CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE
CALIFORNIA

Flood Control System Status Report

December 2011

Cover Photo:

Critical levee repairs are being completed along the Sacramento River.

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CALIFORNIA

Flood Control System Status Report

December 2011

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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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 2010 *State Plan of Flood Control Descriptive Document* 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. [1]

California Water Code Section 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.

(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.

This *Flood Control System Status Report* (FCSSR) describes the current status (physical condition) of SPFC facilities at a systemwide level. DWR prepared the FCSSR to meet the legislative requirements of California Water Code Section 9120, 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.

The FCSSR is primarily intended to present information on the physical condition of SPFC facilities, and to help guide future inspection, evaluation, reconstruction, and improvement of the facilities. Information contained in the FCSSR should not be used to predict how a levee or associated facilities may perform in a specific flood event. More detailed information (such as additional geotechnical explorations and analyses at a greater frequency) would be necessary to meet other purposes, such as assessing 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 Flood Control System Status Report

DWR is fulfilling California Water Code requirements and supporting development of the CVFPP through two contributing documents. First, the DWR 2010 *State Plan of Flood Control*

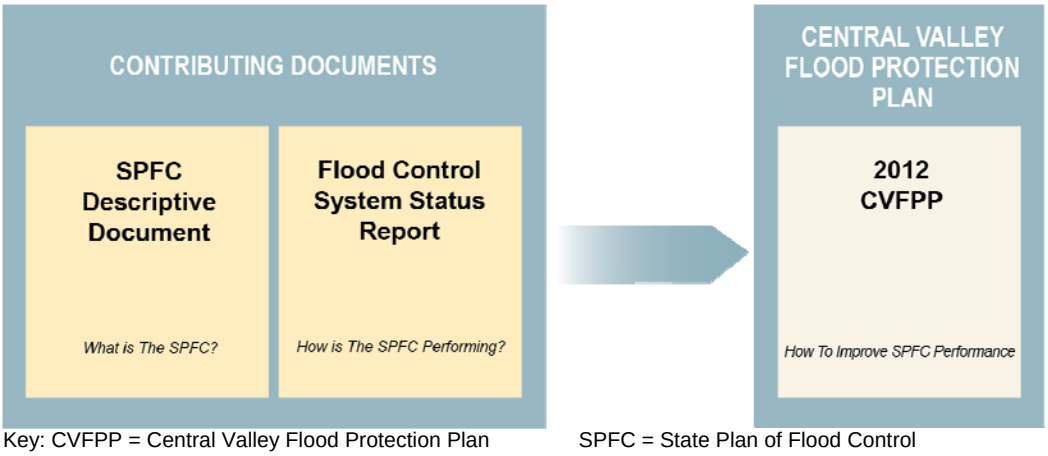
[1] State Plan of Flood Control facilities also include other elements identified in California Water Code Section 8361.

Descriptive Document identifies and describes major components of the SPFC (facilities, lands, programs, plans, conditions, modes of operations and maintenance), or *what the SPFC is*. It also fulfills part of the requirements of California Water Code Section 9120 (a) and (b). The *FCSSR* describes and analyzes the status or physical condition of SPFC facilities, or *how well the SPFC is performing*. It also fulfills requirements of California Water Code Section 9120.

Together, the two documents and additional technical studies (including the CVFPP Program Environmental Impact Report (DWR, anticipated 2012) are the foundation needed for preparing the CVFPP (Figure ES-1). In particular, the FCSSR contributes to development of the CVFPP 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 future updates.

- Supports 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.



Key: CVFPP = Central Valley Flood Protection Plan SPFC = State Plan of Flood Control

Figure ES-1. Documents Contributing to Central Valley Flood Protection Plan

In addition to meeting legislative requirements and contributing to the CVFPP, information in the FCSSR 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 of the FCSSR 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.

Need to Evaluate SPFC 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 project (Sacramento River Flood Control Project) was established. The U.S. Army Corps of Engineers (USACE) accepted some of these levees into the federal project without modification, improved some, 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 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.

Approach

To evaluate SPFC conditions, DWR is considering a wide 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 as high-level indicators of physical conditions relative to specified standards. 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 results presented in the FCSSR.

The DWR Levee Evaluations Program, including its Urban Levee Evaluations (ULE) and Non-Urban Levee Evaluations (NULE) projects, is the primary source of information to evaluate the condition of SPFC levees. ULE and NULE both assess geotechnical conditions of levees, but urban levees are undergoing a more comprehensive evaluation because of public safety considerations for densely populated areas. Levee conditions reported in the FCSSR also rely on information from DWR's annual inspections and other available data to supplement the results of the DWR Levee Evaluations Program.

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.

The FCSSR reflects existing facility conditions (including past performance) at the time the FCSSR 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 the FCSSR. Where applicable, any changes in findings will be reflected in future updates to the FCSSR.

Findings

The flood management system has provided tremendous benefits to public safety and protection of property in the Central Valley – it has prevented many billions of dollars in flood damages since facilities were originally constructed. However, when evaluated against modern engineering and safety criteria, some SFPC facilities face a higher chance for 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 1) the prevalence of the factor and 2) 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 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.

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

- **Urban levees** – Approximately half of about 300 miles[2] of SPFC urban levees evaluated do not meet current levee freeboard, stability, or seepage design criteria[3] at the design water surface elevation.

