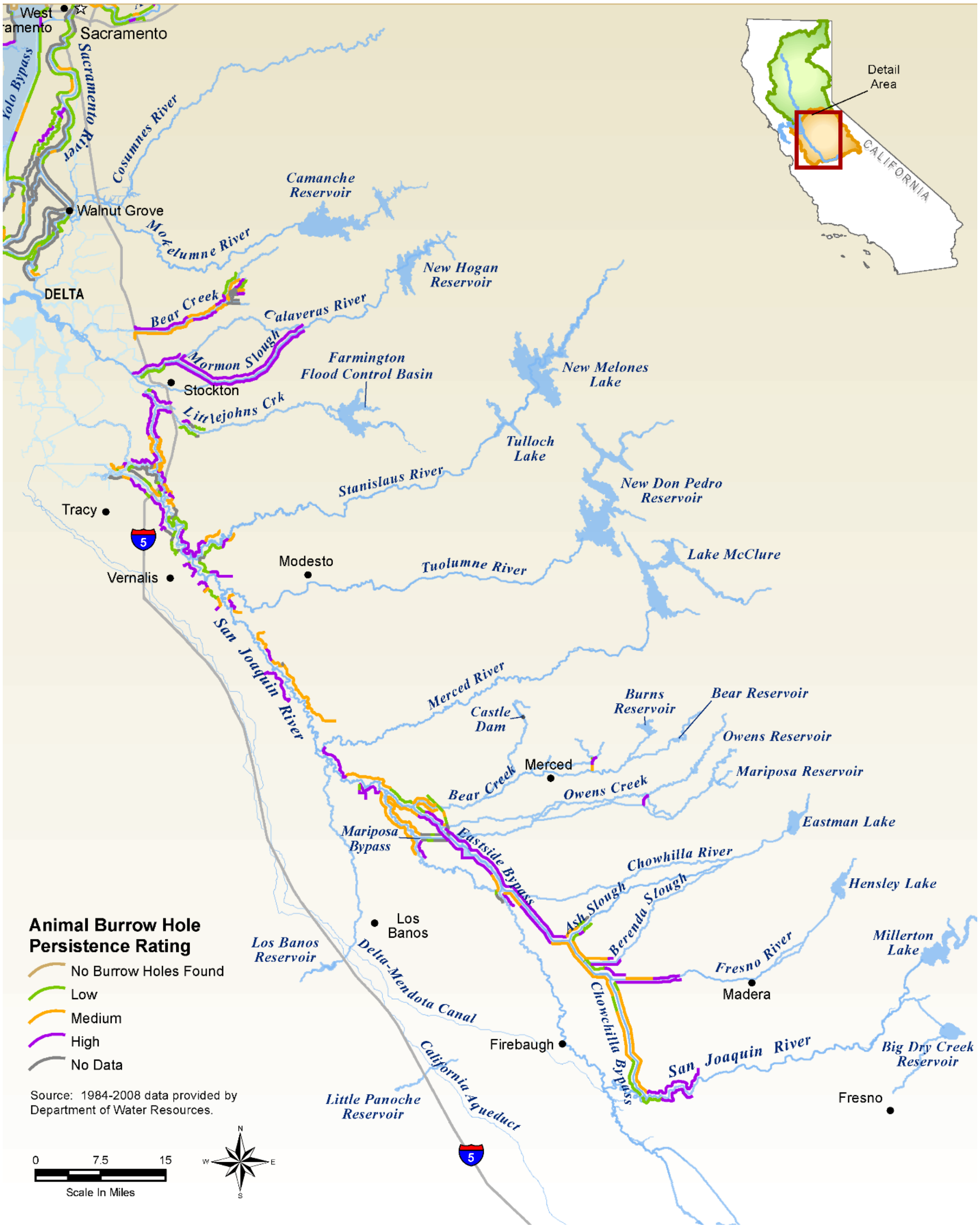

Figure 4-26. Animal Burrow Hole Persistence in the San Joaquin River Watershed

Unmaintained or unpermitted encroachments often jeopardize levee integrity and can interfere with floodfighting, inspection, and maintenance. Although adverse impacts to levees from encroachments can be associated with deferred maintenance, some encroachments posing a geotechnical hazard fall outside the jurisdiction of maintaining agencies to remediate because the encroachment may be Board-permitted or other factors may prevent maintaining agencies from taking action.

Encroachments can interfere with floodfighting, inspection, and maintenance

DWR has completed its ULDC (DWR, 2012a), which includes encroachment criteria for urban levee design.

4.9.1 Status Evaluation Methodology

DWR visually inspects SPFC levees for encroachments at least two times per year, and reports results annually. Table 4-13 shows DWR inspection rating descriptions for encroachments on earthen levees, used for annual inspections in 2015.

DWR documents and rates three types of encroachments:

- Encroachments that threaten levee integrity
- Encroachments that are inappropriately placed on a levee, such as trash, prunings, or equipment
- Encroachments that obstruct visibility and access

Table 4-13. Summary of Levee Inspection Rating Descriptions for Encroachments on Earthen Levees

Inspection Rating	Rating Descriptions
Acceptable (A)	No trash or debris present. No excavation, structures, or other encroachments threaten levee integrity. No encroachments obstruct visibility or access to the levee or landside toe easement.
Minimally Acceptable (M)	Minimal trash or debris present. Minor excavation, structure, or other encroachments pose minor threat to levee integrity.
Unacceptable (U)	Significant trash or debris present. Major excavation, structure, or other encroachments pose major threat to levee integrity.
Acceptable/Watch/Monitor (A/W)	This rating is used to document issues found during inspections that do not yet warrant an M or U rating but that should be monitored or maintained to avoid a maintenance deficiency in the future.
Corrected (C)	The deficiency noted previously has been corrected.

Note:
This is a summary table of the extensive encroachment rating criteria descriptions found in Appendix G of the 2015 Inspection and Local Maintaining Agency Report. Source: (DWR, 2015b)

Inspections completed from 2007 through 2011 rated the first two encroachment types as either Minimally Acceptable (M) or Unacceptable (U). The first two types of encroachments are generally included in the overall ratings and should generally be corrected by the maintaining agencies. The third type of encroachment that the USACE identified as unacceptable may be beyond the current authority of the maintaining agencies to correct because the encroachment may be Board permitted or have other factors associated with it that prevent maintaining agencies from taking action. These Partially Obstructing (PO) and Completely Obstructing (CO) encroachments are not included in the overall ratings (A, M, and U). Instead, they are identified to generate an inventory of those encroachments that the USACE has, in the past, found to be unacceptable and those encroachments that could affect the operation of the system. The permit status of these encroachments may not have been determined.

Since 2012, DWR inspectors have rated all encroachments as A, M, or U and identified as appropriate, an issue type for each. Encroachments that maintaining agencies may not be able to address and would have been previously rated as PO or CO are assigned an issue type of enforcement in all inspections since 2012.

The DWR inspection criterion includes three issue types: Maintenance, Enforcement, and Design/System Obsolescence. The criteria are described as follows:

- **Maintenance** – These issues include animal control, vegetation, and other deficiencies, as described in Appendix G of the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b), where annual maintenance is required by the maintaining agencies to maintain the levees to an acceptable condition to ensure the project will function as designed, intended, or required. Items with this issue type are included the overall ratings.
- **Enforcement** – These issues include encroachments that threaten levee integrity, that are inappropriately placed on the levee, or that obstruct visibility and access during the flood fighting efforts. Some of these encroachments may require enforcement action and may have been permitted by the Board.
- **Design/System Obsolescence** – These issues encompass deficient conditions that may be a part of or a result of the original design and construction of the project. These conditions may also be due to the age of the project and require actions beyond the ability of the LMA. Items of this type are not included in the overall ratings but still need to be addressed.

Not all encroachment issues are documented using these three issue types.

As discussed in Section 3.3, encroachment data were not considered in the assignment of ULE hazard classification or NULE hazard categorization. Detailed assessments or surveys of encroachments were beyond the scope of the DWR Levee Evaluations Program.

4.9.2 Limitations of Status Evaluations

USACE, in cooperation with the Board, has developed a web-based GIS (eGIS) database of historical encroachment permits. However, current inspection reporting does not distinguish between permitted and non-permitted encroachments. It is also difficult for inspectors to determine whether observed encroachments are located within existing easement or right-of-way boundaries. A more thorough evaluation of encroachment status would include a complete inventory of permitted and nonpermitted encroachments and associated documentation, along with project-specific hydraulic modeling to assess the potential impact of encroachments on water surface elevation and levee integrity.

4.9.3 Results of Status Evaluations

The 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b) encroachment inspection ratings are shown in Figures 4-27 through 4-30 for the Sacramento and San Joaquin river watersheds, respectively (DWR, 2015).

Minimally Acceptable and Unacceptable ratings with a maintenance issue type are shown in Figures 4-27 and 4-28. Inspection results include 235 encroachment sites identified as minor threats to levee integrity (i.e., Minimally Acceptable) and 24 encroachment sites identified as major threats to levee integrity (i.e., Unacceptable). Encroachment sites may consist of multiple individual encroachments.[12]

Minimally Acceptable and Unacceptable ratings with an enforcement issue type are shown in Figures 4-29 and 4-30. Inspection results include 1,096 encroachment sites identified as minor threats to levee integrity (i.e., Minimally Acceptable) and 372 encroachment sites identified as major threats to levee integrity (i.e., Unacceptable).

Minimally Acceptable and Unacceptable ratings with a design/system obsolescence issue type are shown in Figure 4-27. Inspection results include two encroachment sites identified as minor threats to levee integrity (i.e., Minimally Acceptable) and zero encroachment sites identified as major threats to levee integrity (i.e., Unacceptable). Additional information about recent, ongoing, and planned levee remedial actions for encroachments and ongoing actions to improve future evaluations is included in Appendix A, Section A-10. Also, USACE periodic inspection results on encroachments for 10 USACE levee systems are included in Appendix A, Section A-1.

[12] Annual DWR inspections rate both individual encroachments and ranges of multiple adjacent encroachments. These ranges vary in length, but are rarely longer than a mile. Since ranges less than a mile long are difficult to identify at the map scale shown, all encroachment sites (both ranges and individual encroachments) are shown as points on the map.

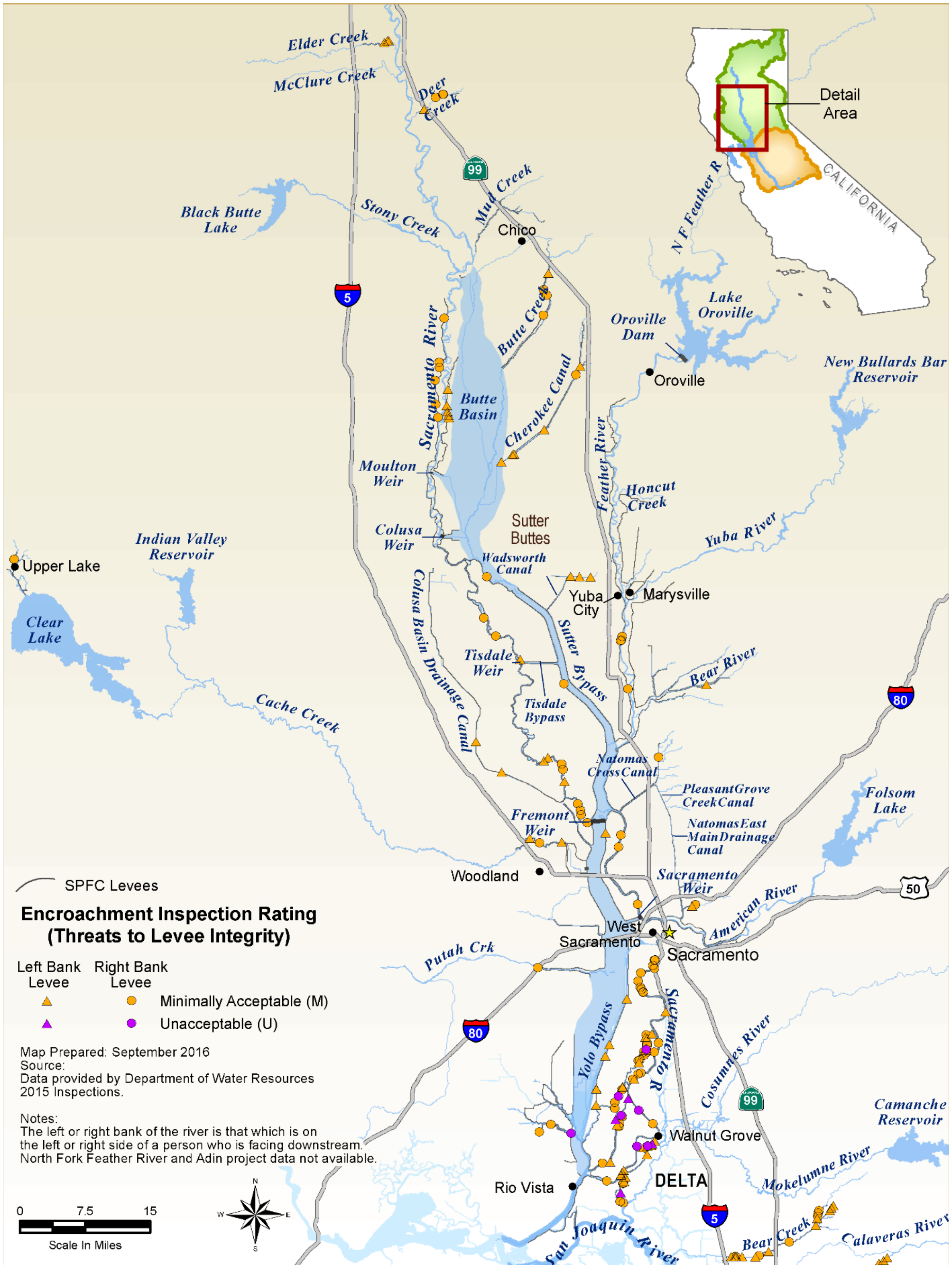

Figure 4-27. 2015 Encroachment Inspection Ratings in the Sacramento River Watershed (Maintenance Issue Type)

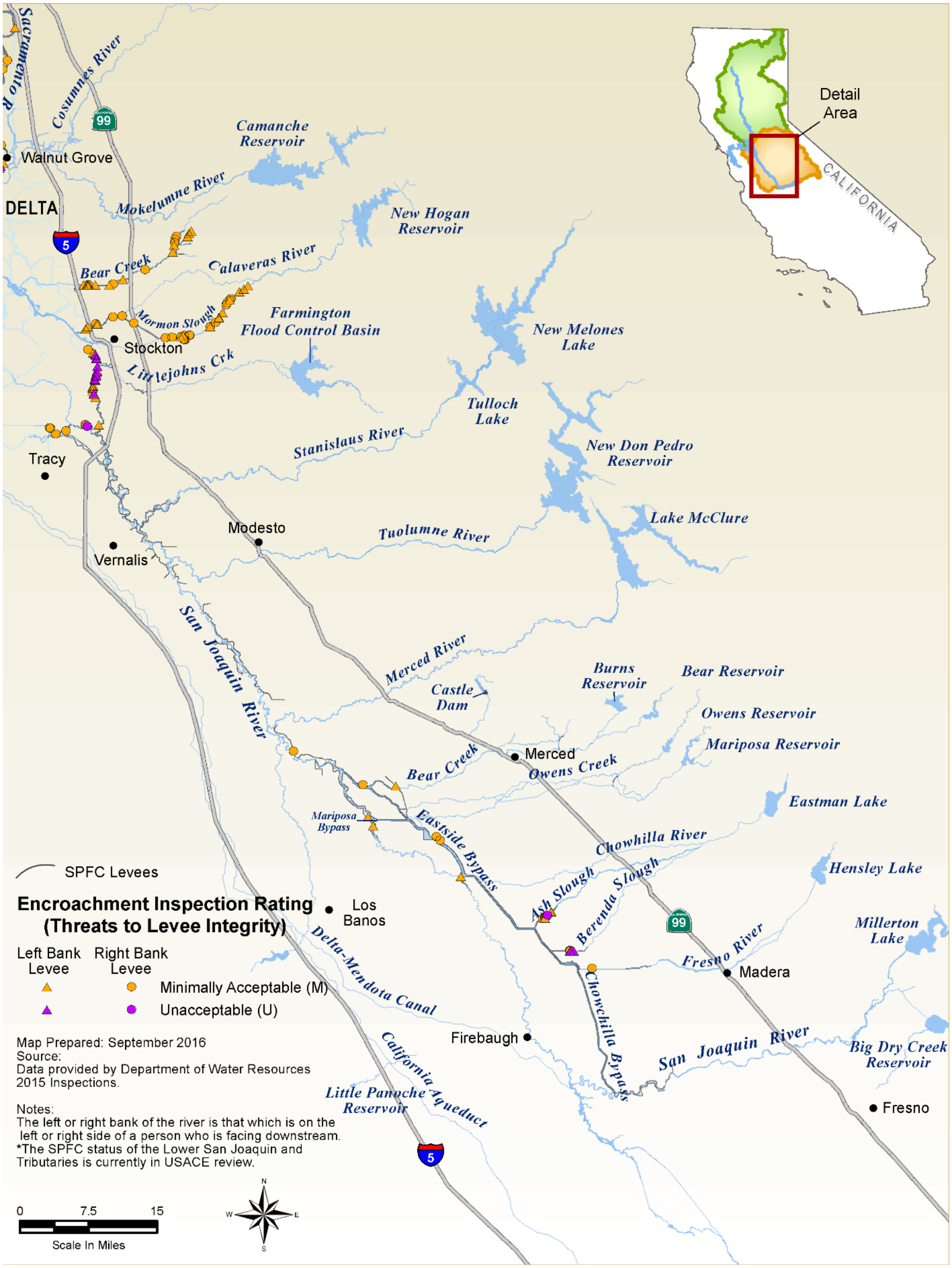

Figure 4-28. 2015 Encroachment Inspection Ratings in the San Joaquin River Watershed (Maintenance Issue Type)