[2] Additional 50 miles of SPFC urban levees are being evaluated, and results will be included in future updates.

- **Nonurban levees** – Approximately three-fifths of about 1,230 miles of SPFC nonurban levees evaluated have a high potential for failure from under-seepage, through-seepage, structural instability, and/or erosion at the assessment water surface elevation.[4] 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.[5]

- **SPFC channels** – Approximately half of the 1,016 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, 2 were in need of repairs.

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[3] The design criteria used were based on the USACE 2000 *Design and Construction of Levees Engineering Manual 1110-2-1913* and DWR 2010 *Interim Levee Design Criteria for Urban and Urbanizing Areas in the Sacramento Valley, Version 4*.

[4] 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).

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

Table ES-1. Summary of Flood Control 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 under-seepage, through-seepage, structural instability, and/or erosion at the assessment water surface elevation.	See Figure ES-2
	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 under-seepage. • 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 6,000 penetration sites are documented in SPFC levees, and many more remain undocumented.	Medium
	Levee Vegetation	• About 15 miles of SPFC levees are noncompliant with DWR 2007 *Interim Levee Vegetation 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]	• 1,223 encroachment sites were identified as partially or completely obstructing visibility and access to the levee and/or within 10 feet of the landside toe.[5]	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 186 miles of SPFC channels inspected by DWR, one location was rated Unacceptable and 54 locations were rated Minimally Acceptable because of vegetation and obstructions.[5]	Low

Table ES-1. Flood Control System Status Report Findings (contd.)

	Factors	Findings	Relative Threat Posed by Factor[1]
	Channel Sedimentation	• Of 186 miles of SPFC channels inspected by DWR, 1 location was rated Unacceptable and 23 locations were rated Minimally Acceptable because of shoaling/sedimentation.[5]	Low
Structures	**Inadequate Hydraulic Structures**	• Of 32 SPFC hydraulic structures inspected by DWR, no structures were rated Unacceptable because of structural, vegetation/obstruction, encroachment, or erosion/sedimentation issues.[5]	Low
	Inadequate Pumping Plants	• Of 11 SPFC pumping plants inspected by DWR, none were rated Unacceptable.[5]	Low
	Inadequate Bridges	• Of 10 SPFC bridges inspected by DWR, 2 were in need of repairs.[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 DWR 2007 *Interim Levee Vegetation Criteria* 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 2009 Inspections.

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

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 very 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. DWR and USACE continue to work to resolve these differences.

The overall physical condition of SPFC levees, considering most of the levee factors in Table ES-1, is summarized in Figure ES-2. To simplify representation of levee conditions, the figure includes ULE and NULE results that are not directly comparable because different evaluation methodologies were used for each project. The figure is intended to show broadly which levee reaches are of relatively higher, medium, and lower concern, based on physical conditions of the levees. Levees shown as purple (higher concern) on the map generally display more performance problems than those shown in green (lower concern). Results do not reflect economic or life safety consequences of flooding, which are key factors in planning system repairs and improvements. As mentioned, potential economic and life safety consequences associated with flooding are being 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 SPFC facilities that exist 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 improve identified problems properly, and to improve 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 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 20 to 25 years to make appropriate improvements to the SPFC. FCSSR 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.

Recommendations

Key FCSSR recommendations regarding future DWR work activities include the following:

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

- Per California Water Code Section 9120(a), update the FCSSR periodically, as requested by the Board, following adoption of the 2012 CVFPP, by incorporating updated results of inspections, evaluations, and special studies.

- 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.

- 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.

Figure ES-2. Composite Map of Physical Levee Conditions Based on ULE and NULE Results

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

The FCSSR is primarily intended to present information on the physical condition of SPFC facilities, and to help guide future inspection, evaluation, reconstruction, and improvement of the facilities. Information presented should not be used to predict how a levee or associated facilities may perform in a specific flood event. More detailed information (such as additional geotechnical explorations and analyses at a greater frequency) would be necessary to meet other purposes, such as assessing whether a levee could be certified under Federal Emergency Management Agency (FEMA) standards to provide base flood protection under the National Flood Insurance Program.

1.1 Report Purpose and Scope

In 2007, the California State Legislature directed DWR to prepare this FCSSR for the SPFC in 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*

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

> *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.*

California Water Code Section 9110 (f) 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.*

As mentioned, the purpose of this report is to comply with California Water Code Section 9120 and contribute to CVFPP development along with other technical studies underway. DWR is fulfilling California Water Code requirements through preparation of two documents, including the FCSSR. These documents are highlighted below and illustrated in Figure 1-1. Each document also contributes to development of the CVFPP.

- ***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*** – This FCSSR describes and analyzes the SPFC, and makes recommendations regarding SPFC levees and future work activities.

The FCSSR specifically contributes to development of the CVFPP 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 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.

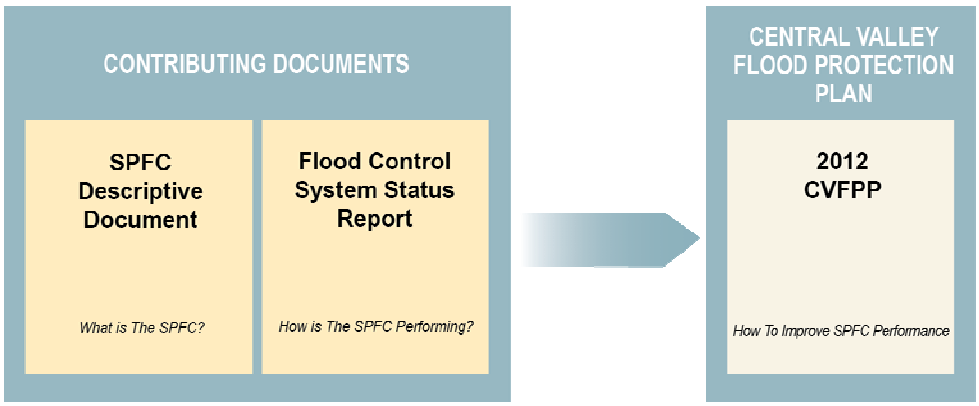

Figure 1-1. Documents Contributing to Central Valley Flood Protection Plan

In addition to meeting legislative requirements and contributing to the CVFPP, information in the FCSSR 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 this FCSSR 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 the FCSSR 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 1-2) 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. Performance of SPFC facilities relies on many non-SPFC facilities constructed by U.S. Army Corps of Engineers (USACE), DWR, U.S. Department of the Interior, 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 (and/or provide flood risk reduction benefits to areas protected by SPFC levees) include levees that are not part of the federal project (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. Processes for evaluating facility additions to and removals from the SPFC are under development as part of the CVFPP.

This FCSSR reflects existing facility conditions (including past performance) at the time this FCSSR 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 FCSSR. Where applicable, any changes in findings will be reflected in future updates to this FCSSR.

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 results presented.

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

1.2 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 project (Sacramento River Flood Control Project) was established. USACE accepted some of these levees into the federal project without modification, improved some, 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.

1.3 Report Overview

This FCSSR 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 FCSSR contains the following sections:

- **Section 1 (Introduction)** provides background information, including the purpose and scope of the FCSSR, overview of documents

complementary to the FCSSR, the need to evaluate the status of SPFC facilities, and this report overview.

- **Section 2 (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 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 through 6.

- **Section 3 (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 (ULE) and Non-Urban Levee Evaluation (NULE) projects of DWR's Levee Evaluations Program. Geotechnical hazard is assessed considering geotechnical factors for levee performance.

- **Section 4 (Levee Status)** presents SPFC levee conditions based on data from inspections and evaluations described in Section 2, 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. The ULE Project evaluated compliance with current seepage design criteria for urban levees, and the NULE Project evaluated potential for levee failure from under-seepage and through-seepage.

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

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

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

- **Settlement**, with conditions summarized from results of DWR 2009 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 2009 annual inspections for vegetation on earthen levees based on DWR 2007 *Interim Levee Vegetation Inspection Criteria* for visibility and accessibility.

- **Rodent damage**, with conditions summarized from results of a 2009 DWR assessment of animal burrow hole persistence on SPFC levees using inspection data from 1984 through 2008.

- **Encroachments,**[4] with conditions summarized from results of DWR 2009 annual inspections for encroachments.

- **Section 5 (Channel Status)** presents SPFC channel conditions based on data from inspections and evaluations described in Section 2, 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 from the *SPFC Existing Channel Capacity Assessment Technical Memorandum* (CVFED, 2009) and project-specific modeling. Information is also presented to show where design capacities in USACE O&M manuals are inconsistent with

[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.

[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.

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 2009 annual inspections for channel vegetation.

- **Channel sedimentation**, with conditions summarized from results of DWR 2009 annual inspections for channel shoaling and sedimentation.

- **Section 6 (Flood Control Structures Status)** presents SPFC flood control structure conditions based on data from DWR inspection activities described in Section 2. 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 2009 annual inspections for hydraulic structures.

  - **Pumping plants**, with conditions summarized from DWR 2009 annual inspections for pumping plants.

  - **Bridges,** with conditions summarized from DWR 2009 annual bridge inspections.

- **Section 7 (Approach for SPFC Improvements)** describes the approach and work organization for improving existing conditions of SPFC facilities, including development of the CVFPP.

- **Section 8 (Findings and Recommendations)** presents findings from the information presented in Sections 3 through 6, and provides recommendations specific to levees and future work activities.

- **Section 9 (References)** lists sources used to prepare this FCSSR.

- **Section 10 (Acronyms and Abbreviations)** lists acronyms and abbreviations used in this FCSSR.

Appendices to the main report include the following:

- **Appendix A (Levee Status)** provides supplemental information related to levee conditions described in Section 4, 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, 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, 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 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 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 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 the features (e.g., encroachments, animal burrows, vegetation, and their types and locations) and document their maintenance 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.

Beginning in 2007, USACE required DWR to use the checklist in the USACE *Flood Damage Reduction System Inspection Report* when inspecting the flood management system (2007). During 2007 inspections, DWR began adapting to the new USACE checklist.

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. DWR continues to work with USACE to improve inspections, and coordinates with USACE through an Inspection Program Working Group established in May 2009 (DWR, 2009a).

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.
Monthly Reports to the Board	√	√	√	DWR verbal presentations outlining inspection activities.
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, 2010b

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 *2009 Inspection Report of the Central Valley State-Federal Flood Protection System* (DWR, 2010b) and described in Sections 4 through 6 and Appendix A of this FCSSR. These criteria provide the bases for

inspection results contained in DWR maintenance inspection reports (Table 2-1) and elsewhere in this FCSSR.

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

- **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 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 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 FCSSR.