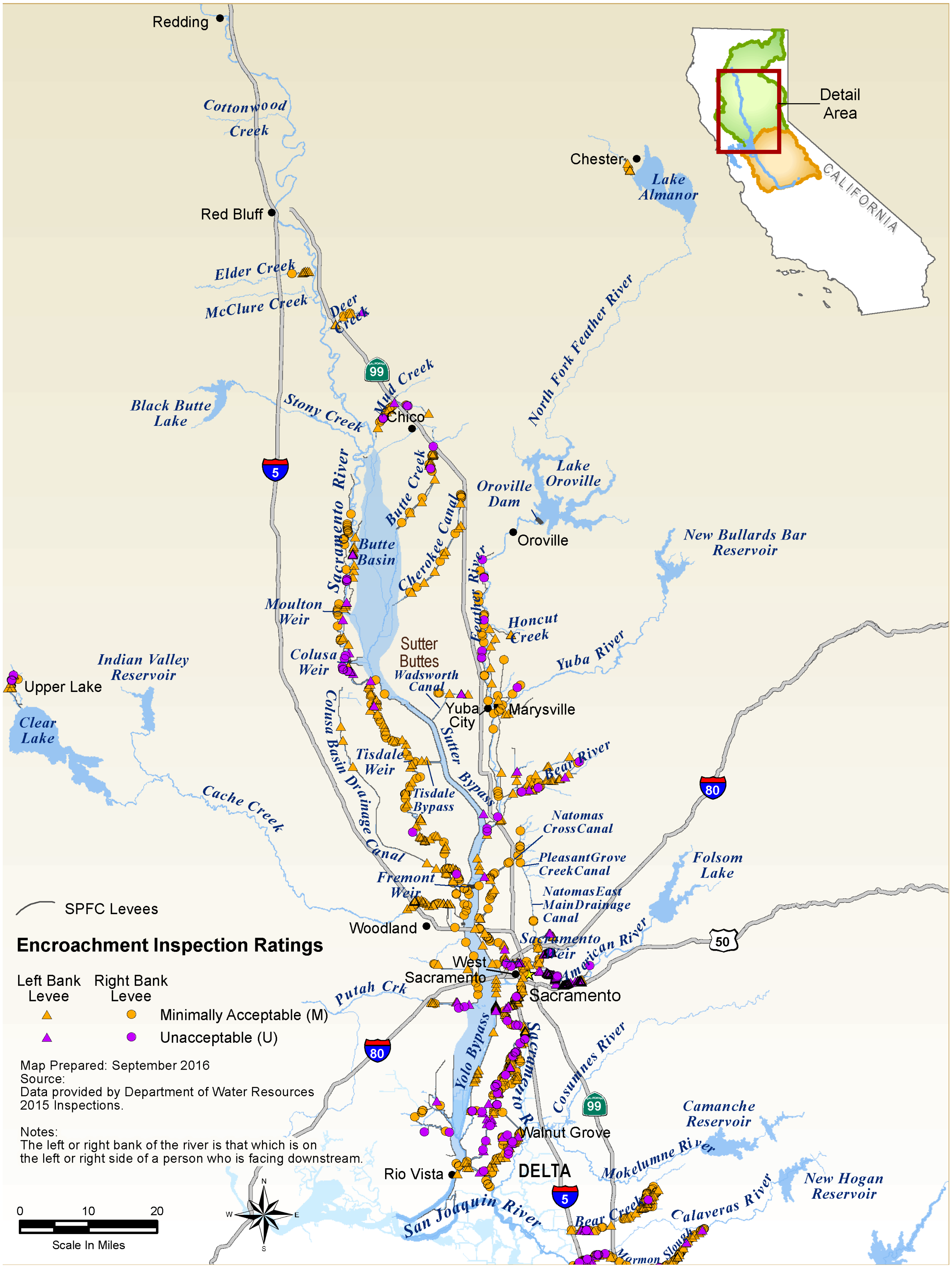

Figure 4-29. 2015 Encroachment Inspection Ratings in the Sacramento River Watershed (Enforcement and Design/System Obsolescence Issue Type)

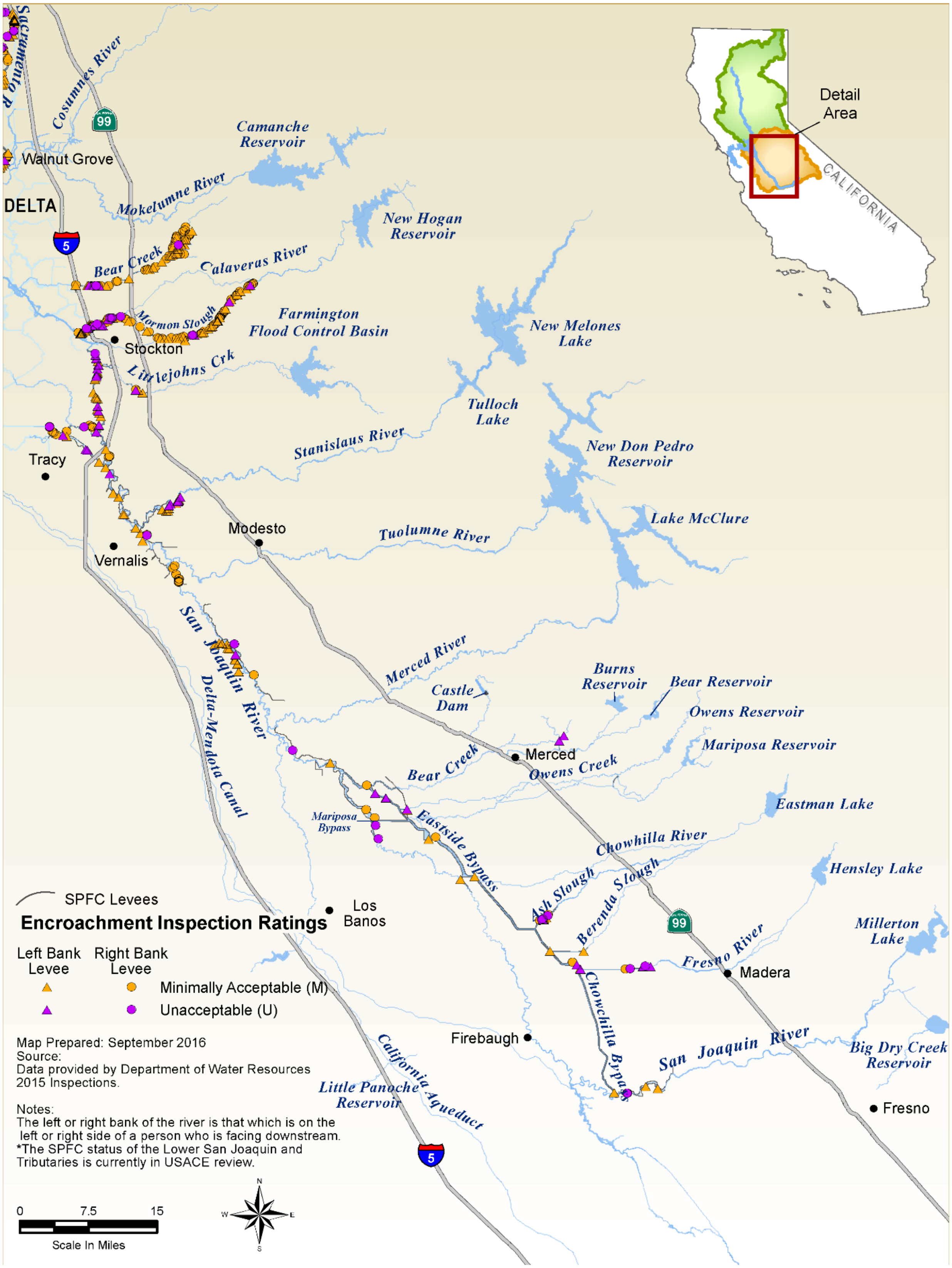

Figure 4-30. 2015 Encroachment Inspection Ratings in the San Joaquin River Watershed (Enforcement Issue Type)

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5.0 Channel Status

Channel conveyance capacity can be reduced by a number of factors. These factors can be the result of conditions in the channel, such as vegetation growth in the channel, sediment deposited in the channel, encroachments in the channel, bank erosion, revetments, and bank caving. Levee conditions such as lack of freeboard due to localized settlement, erosion, or original levee design can also reduce channel conveyance capacity. Consequently, identifying the causes of channel conveyance problems (and whether they are channel-related or levee-related) often requires additional site-specific investigation that is beyond the scope of this 2017 FSSR. Furthermore, the conveyance capacity of the system is dynamic and therefore needs to be reevaluated at regular intervals.

Estimates of DWR channel conveyance capacity, as presented in this 2017 FSSR, are not based on the same approach as USACE channel conveyance capacity estimates. DWR uses freeboard as an index point to estimate conveyance capacity, expressed as a flow value. USACE uses a risk-based or probabilistic approach to estimate conveyance capacity. While a risk-based approach provides a better indicator of flood risk, this approach has not been used to define performance expectations for SPFC channels. A risk-based approach can sometimes be impractical to use because of limited geotechnical data and dependence of the approach on the hydrological record, which changes dynamically based on new flood events.

This section summarizes channel conveyance capacity conditions, and then discusses channel vegetation and channel sedimentation as two key factors affecting channel conveyance capacity. Other factors that could reduce channel conveyance capacity (such as encroachments in the channel) were not evaluated because supporting data were not available.

5.1 Channel Conveyance Capacity

SPFC channel conveyance capacity has been estimated based on the ability of a channel to pass original design flood flows. Design flood flows (or design channel capacities) from different official sources have been sometimes inconsistent. These discrepancies have complicated the evaluation of channel conveyance capacities throughout the Sacramento and San Joaquin river watersheds.

The basis for evaluating channel conveyance capacity in the Sacramento River watershed was refined several times after the Flood Control Act of 1917. Design flows were later amended by the Flood Control Act of 1928, Senate Document Number 23, the 1953 Memorandum of Understanding between USACE and the Board (USACE and Board, 1953), and the 1957 design profile for the Sacramento River (USACE, 1957a). The profile and associated design capacities were developed based on USACE analysis of the 1937, 1951, and 1955 floods on the Sacramento River at the request of the Board.

In the San Joaquin River watershed (excluding the Mormon Slough Project), original design flows were derived from the Report on Control of Floods, San Joaquin River and Tributaries Between Friant Dam and Merced River (DWR, 1954) and later changed to reflect the 1955 design profile for the San Joaquin River, as shown in Design Memorandum No. 1, San Joaquin River Levees, Lower San Joaquin River and Tributaries Project (1955 design profile) (USACE, 1955b). For SPFC channels in the Mormon Slough Project, design capacities were based on the 1965 design profile (USACE, 1965).

All design profiles for the SPFC are available on the 2017 CVFPP webpage at http://www.water.ca.gov/cvfmp/2017cvfpp.cfm. For channels not delineated in the 1955, 1957, or 1965 design profiles above, design capacities were determined based on as-constructed capacities specified in appendices to O&M manuals provided by USACE.

Design channel capacities were calculated from the design profiles based on steady state, uniform flow hydraulic computations of historical floods using data available at the time. Therefore, design channel capacities were based on a limited hydrological record, were dependent on the boundary conditions assumed, and did not consider variations in flow and depth with respect to time and distance. Furthermore, the design profiles could not account for changes in vegetation and sedimentation patterns within the channels, or flood system improvements that have taken place after the historical floods used to derive the design flood flow capacities. For example, the 1955 historical flood used to determine the 1955 design profile for the San Joaquin River downstream from the Merced River confluence occurred before construction of the San Joaquin River bypass system.

Design channel capacities reported in USACE O&M manuals sometimes do not agree with channel capacities associated with design profiles. This is because USACE created some O&M manuals before the design profiles were adopted. DWR operates and maintains SPFC facilities based on design capacities calculated from the design profiles when available, rather than on design capacities included in the USACE O&M manuals (USACE, 1969). Design channel capacities from both the design profiles and O&M manuals are used as the basis for evaluation of channel conveyance capacities in this 2017 FSSR.

5.1.1 Status Evaluation Methodology

Channel conveyance capacity conditions are evaluated in this 2017 FSSR by comparing estimated capacities under existing conditions (existing capacities) with design channel capacities specified in O&M manuals and design profiles provided by USACE for each SPFC channel.

Existing channel capacities were determined to be the lowest flow rate (limiting capacity) that occurs when the water surface encroaches on a levee low point (on either the left bank or right bank) minus the design freeboard height. It was assumed that when the water surface encroaches on freeboard at a single location, the capacity of the entire reach is compromised. Therefore, the reported capacity for each reach or a segment of a reach is the limiting capacity for that section. The channel capacity performances for the systems reflect the above assumption and are presented in Figure 5-3 for the Sacramento River and in Figure 5-4 for the San Joaquin River systems, respectively. The data source for each existing channel capacity is listed by reach in Appendix B, Tables B-1 and B-2.

Freeboard requirements were established from the USACE report entitled “Standard Operations and Maintenance Manual for the Sacramento River Flood Control Project,” dated May 1955. Freeboard was established due to uncertainties in hydrology and ever-changing channel conditions. For all riverine streams, 3-foot is the minimum freeboard requirement with exception of flood control bypasses where 6-foot is the minimum freeboard requirement for the Sacramento River system and 4-foot is the minimum freeboard requirement for the San Joaquin River system.

Since publishing the 2011 FCSSR (DWR, 2011c), DWR has acquired new topographic data and stream bathymetric data, developed detailed riverine hydraulic models and hydrological models. To estimate the existing channel capacities for the Sacramento and San Joaquin rivers and their tributaries associated with SPFC levees, hydraulic models developed by the CVFED Program (CVFED, 2009) and hydrology data developed by the Central Valley Hydrology Study were used as the key analytical tools. The CVFED Program hydraulic models included the most up-to-date channel and levee geometry data (based on detailed field surveys) and the flood control structures and their operations for the entire SPFC system. The CVFED Program hydraulic models for the Sacramento and San Joaquin systems extended into the Delta. The downstream boundary elevations accounted for tidal conditions based on the 1997 flood event. This report did not provide channel capacities in the areas influenced by tidal conditions. It should be noted that the channel capacity evaluation effort for the Sacramento and San Joaquin river systems supercedes information developed for the CVFED Program, and is the main informational source for evaluating channel capacities in the 2017 FSSR.

For the 2017 FSSR, the following criteria were used to determine whether estimated existing capacities of the SPFC channels were sufficient to safely convey identified design capacities in the O&M manuals or design capacities calculated from design profiles:

- If the estimate of existing capacity was greater than both the design capacity reported in the O&M manual and the design capacity based on the design profile, channel status was reported as “Sufficient Capacity.”
- If the estimate of existing channel capacity was less than the design capacity reported in the O&M manual, or the design capacity based on the design profile (or both), but less than the top of levee capacity, the channel status was reported as “Potential Encroachment.”
- If the estimate of existing channel capacity was less than the design capacity reported in the O&M manual, or the design capacity based on the design profile (or both), and more than the top of levee capacity, the channel status was reported as “Potential Overtopping.”
- If the estimate of existing channel capacity for a reach depends on backwater flow assumptions, channel status was reported as “Backwater Zone; additional evaluation required.”

  Please note that when referring to figures associated with channel capacities at both the basin and reach specific level, the legend related categories as follows:

  - **Sufficient Capacity** – “Sufficient Capacity”
  - **Potential Encroachment** – “Freeboard Encroachment”
  - **Potential Overtopping** – “Insufficient Capacity”

- **Backwater Zone; Additional Evaluation Required** – “Backwater Influence” or “Undefined.” This denotes two separate categories, and legend items and will be specific to reach maps.

5.1.2 Limitations of Status Evaluations

Accuracy of the existing channel capacity estimates in this 2017 FSSR was limited by the topographic and hydraulic modeling performed. Project-specific modeling results generally are less uncertain than systemwide modeling results. Uncertainties associated with estimating current channel capacities throughout the system include vertical datum errors, inaccurate levee crown profiles, arbitrary nature of standard freeboard values, limited calibration data, fixed-bed assumption, wind/wave effects, and unaccounted-for local hydrodynamic effects. Also, differing hydraulic modeling assumptions for boundary conditions, freeboard criteria, and top-of-levee elevations likely contribute to conflicting results among hydraulic modeling evaluations and should be resolved with additional evaluation.

Furthermore, estimates of current channel capacities throughout the system using modeling generally characterizes impedance to flow, and are not designed or intended to evaluate subtle changes in the channels as a result of vegetation, sediment deposition, and/or other obstructions in the channel.

Another uncertainty results from identifying levee low points. In many cases, low levee crown elevations for only a mile or so constrained the capacity of reaches as long as 30 miles. Project-specific modeling of individual reaches could demonstrate that the channel conveyance capacity at one location in a reach is not representative of the entire reach.

Because of these uncertainties, data included in this 2017 FSSR cannot conclusively identify locations of channel conveyance capacity inadequacies, but instead the data identify potential inadequacies requiring additional evaluation.