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).

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 Supplemental 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 *Annual Supplemental Erosion Survey of the San Joaquin River Flood System* (DWR, 2010e). Additional details on this survey are described in Appendix A, 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 taken. The annual Hydraulic Structure Inspection Report 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, 2010c).

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 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 FCSSR

DWR inspection data are presented in FCSSR Sections 4 through 6 according to status factors described in Section 3. Note that inspection data included in this FCSSR are for status factors not considered in systemwide evaluations (Section 2.2). 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 2009 inspections, and are located in this FCSSR 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 84-99. All USACE inspections incorporate instructions from the most recent USACE inspection checklist, in the *Flood Damage Reduction Segment/System Inspection Report* (2009a).

Linking USACE inspection results to eligibility for Public Law 84-99 rehabilitation assistance has increased the significance of USACE inspections in recent years. A levee system[1] must maintain an Acceptable or Minimally Acceptable rating to retain an "Active Status" in the USACE Rehabilitation and Inspection Program. Levees with an Active Status

[1] 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.

before a flood event are eligible for federal assistance after a flood event to repair damages caused by a flood (as authorized by Public Law 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, 2009a).

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 Public Law 84-99 eligibility. USACE has identified several levee systems as inactive in the Public Law 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 Public Law 84-99 Rehabilitation Assistance Program.

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 Public Law 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, Engineering Circular (*EC) 1110-2-6067 – USACE Process for the NFIP 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.

The *2009 – Field Reconnaissance Report of Bank Erosion Sites and Site Priority Ranking: Sacramento River Flood Control Levees, Tributaries and Distributaries* (USACE and DWR, 2010) includes an inventory of levee erosion sites. 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 FCSSR.

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 is conducting site-specific geotechnical evaluations of levees through the Levee Evaluations Program. DWR is also conducting hydraulic evaluations of channel conveyance capacity through the Central Valley Floodplain Evaluation and Delineation Program and DWR Maintenance Program. Similar detailed evaluations of flood control structures are not being conducted because information from enhanced visual inspections provides sufficiently detailed status information.

Geotechnical Evaluations

As part of developing the CVFPP, DWR is evaluating 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 two projects, the ULE Project and NULE Project, each of which is further divided into multiple study areas.

The ULE Project is evaluating approximately 350 miles of SPFC levees and approximately 120 miles of appurtenant non-SPFC levees protecting areas with populations exceeding 10,000. The NULE Project is evaluating 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 (1) that abut SPFC levees, (2) whose performance may affect the performance of SPFC levees, or (3) that provide flood risk reduction benefits to areas also being protected by SPFC features.

The goals of the ULE and NULE projects 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. The methodology, criteria and results from the ULE and NULE projects are described in more detail in Section 3.3, Risk of Levee Failure.

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

Figure 2-1. Levees Evaluated by ULE and NULE Projects

Table 2-2. ULE Project 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 Project 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

Hydraulic Evaluations

Hydraulic evaluations help identify and evaluate SPFC channel conveyance capacity conditions. As mentioned, DWR is conducting hydraulic evaluations through the Central Valley Floodplain Evaluation and Delineation Program and DWR Maintenance Program.

The DWR Central Valley Floodplain Evaluation and Delineation Program provided the primary source of SPFC channel conveyance capacity data. The DWR Central Valley Floodplain Evaluation and Delineation Program is gathering updated topographic, hydrologic, and hydraulic data, which will be used to develop new 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. Meanwhile, preliminary data gathered by the DWR Central Valley Floodplain Evaluation and Delineation Program was used to evaluate channel status in Section 5.1 of this FCSSR.

The new hydraulic models for major rivers, tributaries, and overbank areas associated with the SPFC (expected to be completed in 2012) will be used to evaluate flood risks in the Sacramento and San Joaquin river watersheds and system performance during storm events of differing severity, and to delineate potential extent of flooding. The models will be 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, 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.

DWR 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 Central Valley Floodplain Evaluation and Delineation 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 as part of ongoing studies of the SPFC for the CVFPP, DWR uses a risk-based approach more similar to USACE's approach. Risk-based approaches are better for evaluating flood risk, but their accuracy depends on having sufficient geotechnical and hydrologic data to support the 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 American River Watershed Common Features Project, Marysville Ring Levee Project, South Sacramento County Streams Project, West Sacramento Levee Improvement Program and Lower San Joaquin Feasibility Study.

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
Historic 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, “Levee Status.”

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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 that would have occurred if the levees were not in place. 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 because of higher consequences that would result if a flood occurs.

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,[1] loading,[2] exposure,[3] 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 FCSSR, "hazard" refers specifically to geotechnical hazard when discussed in relation to the hazard assessments performed by the ULE and

[1] 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).

[2] 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.

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

NULE projects. The geotechnical hazard data presented are used to meet the FCSSR 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 FCSSR 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 the ULE project is evaluated against hazard classifications relative to established levee design criteria. Levee performance for the NULE project is evaluated as hazard categories, which are qualitative indicators of the potential for levee failure. The ULE and NULE project assessments contained in this report represent a preliminary analysis of levee conditions based on initial phases of evaluations under both projects. Subsequent phases of the ULE and NULE projects will include additional geotechnical explorations along significant portions of the ULE and NULE levees, and more detailed analyses, which may alter the assessments presented in this report.

3.1 Flood Risk

Many Californians, especially those in deep floodplains in the Central Valley, face a significant chance of harm and damage caused by floods. Facilities of the SPFC play an important role in public safety and protection of property. This FCSSR is one of several ways whereby DWR is improving awareness of flood risk among people 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 society. 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 show a good indication of areas that are vulnerable to floods.

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

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

Levee stability concerns

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). 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. Recently, basin-wide flood damage estimates have been updated based on current physical conditions as part of the 2012 CVFPP and include potential losses to business. It is currently expected that annual flood damages in the Sacramento River basin will average over $300 million. In the San Joaquin River basin, annual flood damages are expected to average nearly $30 million. Life safety consequences are also being evaluated as part of the 2012 CVFPP. Estimates of flood risk will be periodically updated in future versions of the CVFPP.

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 society has now, such as flood protection for rapidly developing floodplains; long-term sustainability; and the public trust purposes of natural resource preservation, water supply, and recreation.

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 FCSSR according to the following status factors:

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

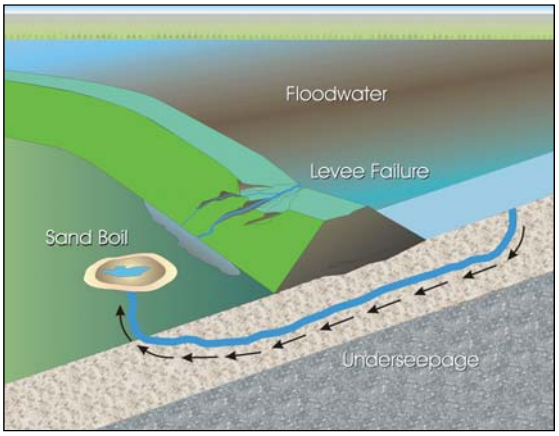
- **Seepage** – Seepage under a levee foundation or through a levee can reduce levee stability and lead to failure.

- **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 crest 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 under-seepage

- **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.

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 is evaluating approximately 2,100 miles of SPFC levees and appurtenant non-SPFC levees in the Central Valley (approximately 1,520 miles of SPFC levees and 520 miles of appurtenant non-SPFC levees). The goals of the ULE and NULE projects 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, the ULE and NULE projects 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 the ULE Project is evaluated as hazard classifications relative to established levee design criteria. For the NULE Project, levee performance is evaluated as hazard categories, which show potential for levee failure. This approach was selected because the extent of the NULE Project is considerably greater than that of the ULE Project, making it difficult to conduct the same level of field explorations and geotechnical data collection performed for the ULE levees.

The following subsections provide more detailed information on the methodologies used to assess levee conditions under the ULE and NULE projects, 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 to discuss levee conditions in more detail, based on individual status factors.

3.3.1 Urban Levee Evaluations – Methodology and Results

The ULE Project involves evaluation of approximately 350 miles of SPFC and 120 miles of appurtenant non-SPFC urban levees, protecting populations greater than 10,000. ULE non-SPFC levee data were not available while this FCSSR was being written. ULE SPFC levees included in the evaluations are shown in Figure 2-1.

ULE Approach

The overall strategy for DWR urban levee evaluations is impacted by two legislative and executive actions. New California Government Code sections added by Senate Bill 5 in 2007 require 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 means the level of protection that is necessary to withstand flooding 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" the ULE Project, with the goal of quickly identifying significant levee deficiencies that require repair.

ULE Project study areas are generally based on urban areas identified by Proposition 1E.[4] Proposition 1E defined an urban area as "any contiguous area in which more than 10,000 residents are 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 are considered urban levees under the ULE Project.

ULE Project evaluations are being implemented in five major steps:

1. **Historical Data Collection** – Available levee data are collected, and State, USACE, and local experts are interviewed. Geomorphology studies are also conducted. For each study area, results are documented in a Technical Review Memorandum, which generally assesses known conditions and potential conditions suggested by available data, as well as levee performance during past flood events. Based on results of the historical data collection, Steps 2 and 3 may not be performed in study areas that have already undergone significant investigation by USACE and/or local stakeholders; in this case, screening efforts proceed to Steps 4 and 5.

2. **Initial Field Investigation** – Initial field exploration (limited to the levee crown) and laboratory testing programs are conducted and documented in a Phase 1 Geotechnical Data Report.

3. **Preliminary Analysis** – Each ULE study area is 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 are conducted; and areas for supplemental evaluation are 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

[4] 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 Project 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 the NULE Project. An urbanizing area is defined in California Government 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.

is developed and implemented to address any significant data gaps. This work is documented in a Supplemental Geotechnical Data Report.

5. **Final Screening** – Additional analyses are conducted to evaluate levee conditions based on available data. As necessary, conceptual remediation and corresponding costs are identified on a segment-by-segment basis for each study area. Analyses and conceptual remediation are documented in a Geotechnical Evaluation Report.

During the preliminary analysis phase and the final screening phase, analyses are 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)

The performance criteria for categories used in these assessments are based on the USACE *Design and Construction of Levees Engineering Manual* (EM) *1110-2-1913* (2000) and the DWR *Interim Levee Design Criteria for Urban and Urbanizing Areas in the Sacramento-San Joaquin Valley, Version 4* (2010d). Although freeboard is not technically a failure mode, it is a performance criterion identified in the above documents and, therefore, the ULE approach considers freeboard in assessing overall hazard classifications.