5.1.3 Results of Status Evaluations

Differences between design capacities reported in O&M manuals and flows associated with the design profiles shown in Figures 5-1 and 5-2 demonstrate the need to resolve discrepancies in some locations. Potential inadequate channel conveyance capacities are shown in Figures 5-3 and 5-4.

For the Sacramento River watershed, approximately four-ninths of the channels show a potential capacity inadequacy and need for additional evaluation, and data are insufficient for approximately one-fifth of the channels. In general, approximately three-fifths of the channels in the San Joaquin River watershed show a potential capacity inadequacy and need for additional evaluation, and data are insufficient for one-eighth. These results will be refined as systemwide and project-specific hydraulic modeling efforts progress. Appendix B, Section B-1, contains tables of the results shown in Figures 5-3 and 5-4.

For additional information about recent, ongoing, and planned remedial actions/improvements, and ongoing actions to improve future evaluations, see Appendix B, Section B-2.

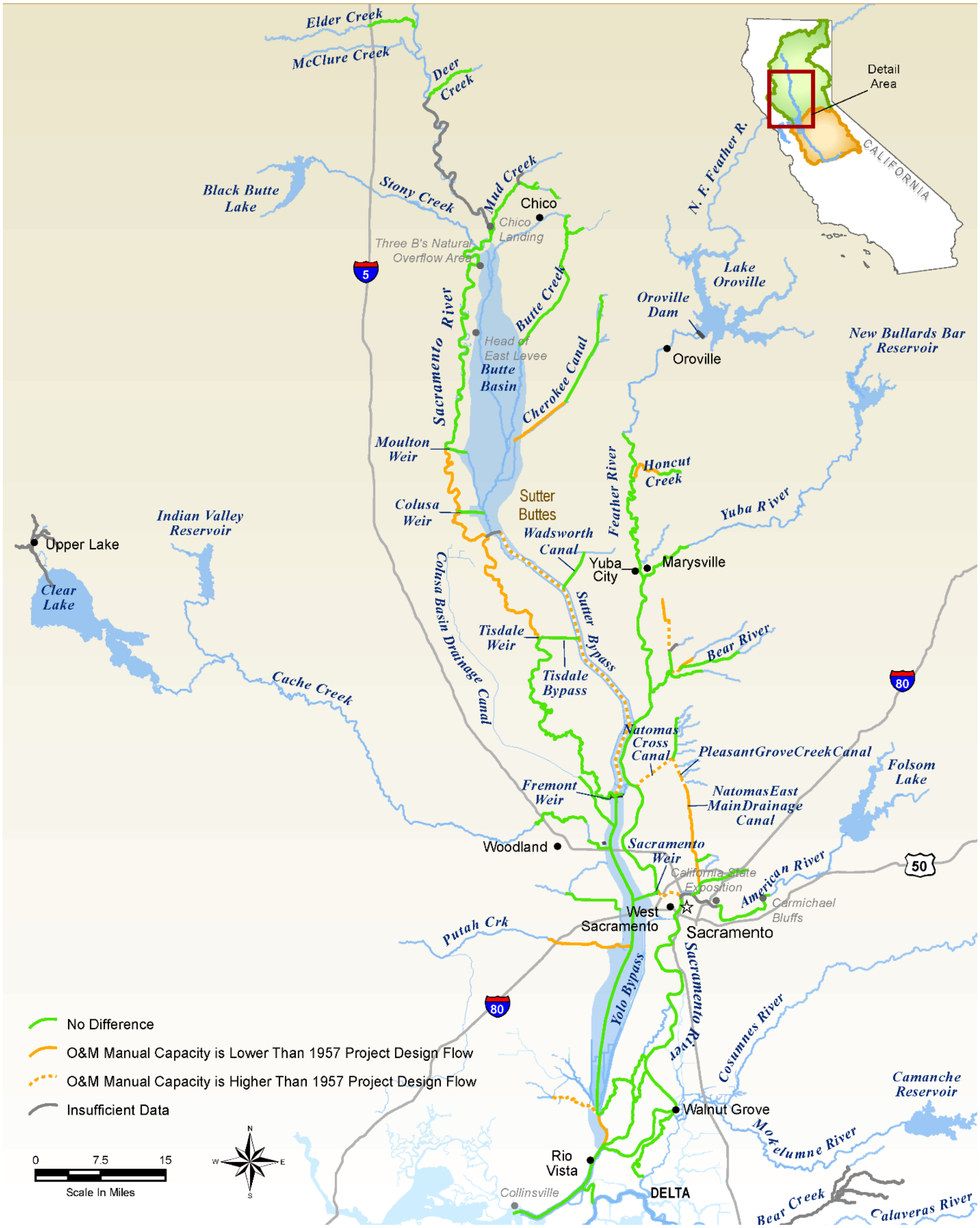

Figure 5-1. Differences Between O&M Manual Design Capacities and Design Profile Flows in the Sacramento River Watershed

Figure 5-2. Differences Between O&M Manual Design Capacities and Design Profile Flows in the San Joaquin River Watershed

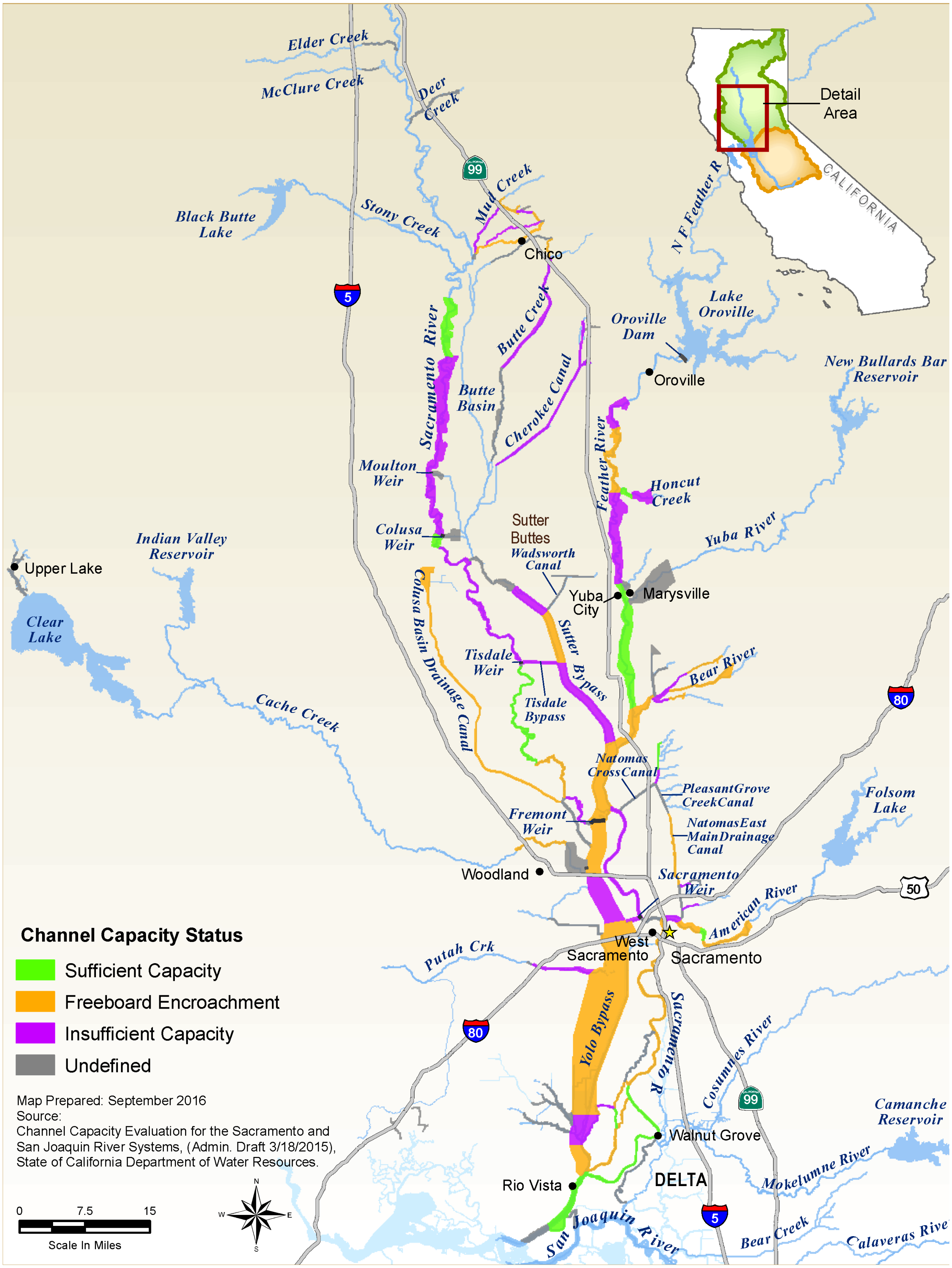

Figure 5-3. Channel Capacity Status in the Sacramento River Watershed

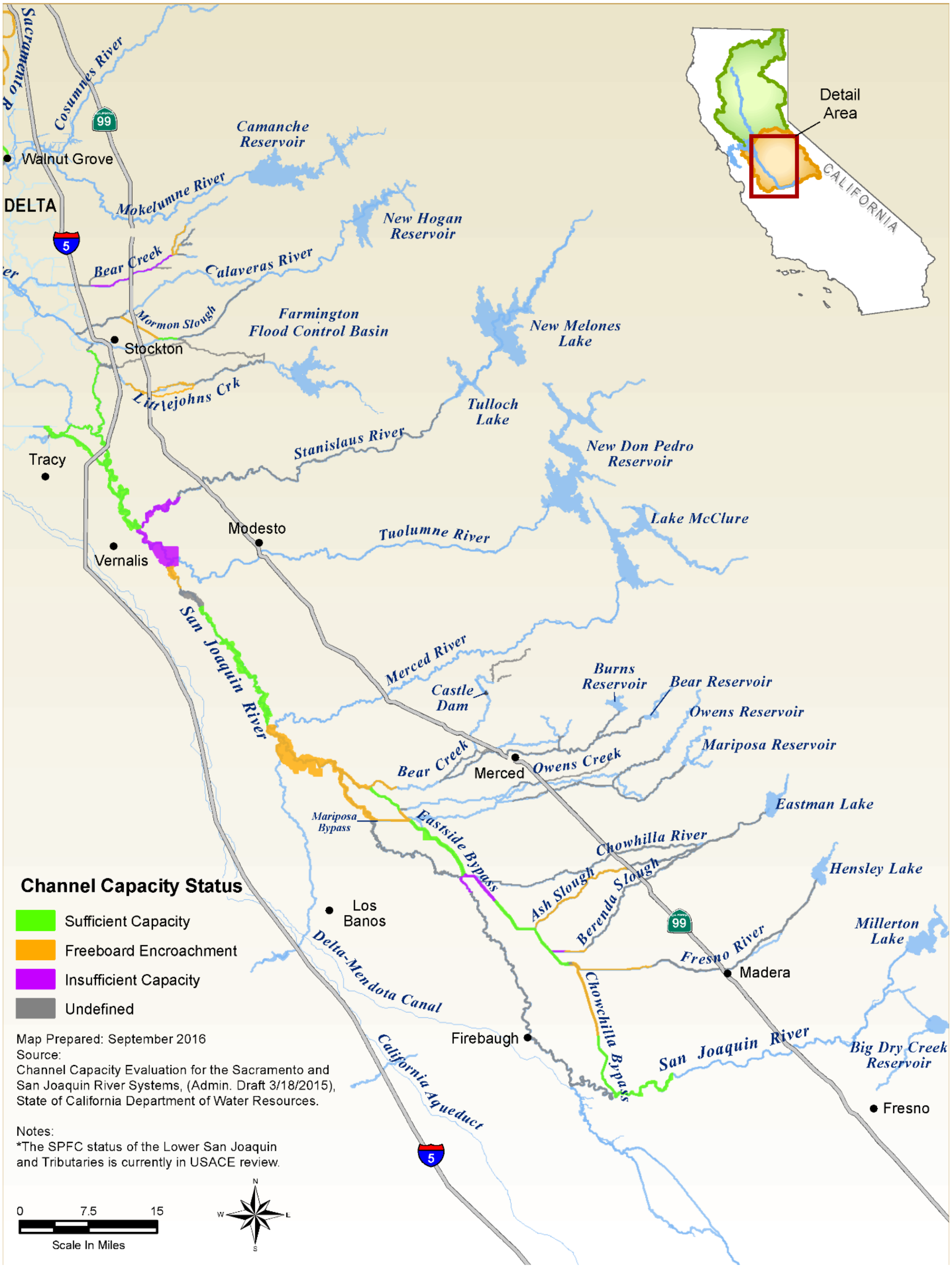

Figure 5-4. Channel Capacity Status in the San Joaquin River Watershed

5.2 Channel Vegetation

Criteria for vegetation management in the channels have been evolving since SPFC facilities were constructed. Maintenance criteria are contained in standard and unit-specific O&M manuals provided by USACE, Title 23 of the California Code of Regulations, and Title 33 of the Code of Federal Regulations.

State and federal environmental laws have complicated efforts to maintain SPFC channels. These environmental laws include the State and federal Endangered Species Acts; the federal Clean Water Act, the federal Porter-Cologne Act and Migratory Bird Treaty Act; and California Fish and Game Code requirements for Stream Bed Alteration Agreements. Specifically, channel maintenance is increasingly challenging because of compliance requirements for these laws and regulations, and the length of time for obtaining approvals for maintenance.

Table 5-1 lists current standards that apply to vegetation management for channels. (Note that standards that apply to vegetation management for levees are discussed in Section 4.7.)

Table 5-1. Current Standards for Channel Vegetation Management

Source of Standard	General Description of Standard
Title 33, Federal Statutes, Part 208	Provides some flexibility in allowing vegetation in a channel as long as project works function properly and are not impaired by debris, weeds, or wild growth.
Title 23, California Code of Regulations	Vegetation that impedes or misdirects floodflows is not permitted to remain within a floodway or bypass.[1]
General and unit-specific O&M manuals	Generally requires that “the channel or floodway is clear of debris, weeds and wild growth.”[2] Limits vegetation in a project flood control channel to nondense brush or trees not more than 2 inches in diameter. Vegetation in channel is allowed if the design water surface profile is maintained.
USACE Sacramento District correspondence[3]	Allowable vegetation in a floodway shall not affect the capability of the project works to convey design flows within specified levels of freeboard, and shall not compromise the integrity or inspectability of the flood control project. In addition, channels shall pass design flows at stage levels at or below the 1957 design profile.[4] Projects containing significant vegetation within a channel will be considered in compliance when the sponsor shows, through hydraulic analysis, that the project is capable of conveying design flows while maintaining the specified levels of freeboard.
Clean Water Act Section 404	Vegetation management activities could require that a Clean Water Act Section 404 permit be obtained from USACE for discharge of dredged or fill material into “waters of the United States, including wetlands.” Waters of the United States include traditionally navigable rivers and their tributaries, and adjacent wetlands that have a significant nexus with waters of the United States. If a Section 404 permit is required, a Clean Water Act Section 401 Water Quality Certification would also be required by the Regional Water Quality Control Board.
Federal Endangered Species Act	Vegetation management activities could potentially adversely impact fish and wildlife species and their habitat. Section 7 of the Endangered Species Act outlines procedures for federal interagency cooperation for implementing the Endangered Species Act. Section 7(a)(2) requires that federal agencies consult with USFWS and/or NMFS so that “any action authorized, funded, or carried out by such agency” does not jeopardize the existence of a listed species or adversely modify critical habitat. If there is no federal nexus, a Habitat Conservation Plan or low-threat Habitat Conservation Plan may need to be prepared and complied with.
California Endangered Species Act	Vegetation management activities could potentially adversely impact fish and wildlife species and their habitat. Pursuant to the California Endangered Species Act, a permit from the California Department of Fish and Wildlife (formerly the California Department

Table 5-1. Current Standards for Channel Vegetation Management

Source of Standard	General Description of Standard
	of Fish and Game) is required for projects that could result in the take of a plant or animal species that is State-listed as threatened or endangered, or is a candidate species. In accordance with Sections 2080 and 2081 of the California Fish and Game Code, a Consistency Determination or Incidental Take Permit could be required.
California Fish and Game Code Section 1600, Streambed Alteration Agreement	Because vegetation management activities conducted in channels could potentially change the bed, channel, or bank of a channel, and potentially adversely impact fish and wildlife species and their habitat, a California Fish and Game Code Section 1600 Streambed Alteration Agreement may be needed (California Department of Fish and Wildlife, 2010).
DWR Levee Vegetation Management Strategy, 2012 CVFPP	This criteria allows vegetation beyond 20 feet from the waterside hinge point; requires grass and weeds to be less than 12 inches in height, and trees to be trimmed 5 feet above ground or 12 feet above the crown road, with thinning to allow clear visibility and floodfight access.

Notes:

[1] Title 23, California Code of Regulations, Section 131.

[2] Standard O&M Manual for the Sacramento River Flood Control Project, revised May 1955, USACE Sacramento District. (USACE, 1955a).

[3] USACE correspondence dated August 14, 2006, regarding The Reclamation Board's request for clarification of the State's O&M responsibilities associated with federal projects for which The Reclamation Board provided assurances of cooperation.