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

- **Meets Criteria (M)** – Levees in this classification meet or exceed criteria.

- **Marginal (MG)**[5] – Levees in this classification are marginal in meeting criteria.

[5] The Hazard Classification of MG (marginal) is assigned when results are sufficiently close to established design criteria that, considering the rating is based on preliminary data that are subject to change as analyses are completed, it is not possible to determine with confidence whether the result would be M or DNM if more detailed data were available. Thus, a levee segment that receives a Hazard Classification of MG is not necessarily more vulnerable to failure during a flood event, but is more likely to need additional evaluation or repair than a levee segment rated as Hazard Classification M.

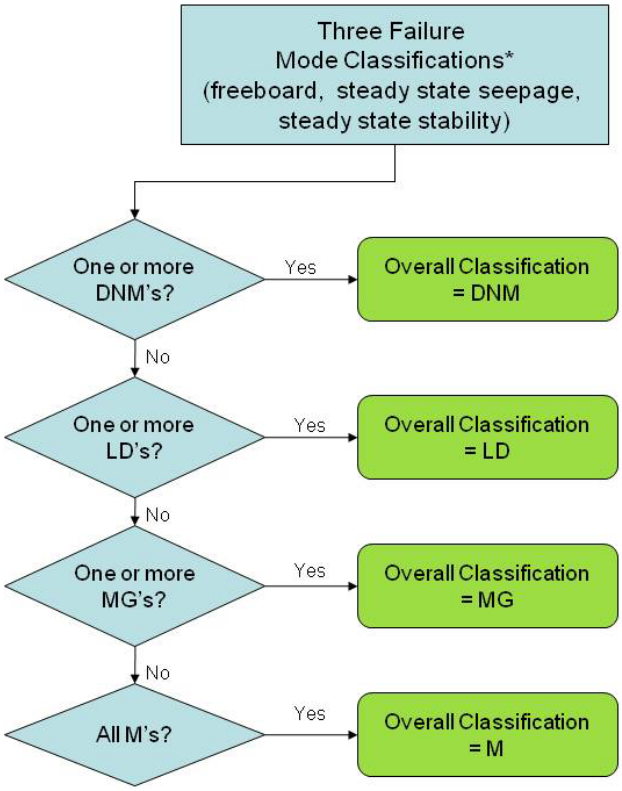
- **Does Not Meet Criteria (DNM)** – Levees in this classification do not meet criteria. These levees require the most immediate attention for repair or replacement.

- **Lacking Sufficient Data (LD)** – Levees in this classification lack sufficient data to be placed into one of the above three classifications.

Results from the ULE Project are being developed in two phases. The first phase presents preliminary criteria-based results for freeboard, levee geometry, seepage, and stability for the 1955 and 1957 design water surfaces (as presented in this FCSSR) (USACE, 1955b; USACE, 1957a; 1957b). By December 2012, the second phase will present 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. 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 is DNM (does not meet criteria), then the overall hazard classification is DNM. If any of the hazard classifications is LD (lacking sufficient data), then the overall hazard classification is LD. If all of the hazard classifications are M (meets criteria), then the overall hazard classification is M. One or more MGs result in an overall hazard classification of MG. 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. ULE classifications do not reflect recent levee improvements for which geotechnical data are not available or have not been provided. When new geotechnical data become available, the data will be incorporated into future updates to this FCSSR.



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
LD = Lacking Sufficient Data
M = Meets Criteria
MG = Marginal

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

Levee geometry, rodent 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 the ULE study areas.

Summary of Overall Hazard Classification

The preliminary analysis phase is significantly complete, and hazard classifications have been 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 will be prepared for all 14 study areas. Table 3-1 summarizes overall hazard classifications for 297 miles of ULE SPFC levees. Evaluations of approximately 50 miles of ULE SPFC levees are still underway as this FCSSR is being prepared. As described above, ULE non-SPFC levee data were not available for inclusion in this FCSSR.

Table 3-1. Summary of ULE Overall Hazard Classification

	Overall Hazard Classification				Total
	Meets Criteria (M)	Marginal (MG)	Does Not Meet Criteria (DNM)	Lacking Sufficient Data (LD)	
ULE Levees in Sacramento River and San Joaquin River Watersheds					
ULE SPFC Levee Miles Evaluated	130	9	151	7	297
Percentage of ULE SPFC Levees Evaluated	44%	3%	51%	2%	100%

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

Overall, almost half of ULE SPFC levees meet criteria (Hazard Classification M) at the design water surface elevation. In some urban areas, substantial segments of levees meet criteria, but also have substantial segments of levees that do 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 evaluation 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 FCSSR.