[4] USACE *Levee and Channel Profiles, File Number 50-10-334.*

rnia Code of Regulations

Key:

CVFPP = Central Valley Flood Protection Plan
DWR = California Department of Water Resources
O&M = operations and maintenance
USFWS = United States Fish and Wildlife Service
DFG = California Department of Fish and Game
NMFS = National Marine Fisheries Service
USACE = United States Army Corps of Engineers

5.2.1 Status Evaluation Methodology

Channel vegetation conditions are evaluated by the degree to which vegetation impedes flood flows. Vegetation management conditions were evaluated against DWR's current maintenance standards using results from the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b). A total of 26 SPFC Channels are inspected annually. Table 5-2 contains rating descriptions for channel vegetation. Each channel inspection location includes a separate upstream and downstream channel inspection rating. In this 2017 FSSR, only the worst of the two ratings is reported for each location.

Table 5-2. Channel Inspection Rating Descriptions for Channel Vegetation

Inspection Rating	Rating Description
Acceptable (A)	Log jams, snags, vegetation growth (such as cattails, bulrushes, bushes or saplings) or other obstructions block approximately 25 percent of the capacity.
Minimally Acceptable (M)	Log jams, snags, vegetation growth (such as cattails, bulrushes, bushes or saplings) or other obstructions block approximately 50 percent of the capacity.
Unacceptable (U)	Log jams, snags, vegetation growth (such as cattails, bulrushes, bushes or saplings) or other obstructions block approximately 25 percent of the capacity.

5.2.2 Limitations of Status Results

Information on channel vegetation management conditions is limited to the channels that DWR inspects (26 channels and 233 total miles) and to conditions that are visible. Channel vegetation inspections are usually performed from selected points along a channel and from the crown of a levee. Impacts of vegetation on channel conveyance can be evaluated more thoroughly using past performance evaluation, vegetation surveying, and project-specific hydraulic modeling.

To comply with USACE guidance, DWR must demonstrate that vegetation in a channel does not impact channel conveyance capacity and does not encroach on the levee's freeboard. Clarification is often needed about the specified levels of freeboard used to determine the extent of allowable vegetation throughout a channel. Inconsistencies about the required level of freeboard are common among SPFC channels; the freeboard cited in O&M manuals often conflicts with the freeboard specified in as-constructed plans. Determining the required levels of freeboard is therefore critical in assessing conveyance capacity, and whether vegetation or other factors are impeding proper functioning of SPFC facilities.

5.2.3 Results of Status Evaluations

Channel inspection ratings for vegetation from the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b) are shown in Figures 5-5 and 5-6 for channels maintained by DWR and other maintaining agencies. Of the 233 miles of SPFC channels (containing 157 checkpoints) inspected by DWR, 13 checkpoints were rated Unacceptable and 56 locations were rated Minimally Acceptable for channel vegetation. Additional vegetation problems may be present in channels not inspected by DWR.

Areas that are undergoing active vegetation management, or in which vegetation management has been initiated or required in the Sacramento River watershed are shown in Figure B-5 in Appendix B, Section B-2. Similar data were unavailable for the San Joaquin River watershed.

For additional information on recent remedial actions/improvements, ongoing and planned remedial actions/improvements, and ongoing actions to improve future evaluations of vegetation management in channels, see Appendix B, Section B-2.

5.3 Channel Sedimentation

Since SPFC facilities were constructed, maintenance standards have been consistent in requiring actions to address shoaling or sedimentation that reduces channel conveyance capacity or deflects flows within a channel. Channel sedimentation can occur in areas of significant flow expansion (i.e., bypass inlets), in backwater near confluences, or in some tidally influenced reaches. In addition to reducing channel conveyance capacity, channel sedimentation of natural channels can cause lateral redirection of flows, leading to bank erosion. (In cases where design channel capacity is not impaired, such flow redirection problems caused by sedimentation can be addressed by sediment redistribution within the channel, instead of more expensive sediment removal and disposal.)

Sedimentation can also induce vegetation encroachment when low-flow conditions prevent the natural removal of vegetation on bars that are formed along a channel. Several areas with known sedimentation problems, such as the Cherokee Canal and Yuba River, are associated with hydraulic mining debris from the nineteenth century. Sedimentation also often results from eroding riverbanks and levees and agricultural runoff. Table 5-3 lists current standards that apply to sediment management for channels.

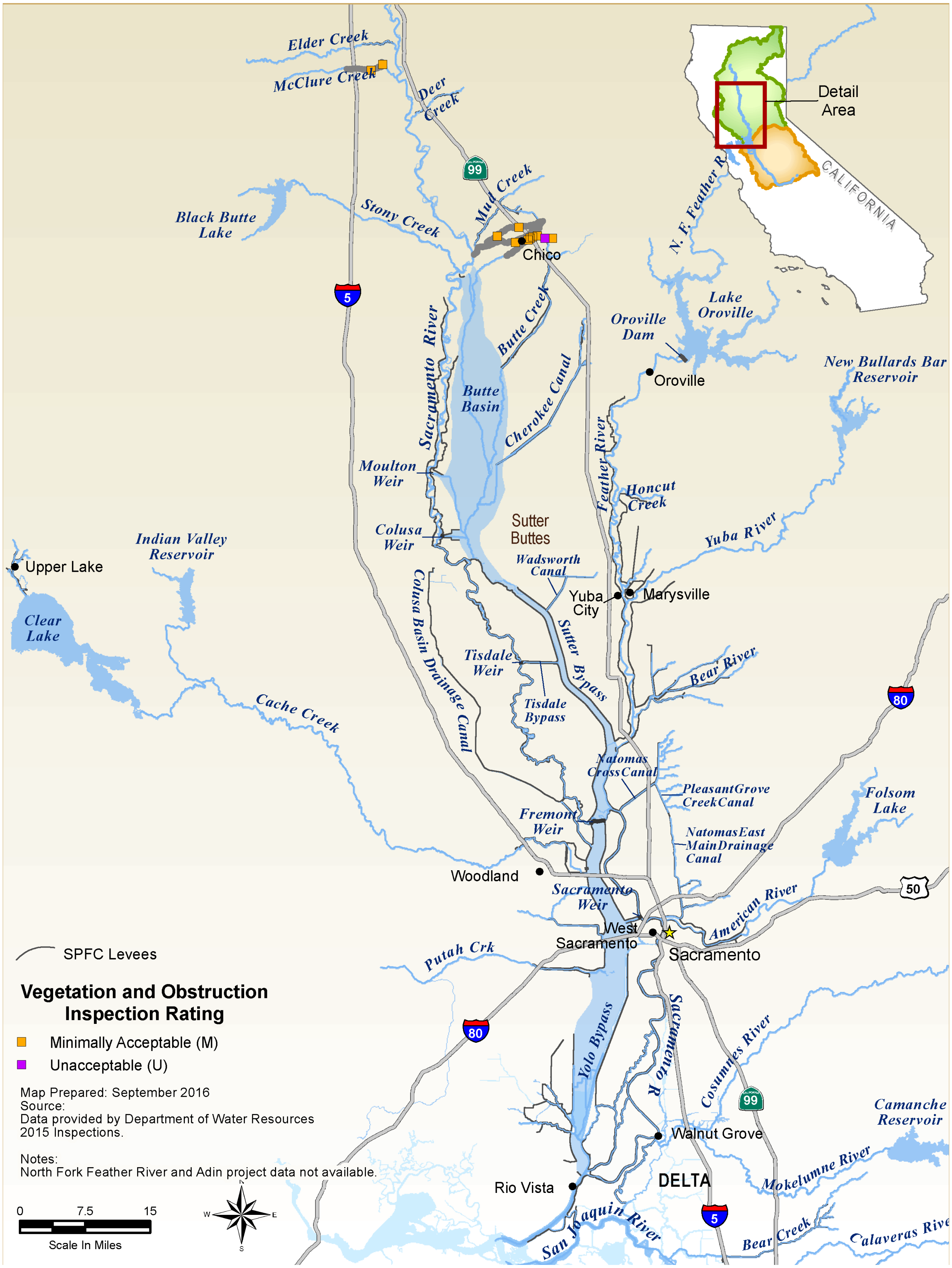

Figure 5-5. 2015 Channel Vegetation Inspection Ratings in the Sacramento River Watershed

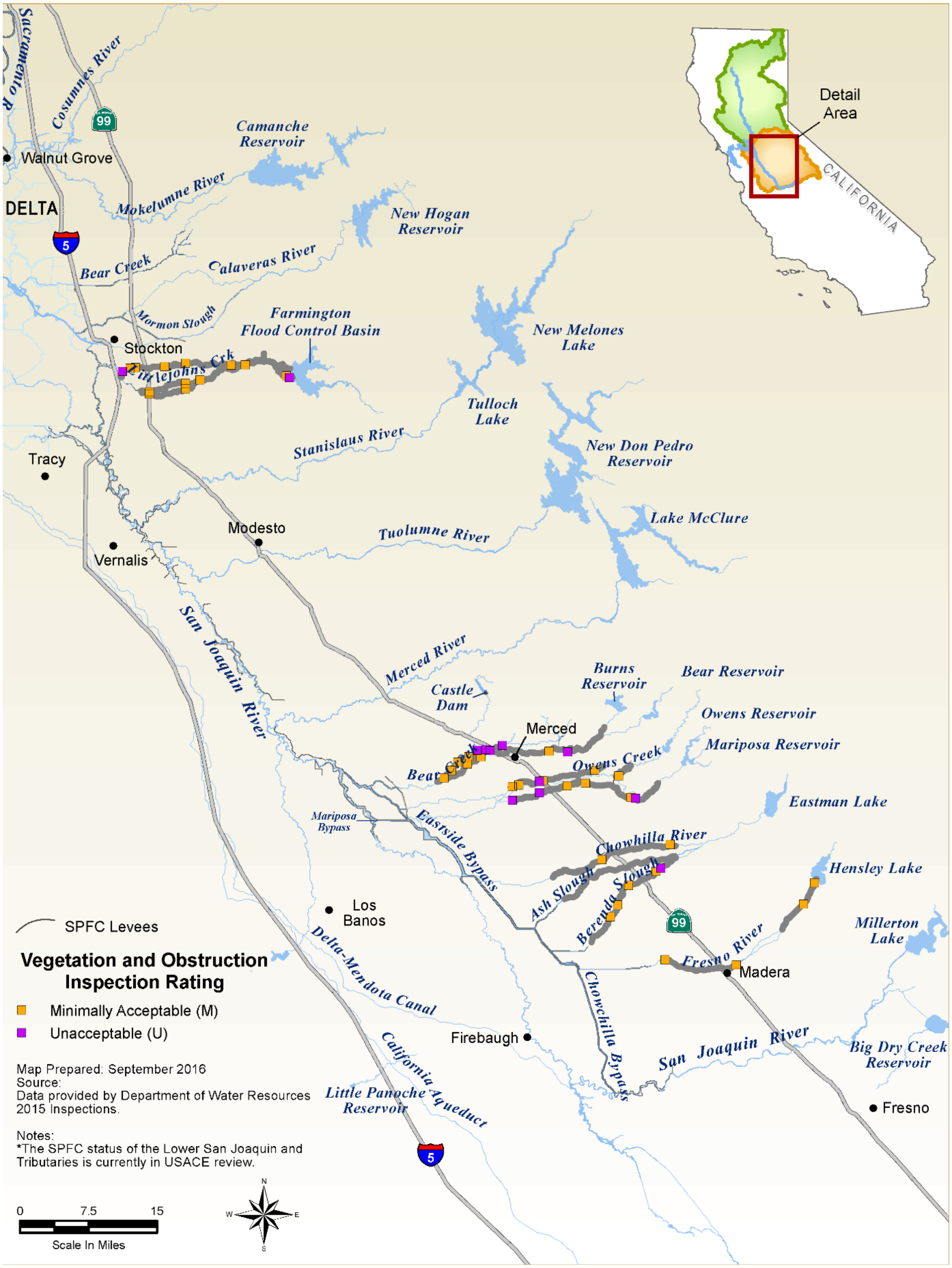

Figure 5-6. 2015 Channel Vegetation Inspection Ratings in the San Joaquin River Watershed

Table 5-3. Current Standards for Channel Sediment Management

Source of Standard	Description of Standard
Title 33, Federal Statutes, part 208	Sediment management is to be performed in channels so that flood conveyance capacity is maintained.
Federal Clean Water Act Section 404	Channel sedimentation management activities could require a Clean Water Act Section 404 permit to be obtained from USACE for discharge of dredged or fill material into "waters of the United States, including wetlands." Waters of the United States include traditionally navigable rivers and their tributaries and adjacent wetlands that have a significant nexus with waters of the United States. If a Section 404 permit is required, a Clean Water Act Section 401 Water Quality Certification would also be required by the Regional Water Quality Control Board.
Federal Rivers and Harbors Act	The River and Harbors Act of 1899 addresses activities that involve the construction of, among other structures, dams, bridges, and dikes across any navigable water. The act also addresses placement of obstructions to navigation outside established federal lines, as well as the excavation or deposition of material in such waters. All of these actions require permits from USACE.
Unit-specific O&M manuals	Generally, limit sedimentation in a project flood protection system so that "the capacity of the channel or floodway is not being reduced by the formation of shoals."
ETL 1110-2-571	Provides some flexibility to sediment management if the water surface profile is maintained. The operative rule is that "capacity of the channel or floodway is not being restricted by the formation of shoals" (USACE, 2009b).
Standard O&M Manual for the Sacramento River Flood Control Project	States that "the capacity of the channel or floodway is not being reduced by the formation of shoals" and "sediment, rubbish, industrial waste or any debris plugs or other obstructions should be removed from the channel to prevent any tendency for the flows to be deflected within the channel" (USACE, 1955a)

Key:
O&M = operations and maintenance
USACE = United States Army Corps of Engineers

5.3.1 Status Evaluation Methodology

Sediment management conditions were evaluated against DWR's current maintenance standards using results from the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b). Table 5-4 shows DWR inspection rating descriptions for shoaling and sedimentation in SPFC channels. Each channel inspection location includes a separate upstream and downstream channel inspection rating. In this 2017 FSSR, only the worst of the two ratings is reported for each location.

Table 5-4. Channel Inspection Rating Descriptions for Shoaling and Sedimentation

Inspection Rating	Rating Description
Acceptable (A)	No shoaling or sedimentation present.
Minimally Acceptable (M)	Nonaquatic grasses present on shoal. No trees or brush are present on shoal, and channel flow is not impeded.
Unacceptable (U)	Shoaling is well established, and stabilized by trees, brush, or other vegetation. Shoals are diverting flow to channel bank causing bank erosion and undercutting.

5.3.2 Limitations of Status Evaluations

Information about channel sedimentation conditions is limited to the channels that DWR inspects (i.e., 26 channels and 233 miles) and to conditions that are visible. Shoaling and sedimentation inspections are usually performed from selected points along a channel and from the crown of a levee. Sedimentation conditions can be evaluated more thoroughly using observation, past performance evaluation, channel surveying, and project-specific hydraulic modeling. Using these methods, a channel is determined to be inadequate if the channel capacity is less than the design capacity. Data about lowering of channel beds, bank instability, and channel widening were not available.

5.3.3 Results of Status Evaluations

Shoaling and sedimentation channel inspection ratings from the shoaling and sedimentation channel inspection ratings from the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b) are shown in Figures 5-7 and 5-8. Of the 233 miles of SPFC channels inspected by DWR, eight locations were rated unacceptable and 26 locations were rated minimally acceptable for shoaling and sedimentation. Additional channel sedimentation problems may exist in areas not inspected by DWR.

Figure B-6 in Appendix B, Section B-3, shows the current status of sediment management projects in channels that DWR is responsible for maintaining in the Sacramento River watershed. Graphs embedded in Figure B-6 show annual cubic yards of sediment removed by DWR from 1983 through 2009. Data for sediment management activities in the San Joaquin River watershed are currently not available.

For additional information about recent remedial actions/improvements, ongoing and planned remedial actions/improvements, and ongoing actions to improve future evaluations of sedimentation in SPFC channels, see Appendix B, Section B-3.

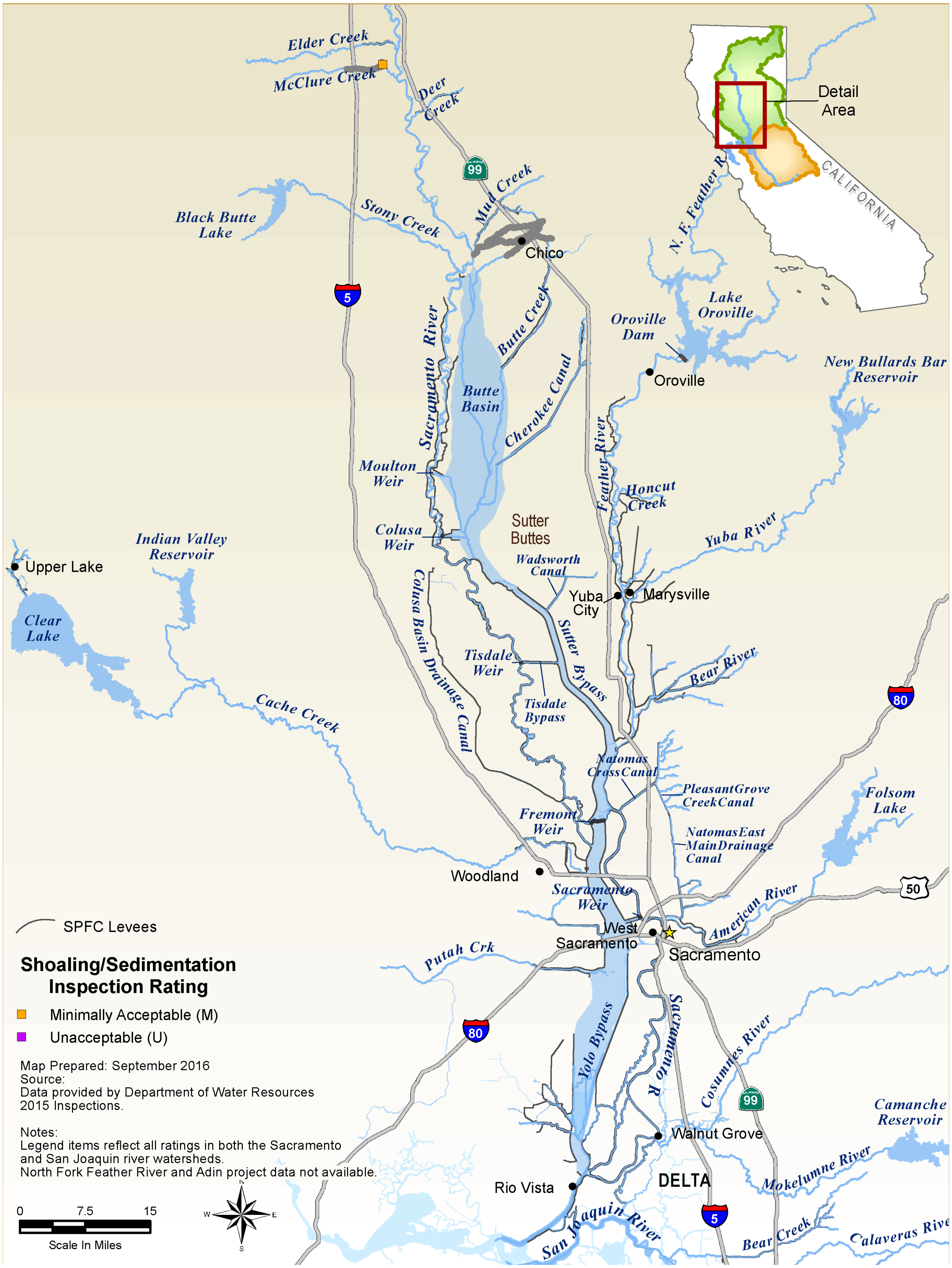

Figure 5-7. 2015 Channel Shoaling/Sedimentation Inspection Ratings in the Sacramento River Watershed

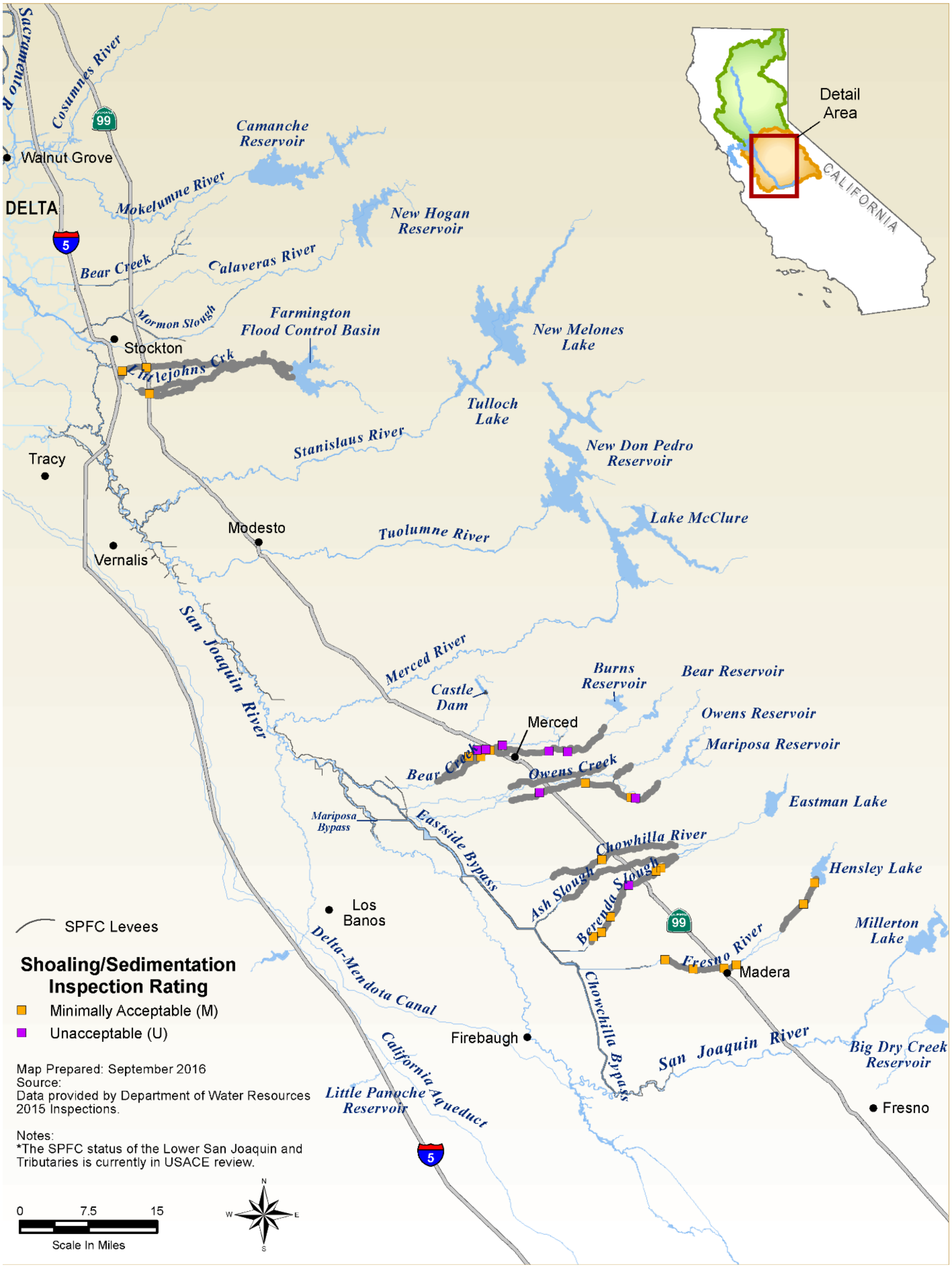

Figure 5-8. 2015 Channel Shoaling/Sedimentation Inspection Ratings in the San Joaquin River Watershed

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6.0 Flood Control Structure Status

The SPFC depends on many flood control structures built along tributaries and bypasses to redirect, restrict, or attenuate floodflows to protect lives and property, including hydraulic structures, pumping plants, and bridges. Although major flood control structures in the Sacramento and San Joaquin river watersheds are part of the SPFC, the flood management system also relies on many non-SPFC hydraulic structures, pumping plants, and bridges to convey floodwaters. Flow in the Sacramento River is reduced by floodwater spilled into bypass areas through five SPFC weirs (i.e., the Moulton, Colusa, Tisdale, Fremont, and Sacramento weirs). Because of these spills to the bypass areas, the design flow capacity of the Sacramento River generally decreases in a downstream direction except where tributary inflow increases river flow. In the upper San Joaquin River, SPFC hydraulic structures help direct flows into the Chowchilla, Eastside, and Mariposa bypasses.

Some flood control structures are multiuse and are operated during both the flood and nonflood seasons under differing parameters. A few of the structures are mainly used to manage flows during nonflood season. These flood control structures include fixed crown diversion weirs, controllable diversion structures, outfall structures, drop structures, and interior drainage pumping plants. Flood control structures also include the M&T and Goose Lake flood relief structures and bridges that are maintained by DWR to convey floodwaters in accordance with California Water Code Section 8361.

Many flood control structures in the SPFC were designed and constructed before current design criteria were adopted, and have not been upgraded to meet current inspection criteria. These structures were generally built between 1940 and 1970, with several structures constructed even earlier. A few structures were modified or improved in the intervening years, but many of the structures are near or have exceeded the end of their expected service lives. Some flood control structures are visibly aging and have significant age-related damage and other problems, in addition to being functionally obsolete (meaning that they have inadequate controls, lack redundant backup power supply, or have restricted access for maintenance).

DWR's maintenance activities for SPFC flood control structures were the subject of an annual report in 1959, entitled Location, Description and Inventory of Miscellaneous Project Structures, Sacramento River Flood Control Project, and American River Flood Control Project. This report was followed shortly by a maintenance status report. DWR has since provided annual maintenance status reports on flood control structures to the Board.

DWR inspects federal project structures in both the Sacramento and San Joaquin watersheds. Several of these project structures are not part of the SPFC because documentation of State assurances of nonfederal cooperation has not been found, but these structures are included in this section to provide status information.

Physical conditions of project flood control structures inspected by DWR in 2015 are summarized below, according to the following categories:

- Hydraulic structures
- Pumping plants
- Bridges

6.1 Hydraulic Structures

SPFC hydraulic structures include weirs, drop structures, control structures, drainage structures, and outfall structures. DWR has historically conducted visual inspections and documented conditions of SPFC hydraulic structures (but not to evaluate their structural integrity). DWR inspection criteria have evolved as USACE has updated design guidance.

The current DWR has inspection program to evaluate overall conditions of the hydraulic structures it maintains. Because the hydraulic structures maintained by DWR are the oldest in the system and are near or have exceeded their expected service lives, DWR is now evaluating these structures to determine their future serviceability. Furthermore, DWR is working with USACE and maintaining agencies to evaluate other hydraulic structures and, if necessary, reconstruct them with USACE to meet federal standards.

6.1.1 Status Evaluation Methodology

Annual inspections for hydraulic structures form the basis for this evaluation, as presented in the 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b). In addition, 2015 inspection results from the DWR Hydraulic Structures Inspection Program were incorporated into the evaluation, as appropriate (see Section 2.1 for details on the two inspection programs). A total of 49 SPFC hydraulic structures and three non-SPFC hydraulic structures were inspected. The hydraulic structure inspections rated conditions as Acceptable (A), Minimally Acceptable (M), or Unacceptable (U) based on the following categories: structural condition, vegetation and obstructions, encroachments, and erosion/bank caving and shoaling/sedimentation.

These categories are based on the USACE Flood Damage Reduction Segment/System Inspection Report (USACE, 2009a).

Hydraulic structure inspection ratings for structural conditions include a variety of inspection categories, including:

- Closure structures
- Concrete surfaces
- Concrete tilting/settlement
- Concrete foundations
- Culverts: inlets/outlets
- Culverts: breaks/holes/cracks
- Electric gate operators

- Flap gates
- Manual gate operators
- Metal pipes
- Monolith joints
- Other metallic items
- Revetments
- Sluice/slide gates
- Trash racks

Detailed hydraulic structure inspection rating descriptions for structural conditions can be found in the DWR 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (USACE, 2015b). Tables 6-1 through 6-3 show DWR inspection rating descriptions of hydraulic structures for vegetation and obstructions conditions, encroachment conditions, and erosion/bank caving and shoaling/sedimentation conditions, respectively. Though results are presented, rating descriptions for the structural inspection criteria are too extensive to list here.

Table 6-1. Hydraulic Structure Inspection Rating Descriptions for Vegetation and Obstruction Conditions

Inspection Category	Inspection Rating	Rating Description
Vegetation and Obstructions	Acceptable (A)	Minimal, scattered obstructions or vegetation. The flow is not impeded.
	Minimally Acceptable (M)	Log jams, snags, vegetation growth (such as cattails, bulrushes, bushes, or saplings), or other obstructions block approximately 25 percent of the flood control work.
	Unacceptable (U)	Log jams, snags, vegetation growth (such as cattails, bulrushes, bushes, or saplings), or other obstructions block approximately 50 percent of the flood control work.

Table 6-2. Hydraulic Structure Inspection Rating Descriptions for Encroachment Conditions

Inspection Category	Inspection Rating	Rating Description
Encroachments	Acceptable (A)	No trash, debris, excavation, structures, or other obstructions present within the project easement area. Encroachments that do not diminish proper functioning of the project have been previously approved by the Board.
	Minimally Acceptable (M)	Trash, debris, excavations, structures, other obstructions present, or inappropriate activities that will not inhibit project operations were observed and maintenance or emergency operations. Encroachments have been approved by the Board.
	Unacceptable (U)	Trash, debris, excavations, structures, other obstructions present, or inappropriate activities that will inhibit project operations and maintenance or emergency operations were observed.

Table 6-3. Hydraulic Structure Inspection Rating Descriptions for Erosion/Bank Caving and Shoaling/Sedimentation Conditions

Inspection Category	Inspection Rating	Rating Description
Erosion/Bank Caving	Acceptable (A)	No active erosion or bank caving observed on the landward or on the waterside of the levee/channel.
	Minimally Acceptable (M)	There are areas where active erosion is occurring or has occurred on or near the levee/bank, but project integrity is not threatened.
	Unacceptable (U)	Erosion or caving is occurring or has occurred that threatens the stability and integrity of the project. The erosion or caving has compromised project integrity.
Shoaling/ Sedimentation	Acceptable (A)	No shoaling or sedimentation present.
	Minimally Acceptable (M)	Nonaquatic grasses present on shoal. No trees or brush are present on shoal, and structure operation and channel flows are not impeded.
	Unacceptable (U)	Shoaling is well established, and is stabilized by trees, brush, or other vegetation. Shoals are obstructing structure operation or diverting flow to channel bank, causing bank erosion and undercutting.

6.1.2 Limitations of Status Evaluations

This evaluation covers only hydraulic structures inspected by DWR, and is limited to conditions that can be visually inspected, annually, during the summer. Most hydraulic structures inspected by DWR are part of the SPFC, but there are a few non-SPFC structures inspected as part of federal projects. Status information for other hydraulic structures in the flood management system is not included because it was not available.

6.1.3 Results of Status Evaluations

Hydraulic structure conditions observed during annual inspections in 2015 (DWR, 20115) are presented in Figures 6-1 through 6-8 for the Sacramento and San Joaquin river watersheds. Tabular results summarizing the Minimally Acceptable and Unacceptable inspection ratings for SPFC and non-SPFC hydraulic structures are shown in Table 6-4.

Ongoing and planned remedial actions and ongoing actions to improve future evaluations are summarized in Appendix C, Section C-1.

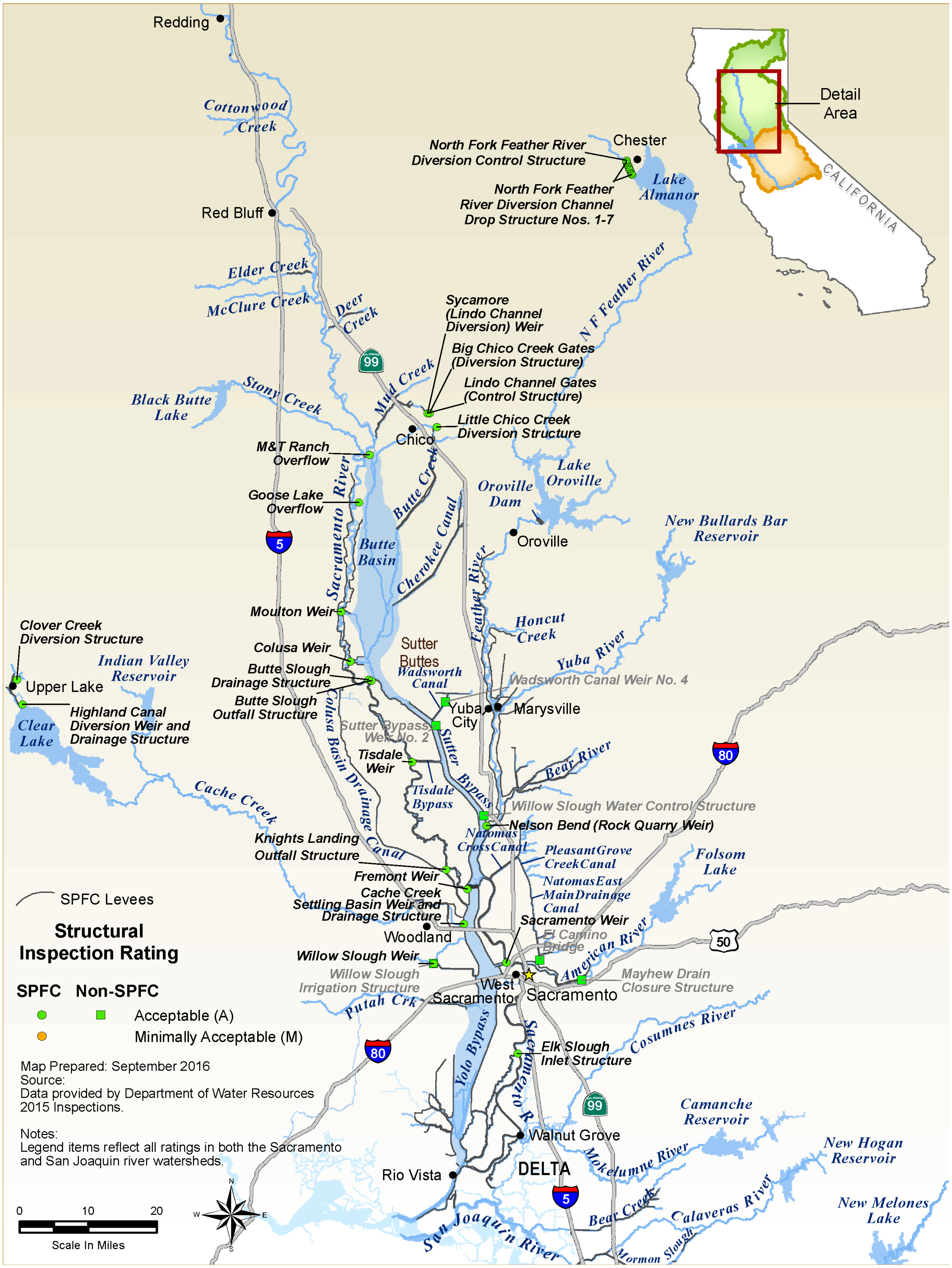

Figure 6-1. Hydraulic Structures – Structural Conditions in the Sacramento River Watershed