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

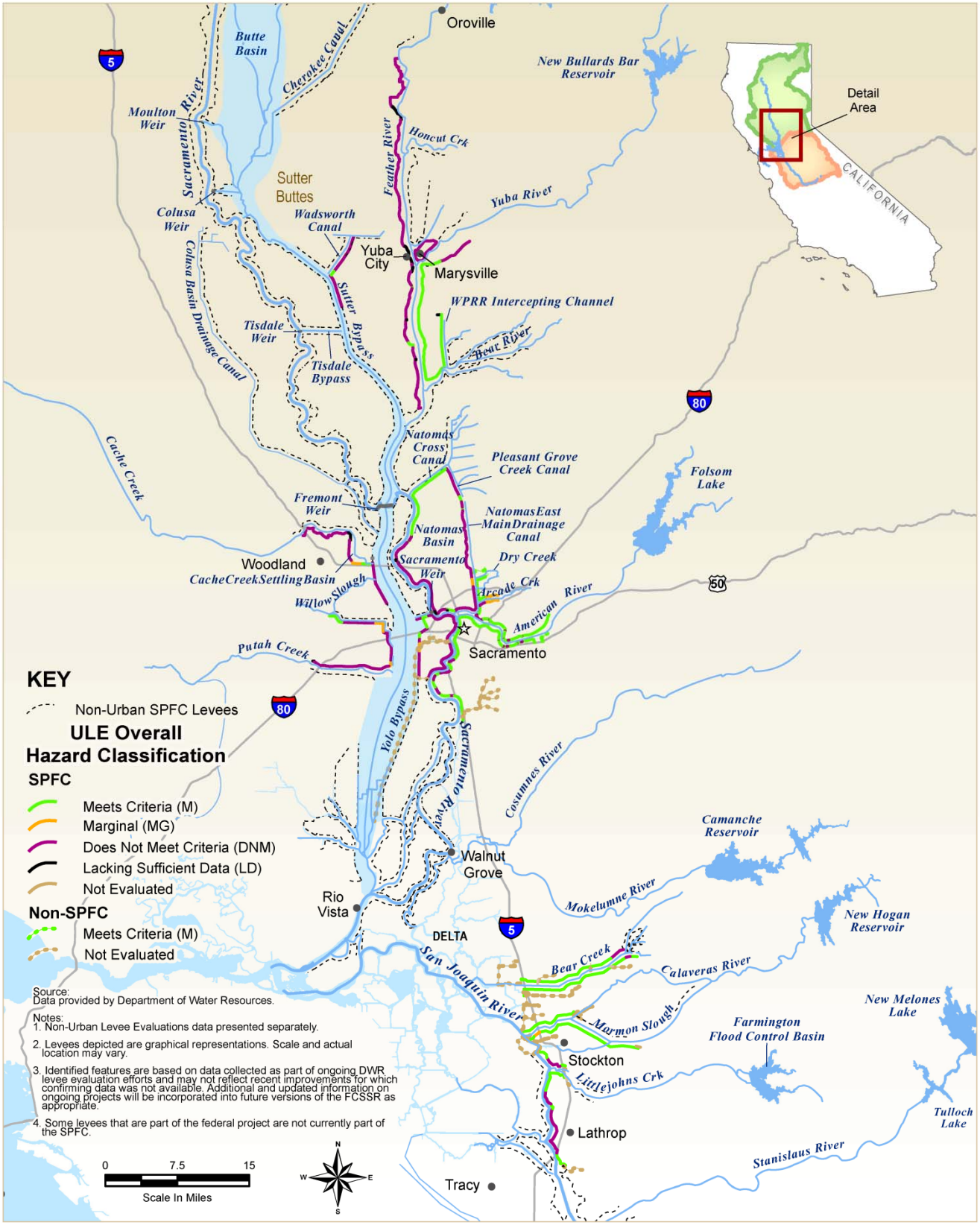


Figure 3-4. ULE Overall Hazard Classifications in Sacramento and San Joaquin River Watersheds

3.3.2 Non-Urban Levee Evaluations – Methodology and Results

The NULE Project encompasses approximately 1,230 miles of SPFC nonurban levees and 300 miles of appurtenant non-SPFC nonurban levees. Nonurban SPFC and non-SPFC levees included in the evaluations are shown in Figure 2-1.

NULE Approach

Levees within the NULE Project are being 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. The NULE levees were evaluated on systematic, consistent, repeatable analysis that correlated geotechnical data with levee performance history, and not relative to any design criteria. Phase 2 consisted of supplemental studies, which were performed for selected nonurban levees, and involve 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 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 – 1915)

- LiDAR topographic surveys
- Assessment water surface elevations (where available, 1955/1957 design water surface profiles were used for Phase 1 assessments)
- Animal burrow persistence data
- Levee penetrations logs
- Maintenance ratings

These data are managed by DWR in a project-specific electronic database to systematically catalog project data and provide quick and efficient data access during levee hazard assessments. The data are used to develop levee construction and performance history, 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, the NULE Project developed a Levee Assessment Tool. The Levee Assessment Tool is a systematic, repeatable process for assessing levee hazard indicators and past levee performance. Details of Levee Assessment Tool development and implementation are provided 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 crest).

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 the NULE geotechnical failure modes differ from the four failure modes

evaluated by ULE, because of different methodology.) NULE geotechnical failure modes include the following:

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

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

- **Low** – When water reaches the assessment water surface elevation, there is a relatively low potential for levee failure or the need to floodfight to prevent levee failure.