Figure 6-2. Hydraulic Structures – Structural Conditions in the San Joaquin River Watershed

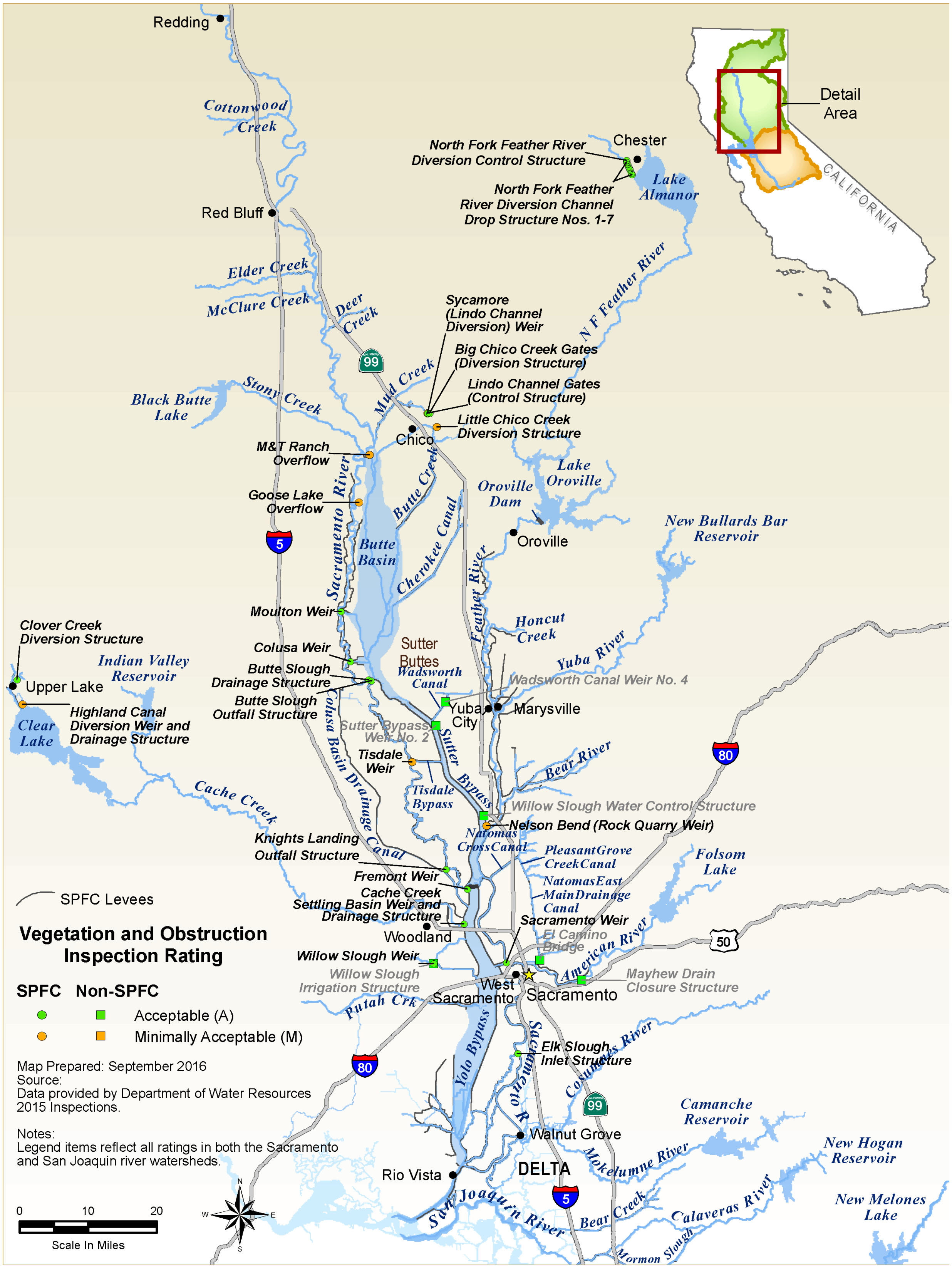

Figure 6-3. Hydraulic Structures – Vegetation and Obstruction Conditions in the Sacramento River Watershed

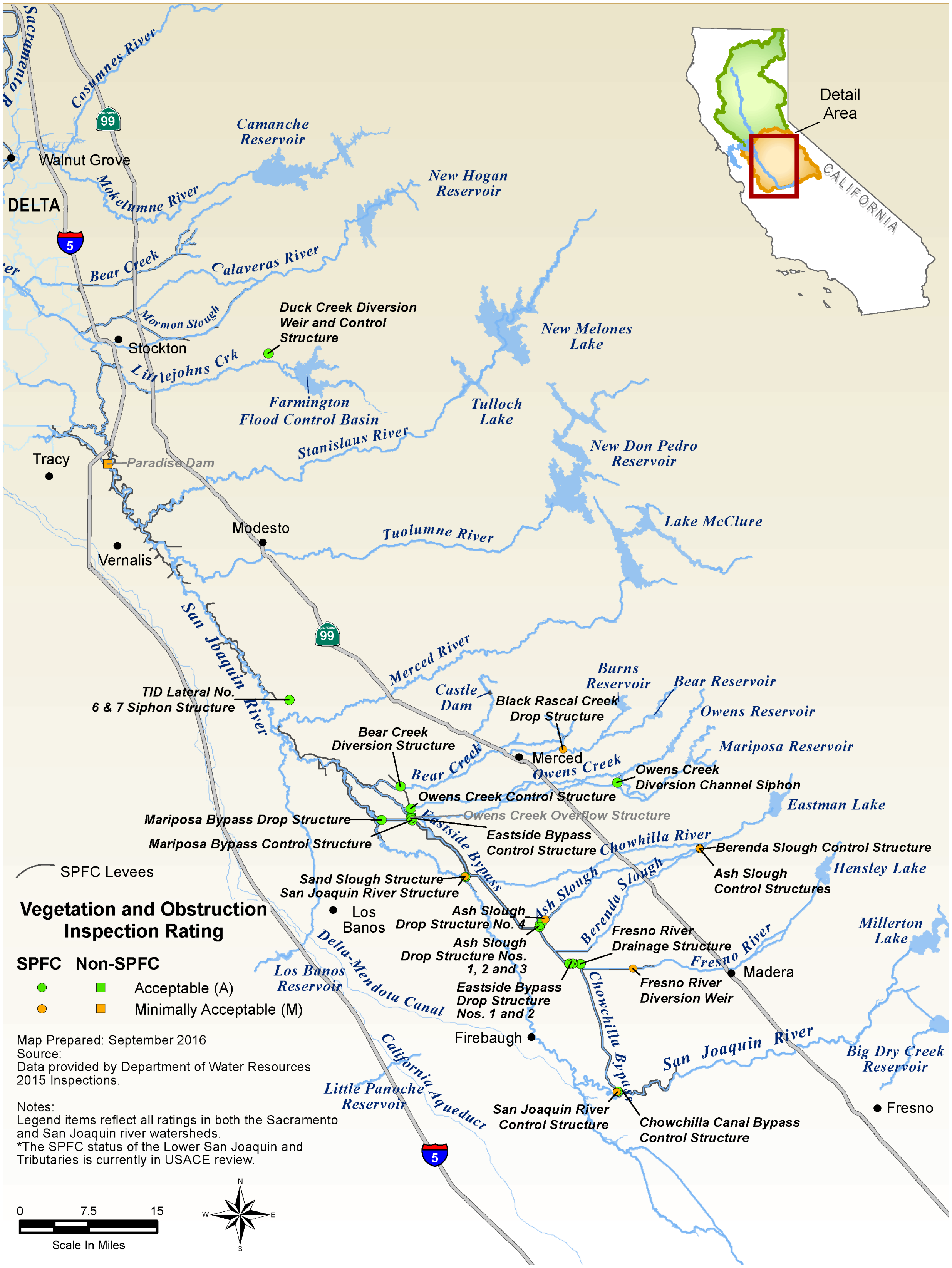

Figure 6-4. Hydraulic Structures – Vegetation and Obstruction Conditions in the San Joaquin River Watershed

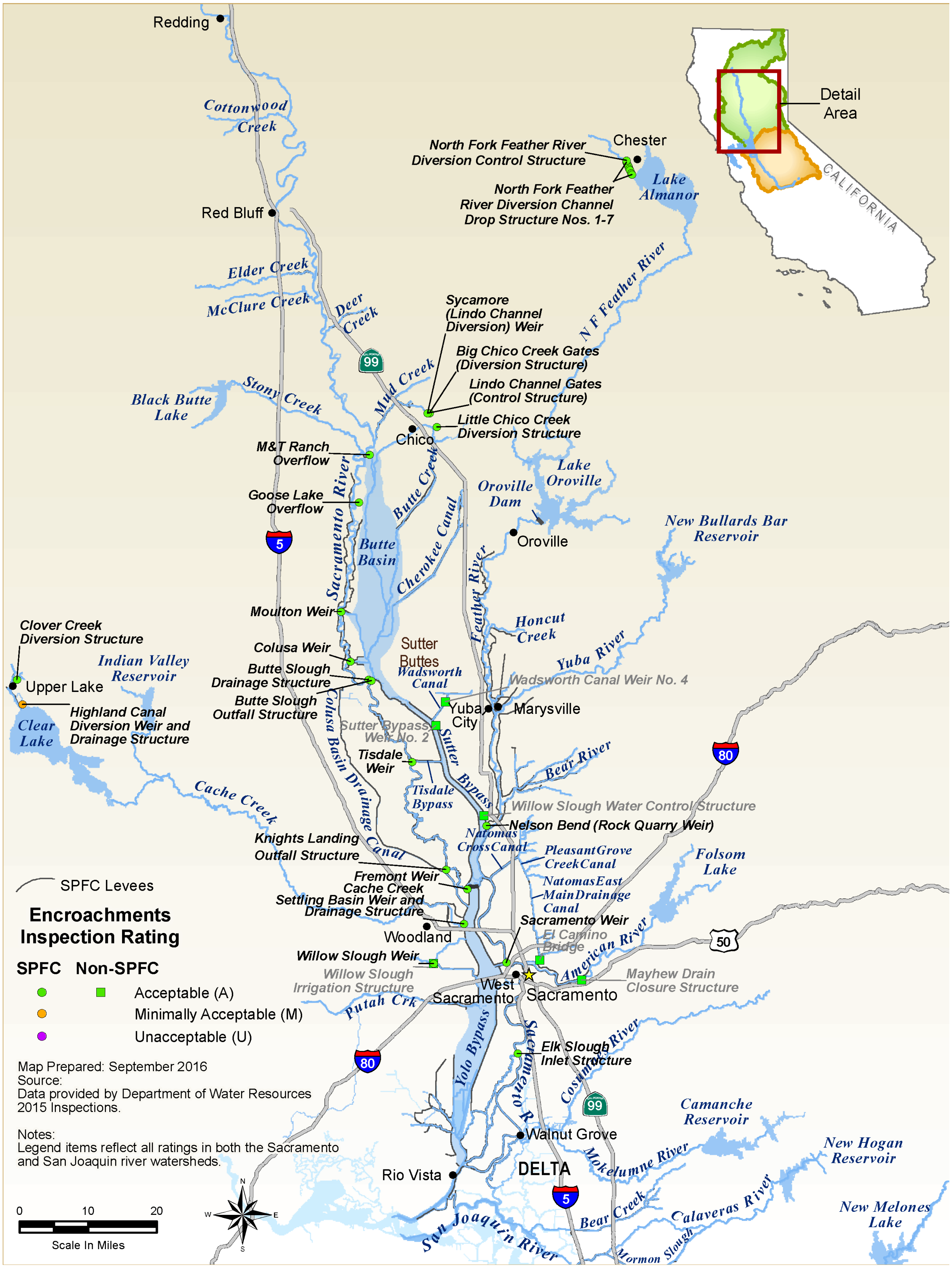

Figure 6-5. Hydraulic Structures – Encroachment Conditions in the Sacramento River Watershed

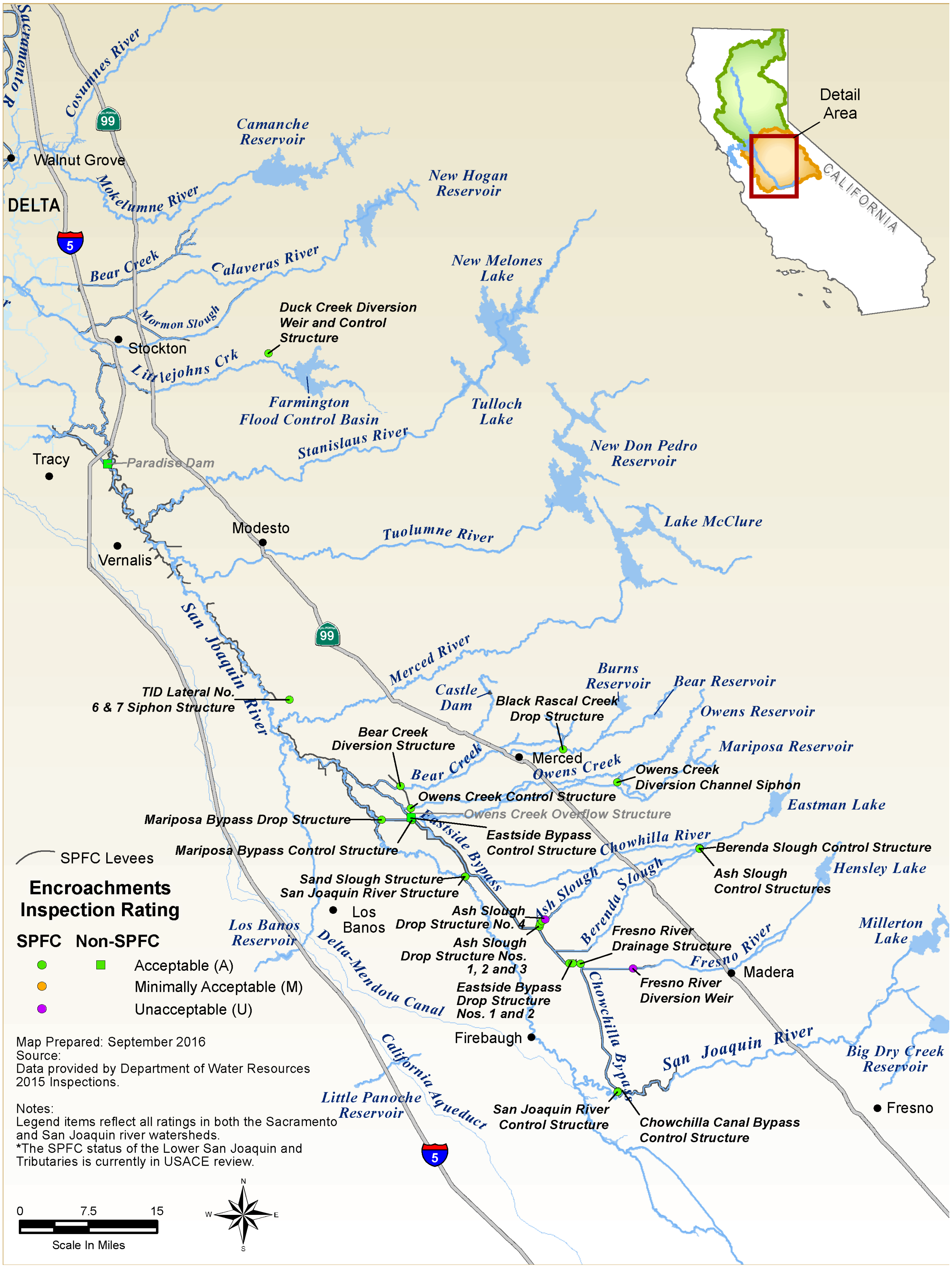

Figure 6-6. Hydraulic Structures – Encroachment Conditions in the San Joaquin River Watershed

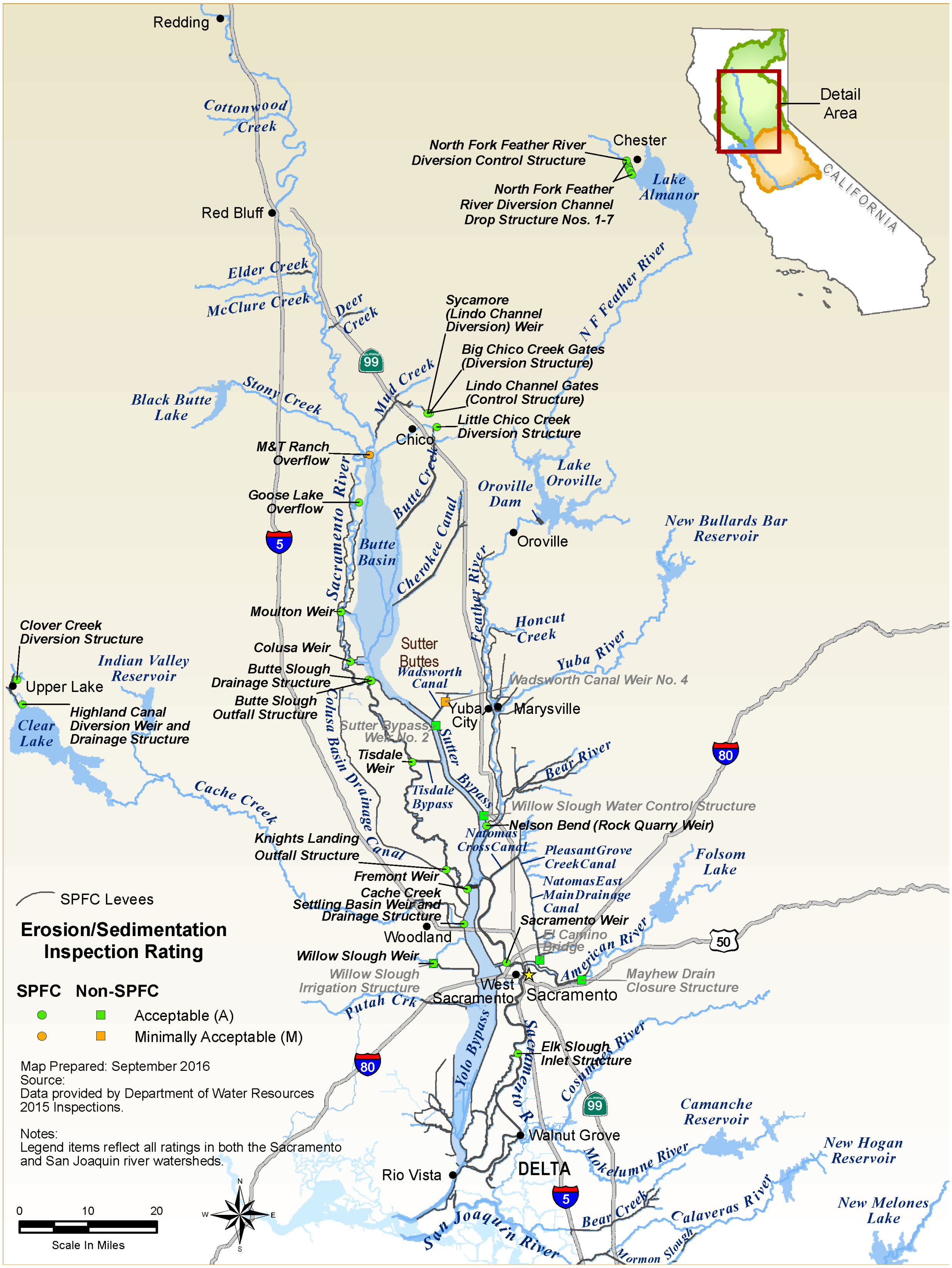

Figure 6-7. Hydraulic Structures – Erosion/Bank Caving and Shoaling/Sedimentation Conditions in the Sacramento River Watershed

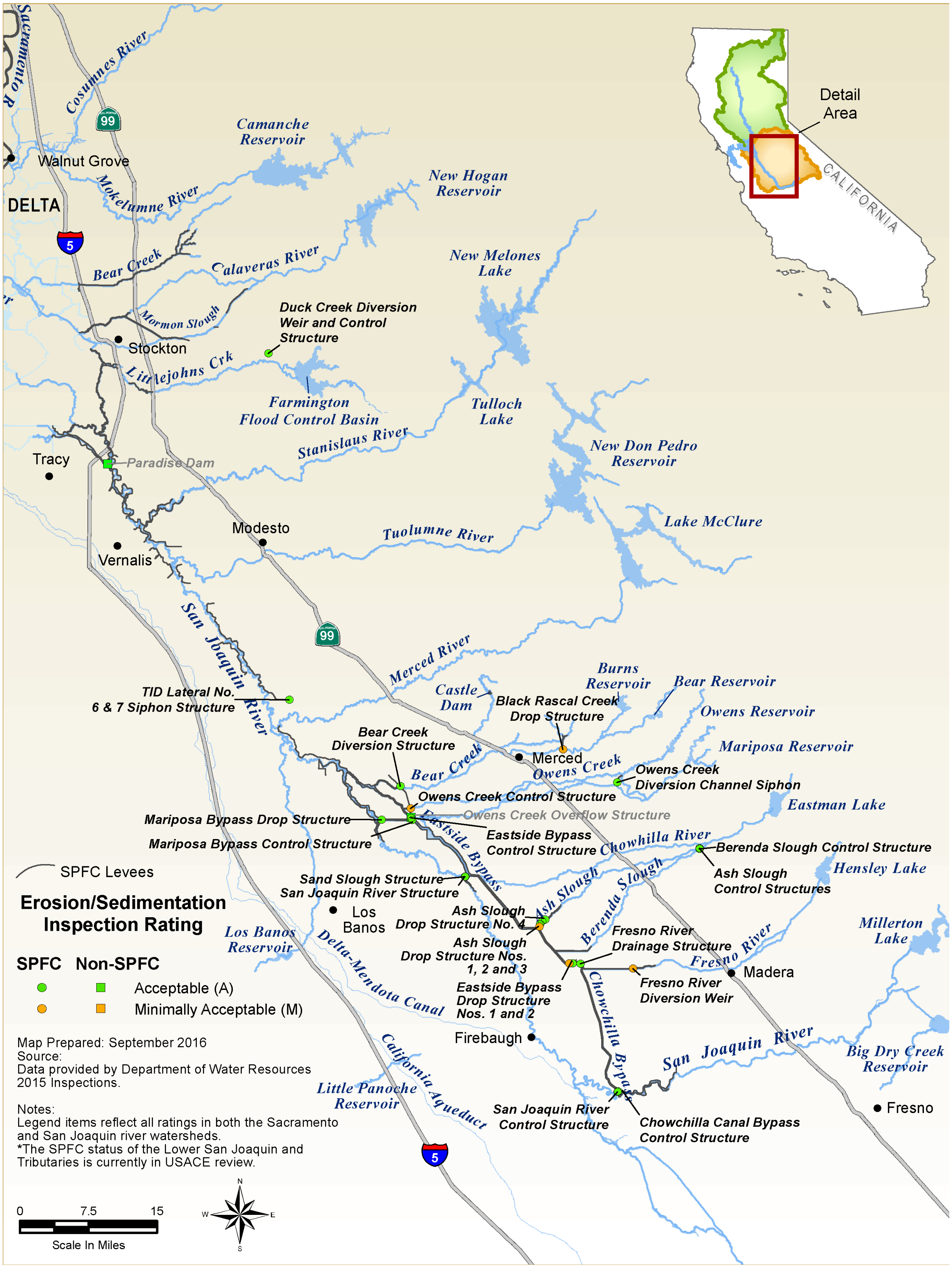

Figure 6-8. Hydraulic Structures – Erosion/Bank Caving and Shoaling/Sedimentation Conditions in the San Joaquin River Watershed

Table 6-4. Hydraulic Structure Conditions Summary (2015)

Inspection Category	SPFC Hydraulic Structures[1]			Non-SPFC Hydraulic Structures[1,2]		
	Unacceptable	Minimally Acceptable	Acceptable	Unacceptable	Minimally Acceptable	Acceptable
Structural	0	6	43	0	0	3
Vegetation/ Obstructions	0	13	36	0	3	0
Encroachment	2	1	46	0	0	3
Erosion/Bank Caving Shoaling/ Sedimentation	0	6	43	0	1	2

Notes:
[1] Information is summarized for hydraulic structures inspected by DWR in 2015, only.
[2] Non-SPFC hydraulic structures summarized are inspected by DWR as part of the federal project, but not as part of the SPFC because they lack documentation of assurances of nonfederal cooperation from the Board to USACE.
Key:
SPFC = State Plan of Flood Control

6.2 Pumping Plants

Pumping plants discharge drainage water into adjacent channels to reduce localized flooding. The evolution of criteria and DWR inspections related to pumping plants is the same as described for hydraulic structures in Section 6.1.

6.2.1 Status Evaluation Methodology

Annual inspections for pumping plants are presented in the DWR 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System (DWR, 2015b). Eleven SPFC pumping plants and two non-SPFC pumping plants were inspected. Pumping plants were rated as Acceptable (A), Minimally Acceptable (M), or Unacceptable (U) based on numerous inspection categories. Table 6-5 shows DWR inspection rating descriptions for pumping plants.

Detailed rating criteria for each inspection category can be found in the DWR 2015 Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System, Appendix C (DWR, 2015b).

Table 6-5. Pumping Plant Inspection Rating Descriptions

Inspection Rating	Rating Description
Acceptable (A)	Weighted calculation of Acceptable, including consideration of operating log, O&M manual, plant building, communications, safety, cranes, pumps, power, motors, engines, fans, gear reducers, pump control systems, sumps/wet well, trash racks, trash rakes, sluice/slide gates, electric gate operators, manual gate operators, other metallic items, flap gates, closure structures, security fencing, intake and discharge pipes, and pressurized pipes.
Minimally Acceptable (M)	Weighted calculation of Minimally Acceptable, including consideration of elements above.
Unacceptable (U)	Weighted calculation of Unacceptable, including consideration of elements above.

Key:
O&M = operations and maintenance

6.2.2 Limitations of Status Evaluations

This evaluation covers only pumping plants inspected by DWR, and is limited to conditions that were visually inspected, annually, during the summer 2015 inspection. Status information for other pumping plants in the flood management system (non-SPFC) is not included because it was not available.

6.2.3 Results of Status Evaluations

Pumping plant conditions from annual inspections in 2015 (DWR, 2015) are presented in Figure 6-9 for the Sacramento and San Joaquin river watersheds. Of the 13 pumping plants inspected, no pumping plants were rated as Unacceptable and one pumping plants was rated as Minimally Acceptable.

Ongoing and planned remedial actions and ongoing actions to improve future evaluations are summarized in Appendix C, Section C-2.

6.3 Bridges

DWR maintains and inspects some bridges in the Sacramento Watershed in accordance with California Water Code Section 8361 (c), and does not maintain or inspect any bridges in the San Joaquin River watershed. Before 2008, DWR did not conduct a separate annual inspection for bridges, but inspected bridges as components of overall channel inspections for conveyance capacity under the DWR Annual Inspection Program. Many bridges in the SPFC were designed and built before other SPFC facilities were constructed. In most cases, conveyance capacity through bridge openings was incorporated into SPFC levee and channel design. However, in some instances, encroachment into the floodflow capacity caused by bridges was not addressed as part of the design capacity (e.g., a bridge is lower than the design stage and/or levees at the bridge abutment have insufficient freeboard or are below the design stage). Bridges constructed after other SPFC facilities were generally evaluated by USACE and the Board so that bridges would not impact flows and/or impede flood emergency and/or maintenance operations.

6.3.1 Status Evaluation Methodology

DWR evaluated the condition of bridges against current maintenance standards using the results of annual bridge inspections in 2015 through the DWR Bridge Inspection Program. Inspection criteria for DWR’s inspection logs were customized to each bridge based on the material used to construct the bridge. Visual inspections were performed on each DWR-maintained bridge regarding safe passage by evaluating the following: foundation scour, abutment erosion, approach grades, and overall structural integrity. Concrete bridges were inspected for cracks, chips, spalling, joint separation, and exposed rebar. Wooden structures were inspected for deterioration, cracking, joint and fastener separation, and wear. Inspection rating descriptions for bridges are listed in Table 6-6, with inspection elements listed above categorized for bridge deck conditions, foundation conditions, approach conditions, foundation scour, and spalling concrete.

Figure 6-9. Pumping Plant Conditions in Sacramento and San Joaquin River Watersheds

Table 6-6. Bridges Inspection Rating Descriptions

Inspection Categories	Rating and Description
Deck Conditions, Foundation Conditions, Approach Conditions, Foundation Scour, and Spalling Concrete	1. Bridge is excellent condition. No visual inadequacies noted.
	2. Bridge has areas of minor cosmetic inadequacies; however, it appears to be in good working condition.
	3. Bridge is in fair condition. The bridge has minor observable inadequacies; however, it remains in good working condition.
	4. Bridge is in need of repair. The bridge condition does not pose an immediate hazard to the public.
	5. Bridge needs immediate repairs. The bridge condition poses an immediate hazard to the public.

6.3.2 Limitations of Status Evaluations

As mentioned, DWR only maintains and inspects the bridges shown in Figure 6-10 in accordance with California Water Code Section 8361(c). DWR does not maintain or inspect any bridges in the San Joaquin River watershed. Reported conditions are limited to items that can be visually inspected annually during summer, and does not involve additional testing by DWR. Status information for other bridges in the flood management system is not included because it was not available.

6.3.3 Results of Status Evaluations

Bridge conditions noted from the DWR Bridge Inspection Program are presented on Figure 6-10 for the Sacramento River watershed. Detailed description, of the DWR inspections can be found in the DWR Annual Bridge Inspection Report (DWR, 2015a).

Of the 11 bridges inspected by DWR, two had ratings of 4 and 5 overall, and were noted as needing repairs. Since 2000, three Sutter Basin bridges (not inspected by DWR or depicted in Figure 6-10) have been replaced and turned over to Sutter County for future O&M.

Ongoing and planned remedial actions and ongoing actions to improve future evaluations are summarized in Appendix C, Section C-3.

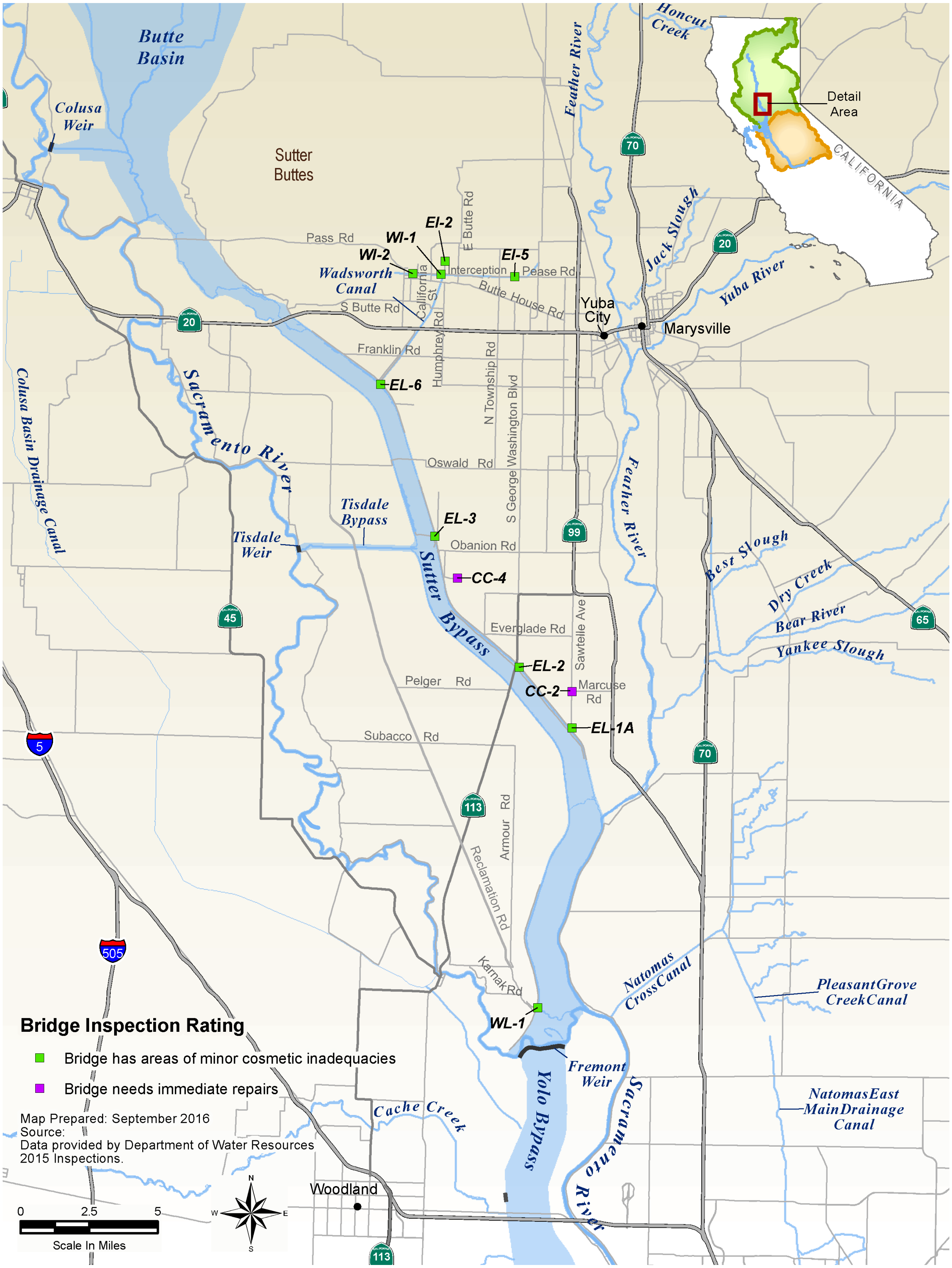

Figure 6-10. Bridge Conditions in the Sacramento River Watershed

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7.0 Approach for SPFC Improvements

Sections 4.0, 5.0, and 6.0 of this 2017 FSSR describe physical conditions of SPFC levees, channels, and flood control structures based on best available information. In some areas of the Sacramento and San Joaquin watersheds, not enough information is available to determine whether SPFC facilities are performing to their expected level. While some SPFC facilities meet their intended performance standards, many do not; they may show visible distress, or otherwise have problems that could impair how the facilities function. These problems likely increase the chances that facilities could fail and contribute to major flooding.

DWR has plans and programs to further evaluate SPFC facility performance, identify needed flood system reconstructions and improvements, and implement reconstructions and improvements as State, federal, and local funding becomes available. This section provides an overview of DWR's systematic approach for addressing problems with flood management facilities and for taking actions to improve SPFC performance supported by the 2012 CVFPP and 2017 CVFPP Update.

7.1 2017 Central Valley Flood Protection Plan Update

The CVFPP is the primary vehicle for addressing problems identified in this 2017 FSSR, and further improvements to the SPFC. It is highlighted again in this section because the CVFPP addresses how to correct, improve, and manage the SPFC. DWR prepared and the Board adopted, the CVFPP in June 2012 to meet legislative requirements. The plan is being updated every 5 years thereafter (in years ending in 7 and 2). As the first edition of this long-term planning document was completed in 2012, the 2017 CVFPP Update will continue to guide State investments for improving integrated flood management in the Sacramento-San Joaquin Valley.

The 2017 CVFPP Update represents a sustainable, integrated flood management plan that will continue to guide State, federal, and local actions to improve flood management in this vital region of the State. To adequately address current and increasing future demands on the SPFC, significant and sustained actions are needed to improve the performance level of SPFC facilities that exist today. Implementing a portfolio of actions to address identified problems as part of a systemwide approach to improving flood management throughout the Sacramento and San Joaquin river watersheds will take many years and significant coordination between local, State, and federal governments.

The CVFPP describes a recommended implementation approach that considers priorities and program phasing. Implementation phasing must account for relationships between upstream and downstream actions, while also ensuring that near-term actions are feasible in terms of readily available funding, secured cost-sharing, stakeholder coordination, and other important factors. Phased implementation will also help accommodate the timing of project design, permitting, land acquisition, stakeholder alignment and partner costshare funding availability.

A range of actions will be required to develop, construct, and manage improvements to the SPFC. This work will be organized into several programs, established and led by DWR and implemented in coordination with local and federal partners. Each program will be responsible for specialized implementation. Together, the programs cover all work required for implementation and management of the improved SPFC. DWR's major flood management programs are as follows:

- Flood Emergency Response Program
- Flood System Operations and Maintenance Program
- Floodplain Risk Management Program
- Flood Risk Reduction Projects Program
- Flood System Management Planning

The first three programs are responsible for residual risk management. The fourth program is responsible for implementing on-the-ground projects for SPFC improvement. The last program is responsible for conducting feasibility evaluations, design, engineering, and other activities necessary for implementation.

As described in Section 1.1, the SPFC Descriptive Document has been updated (August 2017) along with this 2017 FSSR to support the 2017 CVFPP Update.

Following Board adoption of the 2012 CVFPP and its attached Conservation Framework, DWR developed a Conservation Strategy to support development of the 2017 CVFPP Update. It supports the attainment of all CVFPP goals, but focuses on the integration and improvement of ecosystem functions with flood risk reduction projects where feasible. The Conservation Strategy and its appendices describe the basis for recommending various conservation actions and setting long-term objectives for the Central Valley flood management system. The integration of specific ecosystem restoration features with DWR's proposed flood management system improvements will be further described in the 2017 CVFPP Update and supporting documents such as the Sacramento River BWFS and the San Joaquin River BWFS. The Conservation Strategy also is aligned with the CVFPP as a whole and is consistent with the "key actions" identified within the California Water Action Plan. A complete version of the Conservation Strategy is noted in the reference section of this 2017 FSSR. The Central Valley Integrated Flood Management Study, which is being led by USACE, is the federal complement to the CVFPP and focuses on shared opportunities to reduce flood risk in the Central Valley in an integrated water resource and flood management context. Both studies have the common goal of determining a State-federal strategy that will lead to expedient and cost-shared implementation of new and continuing projects to reduce flood risk in the Central Valley. USACE participated in CVFPP development, providing valuable input on all phases of the plan, producing joint data and technical information, and assisting in use of analytical tools. USACE is also providing technical expertise in developing flood hydrology, analyzing reservoir operations, and incorporating risk-based decision-making processes that improve system reliability.

In summary, DWR has plans and programs to further evaluate the status of facility performance, identify needed flood system improvements, and implement those improvements as State, federal, and local funding becomes available. The CVFPP, in particular, will guide improvement and management of the SPFC in the future.

8.0 Findings and Recommendations

This section summarizes major 2017 FSSR findings and recommendations that are also described in the 2017 CVFPP Update.

8.1 Findings

The flood management system has provided tremendous benefits to public safety and protection of property in the Central Valley; the system has prevented many billions of dollars in flood damages since facilities were originally constructed. However, today, the system is being relied on to provide flood protection and other public benefits at levels that were not envisioned when the system was constructed, including providing recreation and environmental/ecosystem benefits. When evaluated against modern engineering and safety criteria, some SPFC facilities face a higher chance of failure during a flood event than other facilities.

The SPFC includes approximately 1,420 miles of levees and approximately 2,600 miles of channels. Of the SPFC levees evaluated by the DWR Levee Evaluations Program, about 320 miles of those levees help protect urban areas and about 1,100 miles help protect nonurban areas. Associated with the SPFC levees are about 300 miles of non-SPFC levees (i.e., 110 miles of urban levees and 190 miles of nonurban levees) that are instrumental to effective functioning of the SPFC. Information from the State Plan of Flood Control Existing Channel Capacity Assessment Technical Memorandum (CVFED Program, 2009), supplemented with project-specific modeling results, supported evaluation of 1,025 miles of SPFC channels. The overall condition of urban levees, nonurban levees, channels, and flood control structures of the SPFC are summarized as follows:

- **Urban levees** – Approximately half of about 320 miles of SPFC urban levees evaluated do not meet current levee freeboard, stability, or seepage design criteria[13] at the design water surface elevation.
- **Nonurban levees** – Approximately half of about 1,100 miles of SPFC nonurban levees evaluated have a high potential for failure from underseepage, through seepage, structural instability, and/or erosion at the assessment water surface elevation.[14] Nonurban levees were evaluated based on systematic, consistent, repeatable analyses that correlated geotechnical data with levee performance history, not relative to any current design criteria.[15]

[13] The design criteria used were based on USACE’s EM 1110-2-1912, Design and Construction of Levees (USACE, 2000) and DWR’s ULDC (DWR, 2012a).

[14] Where available, 1955/57 design water surface elevations were used as the assessment water surface elevation. In the absence of 1955/57 design water surface elevations, the assessment water surface elevation was based on freeboard requirements for each levee segment (i.e., generally 3 feet below the levee crest).

[15] This approach was selected because the extent of NULE is significantly greater than ULE, making it difficult to conduct the same level of field explorations and geotechnical data collection performed for ULE levees.

- **SPFC channels** – Approximately half of the 1,025 miles of channels evaluated in the SPFC have a potentially inadequate capacity to convey design flows, and require additional evaluation to confirm conditions.
- **SPFC flood control structures** – None of the 49 hydraulic structures or 13 pumping plants inspected by DWR for the SPFC were rated Unacceptable during 2015 inspections. Of the 11 SPFC bridges inspected by DWR in 2015, two were in need of repair.

Many potential factors can influence levee performance, and the threats these factors pose are not all equal. Table 8-1 lists factors that influence facility performance, findings related to each factor, and the relative threat posed by the factor. The relative threat posed by each factor is a subjective representation of the prevalence of the factor and the degree to which the presence of that factor would contribute to potential facility failure. Factors identified as a high relative threat to SPFC facilities generally are the most prevalent and/or greatly contribute to potential facility failure. Those identified as a low relative threat to SPFC facilities generally are the least prevalent and/or contribute less to potential facility failure. Likewise, factors identified as a medium relative threat to SPFC facilities are moderately prevalent and/or contribute moderately to potential facility failure. Therefore, the relative threat posed by each factor is subjective in nature and serves only to help identify and prioritize the factors most likely to contribute to SPFC facility failure. However, prioritizing relative threats affecting SPFC facilities does not necessarily translate directly into investment priorities. To decide which levels of investment are prudent for repairs or improvements, economic and life safety consequences associated with potential failure must also be considered. Potential consequences of facility failure are not presented in this report; they are evaluated in the CVFPP.

Table 8-1. Summary of 2017 Flood System Status Report Findings

	Factors	Findings	Relative Threat Posed by Factor[1]
Levees	Overall Levee Condition (multiple factors)	• Approximately half of SPFC urban levees do not meet current levee freeboard, stability, or seepage design criteria at the design water surface elevation. • Approximately three-fifths of SPFC nonurban levees have a high potential for levee failure from underseepage, through seepage, structural instability, and/or erosion at the assessment water surface elevation.	N/A
Levees	Levee Geometry Check	• Approximately one-third of SPFC urban levees deviate from current standard levee design prism criteria. • Levee geometry deviates significantly from the standard levee design prism for some nonurban SPFC levees.	Medium
Levees	Seepage	• Approximately one-third of SPFC urban levees do not meet current seepage design criteria. • Almost half of SPFC nonurban levees have a high potential for levee failure from underseepage. • Approximately one-quarter of SPFC nonurban levees have a high potential for levee failure from through seepage.	High
Levees	Structural Instability	• Approximately one-fifth of SPFC urban levees do not meet current structural stability design criteria. • Approximately one-eighth of SPFC nonurban levees evaluated in the Sacramento River watershed and 1 percent in the San Joaquin River watershed have a high potential for levee failure from structural instability.	Medium

Table 8-1. Summary of 2017 Flood System Status Report Findings

	Factors	Findings	Relative Threat Posed by Factor[1]
Levees (cont)	Erosion	• Erosion assessments for urban levees are underway, and results are not available at this time. • Almost one-seventh of SPFC nonurban levees have a high potential for levee failure from erosion.	Medium
	Settlement	• Four known localized levee locations have settlement (localized depressions) that endangers the integrity of the SPFC levees. [5]	Low
	Penetrations[2]	• More than 6,000 penetration sites are documented in SPFC levees, and many more remain undocumented.	Medium
	Levee Vegetation	• About 309 miles of SPFC levees are noncompliant with the 2012 CVFPP	Low
	Rodent Damage	• More than one-third of the 1,459 miles of SPFC levees studied had at least eight reported occurrences of burrowing activity over a 21-year study span.	Medium
	Encroach-ments[4]	• Approximately 1,730 encroachment sites were identified	Medium
Channels	Inadequate Conveyance Capacity	• Approximately half of the 1,016 miles of SPFC channels evaluated are potentially inadequate to convey design flows, and require additional evaluation to confirm conditions. • Approximately one-quarter of channel design capacities reported in O&M manuals do not agree with flows specified in the design profiles.	Medium
	Channel Vegetation	• Of the 233 miles of SPFC channels inspected by DWR, 13 locations were rated as Unacceptable and 56 locations were rated Minimally Acceptable because of vegetation and obstructions.[5]	Low
	Channel Sedimentation	• Of the 233 miles of SPFC channels inspected by DWR, eight locations were rated Unacceptable and 26 locations were rated Minimally Acceptable because of shoaling/sedimentation.[5]	Low
Structures	Inadequate Hydraulic Structures	• Of the 49 SPFC hydraulic structures inspected by DWR, none were rated as Unacceptable and eight were rated as Minimally Acceptable.[5]	Low
	Inadequate Pumping Plants	• Of the 13 SPFC pumping plants inspected by DWR, none were rated Unacceptable and only one was rated Minimally Acceptable.[5]	Low
	Inadequate Bridges	• Of the 10 SPFC bridges inspected by DWR, two were in need of repairs.[5]	Low

[1] The relative threats listed in Table 8-1 were generated based on professional experience of technical staff from DWR and partner agencies.

[2] Penetrations include man-made objects that cross through or under a levee or floodwall and have the potential to provide a preferential seepage path or hydraulic connection with the waterside. Typically, a penetration is a pipe or transportation structure, such as a roadway or rail line.

[3] This finding is based on DWR's CVFPP Levee Vegetation Management Strategy criteria (DWR, 2012b) and not on USACE levee vegetation criteria. Comparison with USACE levee vegetation criteria would show more SPFC levees as noncompliant.

[4] Encroachments are any obstruction or physical intrusion by construction of works or devices, planting or removal of vegetation, or caused by any other means, for any purpose, into a flood control project, waterway area of the flood control project, or area covered by an adopted plan of flood control (California Code of Regulations Title 23 Chapter 1 Article 2 Section 4 (m)). Encroachments include boat docks, ramps, bridges, sand and gravel mining, placement of fill, fences, retaining walls, pump stations, residential structures, and irrigation and landscaping materials/facilities.

[5] Inspection results reported are from DWR's 2015 Inspections.

Key:

DWR = California Department of Water Resources
N/A = Not applicable
O&M = operations and maintenance
SPFC = State Plan of Flood Control
USACE = United States Army Corps of Engineers

The findings in Table 8-1 are relative to DWR's current criteria for use in the CVFPP. In most cases, these criteria are identical, or similar to USACE criteria. However, differences between DWR and USACE levee vegetation criteria are significant enough that comparison of levees with USACE criteria would likely show more SPFC levees as noncompliant with current USACE criteria. As noted in Section 4.7, DWR and USACE continue to work to resolve these differences.

To adequately address current and increasing future demands on the SPFC, significant and sustained actions are needed to improve the performance level of SPFC facilities that exists today. This will include continued efforts at the State, federal, regional, and local levels to assess and evaluate programs and policies affecting the SPFC and conditions of non-SPFC facilities that affect performance of the flood control system. Implementing an appropriate collection of management actions in a systemwide approach to address identified problems properly, and to improve the conditions of flood management throughout the Sacramento and San Joaquin river watersheds will take many years. It is important to recognize that improvements to the SPFC will be costly and will require the active involvement of State, federal, regional, and local interests. Significant amounts of funding will be needed for future project planning, development, implementation by USACE and the State, and for O&M primarily by maintaining agencies.

Local communities (both urban and nonurban) will require significant financial and technical assistance from the State and federal governments over the next 25 to 30 years to take appropriate actions to improve the current condition of SPFC facilities. FSSR findings provide important input on system conditions for the CVFPP. As mentioned, the CVFPP will guide future State investments through incremental projects to address identified problems in the SPFC.

8.2 Recommendations

As mentioned, California Water Code Section 9120 directs that this 2017 FSSR must to include appropriate recommendations regarding SPFC levees and future work activities. Recommendations regarding potential modifications to the SPFC will be included in the 2017 CVFPP Update. Recommendations regarding future work activities considered important for supporting future efforts as part of the CVFPP include the following:

- Pursue Board adoption of the findings of this 2017 FSSR, as required by California Water Code Section 9120, and support the Board in communicating 2017 FSSR recommendations to the California Legislature.

- Per California Water Code Section 9120(a), Continue to work with State, federal, regional, and local agencies to create a broadly supported CVFPP to guide long-term investments related to the SPFC over the next several decades.

- Build on and improve existing partnerships with federal, regional, and local agencies to develop site-specific actions for the SPFC that are consistent with the integrated, systemwide approach developed in the CVFPP. Recognize that the public expects the flood system to provide other important benefits, such as water supply conveyance, environmental/ecosystem functions, recreation, and other beneficial uses.

- Continue to partner with agencies, and form new partnerships to conduct special studies to improve understanding of the various factors that present threats to SPFC facilities. These studies include continued efforts to research the impacts of levee vegetation, assess locations and importance of levee penetrations, characterize the probability of levee failure, and other technical studies.

- Proceed with multiagency work efforts to further evaluate facility status, identify needed flood system reconstructions and improvements, and implement them, as State, federal, and local funding becomes available.

- Continue to improve data sharing and accessibility of annual inspection results for partner agencies and the public.

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9.0 References

California Department of Fish and Game (DFG). 2010. Lake and Streambed Alteration Program. Questions and Answers. http://www.dfg.ca.gov/habcon/1600/qa.html (accessed July 13, 2010).

California Department of Water Resources (DWR). 1954. Report on Control of Floods, San Joaquin River and Tributaries Between Friant Dam and Merced River. July.

———. 1959. Location, Description and Inventory of Miscellaneous Project Structures, Sacramento River Flood Control Project, and American River Flood Control Project.

———. 2005. Flood Warnings: Responding to California's Flood Crisis.

———. 2007. Interim Levee Vegetation Inspection Criteria.

———. 2009a. AB 156 Local Agency Annual Summary Report 2009 for Project Levees of the State Plan of Flood Control.

———. 2009b. Assessment of Animal Burrow Hole Persistence on Project Levees. Internal Technical Memorandum. October 22.

———. 2010a. State Plan of Flood Control (SPFC) Descriptive Document. Central Valley Flood Management Planning Program. November.

———. 2010b. 2009 Inspection Report of the Central Valley State-Federal Flood Protection System. Flood Project Integrity & Inspection Branch. January.

———. 2010f. Environmental Stewardship Policy Paper. October.

———. 2011a. Geotechnical Assessment Report, North NULE Study Area. April.

———. 2011b. Geotechnical Assessment Report, South NULE Study Area. May.

———. 2011c. Flood Control System Status Report. December.

———. 2012a. Urban Levee Design Criteria. May.

———. 2012b. Central Valley Flood Protection Plan Levee Vegetation Management Strategy.

———. 2015a. Annual Bridge Inspection Report. Flood Maintenance Office (FMO).

———. 2015b. Inspection and Local Maintaining Agency Report of the Central Valley State-Federal Flood Protection System.

———. 2015c. Floodway Ecosystem Sustainability Branch. 2015. Levee Tree Assessment.