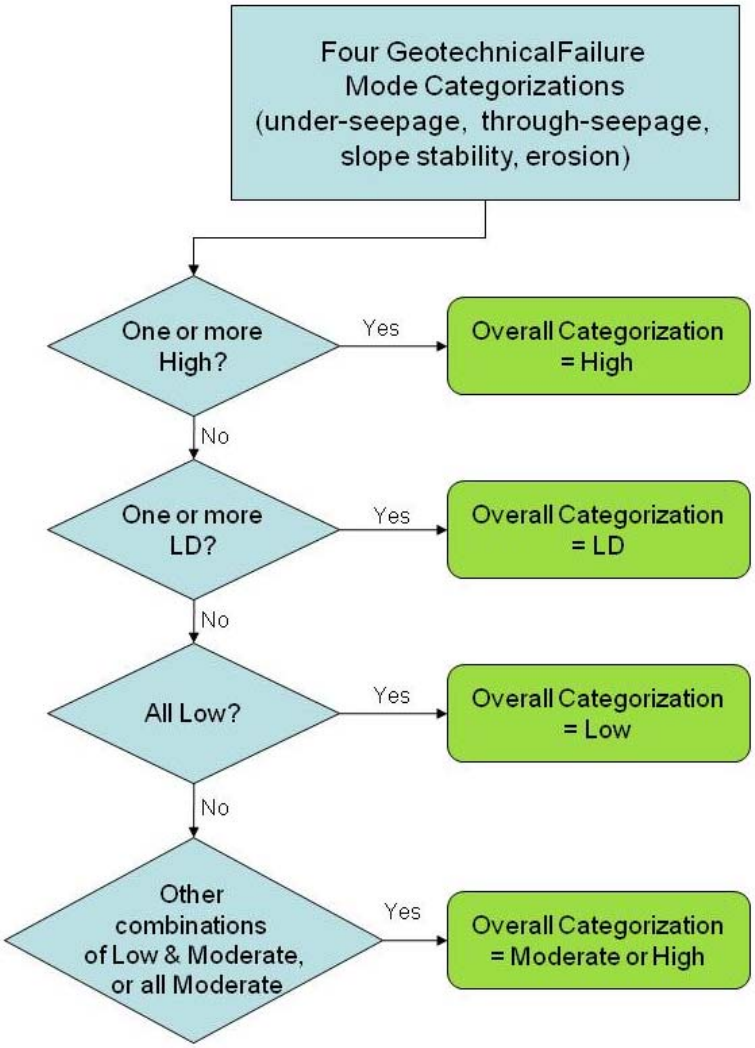
- **Moderate** – When water reaches the assessment water surface elevation, there is a relatively moderate potential for levee failure or the need to floodfight to prevent levee failure.

- **High** – When water reaches the assessment water surface elevation, there is a relatively high potential for levee failure or the need to floodfight to prevent levee failure. **These levees are in the most danger of failure**.

- **Lacking Sufficient Data** – Sufficient data are currently lacking regarding past performance or hazard indicators.

The category "Lacking Sufficient Data" indicates that the available data do not resolve potential discrepancies between expected performance of a levee and actual performance, or that the existing data are contradictory or ambiguous. The category does not indicate that insufficient data were available to assess the NULE levee segment. Where assessment data were not available, the NULE levee segment was not assessed.

An overall hazard category was assigned to each NULE levee segment, considering the collective performance for the geotechnical failure modes, including under-seepage, through-seepage, slope stability, and erosion, as shown in Figure 3-5. The decision tree acknowledges that there may be levee segments with a combination of moderate or low hazards that may cumulatively represent a high overall hazard categorization.



Key:
LD = Lacking Sufficient Data

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

Penetrations and rodent damage data included in this FCSSR were considered in the assignment of through-seepage hazard categorization. Levee geometry check, settlement, encroachment, and levee vegetation data were not considered in the assignment of NULE overall hazard categorization because the NULE Project 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 (Low, Moderate, High, and Lacking Sufficient Data) are summarized for the North (Sacramento River

watershed) NULE and South (San Joaquin River watershed) NULE 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 Categorization				Total
	Low	Moderate	High	Lacking Sufficient Data	
North NULE Study Area (Sacramento River Watershed)					
North NULE SPFC Levee Miles Evaluated	30	287	428	89	834
Percentage of North NULE SPFC Levees Evaluated	4%	34%	51%	11%	100%
North NULE Non-SPFC Levee Miles Evaluated	14	32	27	21	94
Percentage of North NULE Non-SPFC Levees Evaluated	15%	34%	28%	23%	100%
South NULE Study Area (San Joaquin River Watershed)					
South NULE SPFC Levee Miles Evaluated	39	65	291	3	398
Percentage of South NULE SPFC Levees Evaluated	10%	16%	73%	1%	100%
South NULE Non-SPFC Levee Miles Evaluated	6	15	120	69	210
Percentage of South NULE Non-SPFC Levees Evaluated	3%	7%	57%	33%	100%
Combined North and South NULE Study Areas					
NULE SPFC Levee Miles Evaluated	69	352	719	92	1,232[1]
Percentage of NULE SPFC Levees Evaluated	6%	29%	58%	7%	100%
NULE Non-SPFC Levee Miles Evaluated	20	47	147	90	304
Percentage of NULE Non-SPFC Levees Evaluated	7%	15%	48%	30%	100%

Note:
[1] Rounds down to 1,200 miles.
Key:
NULE = Non-Urban Levee Evaluations
SPFC = State Plan of Flood Control

Overall, approximately three-fifths of NULE SPFC levees have a High hazard category at the assessment water surface elevation. Only about one-sixteenth of the NULE SPFC levees have a Low hazard category. In the Sacramento River watershed, NULE SPFC levees categorized as Low are primarily along tributaries; none of the NULE SPFC levees along the Sacramento River are categorized as Low. In the San Joaquin River watershed, NULE levees categorized as Low are primarily along tributaries, with some short segments along the San Joaquin River.

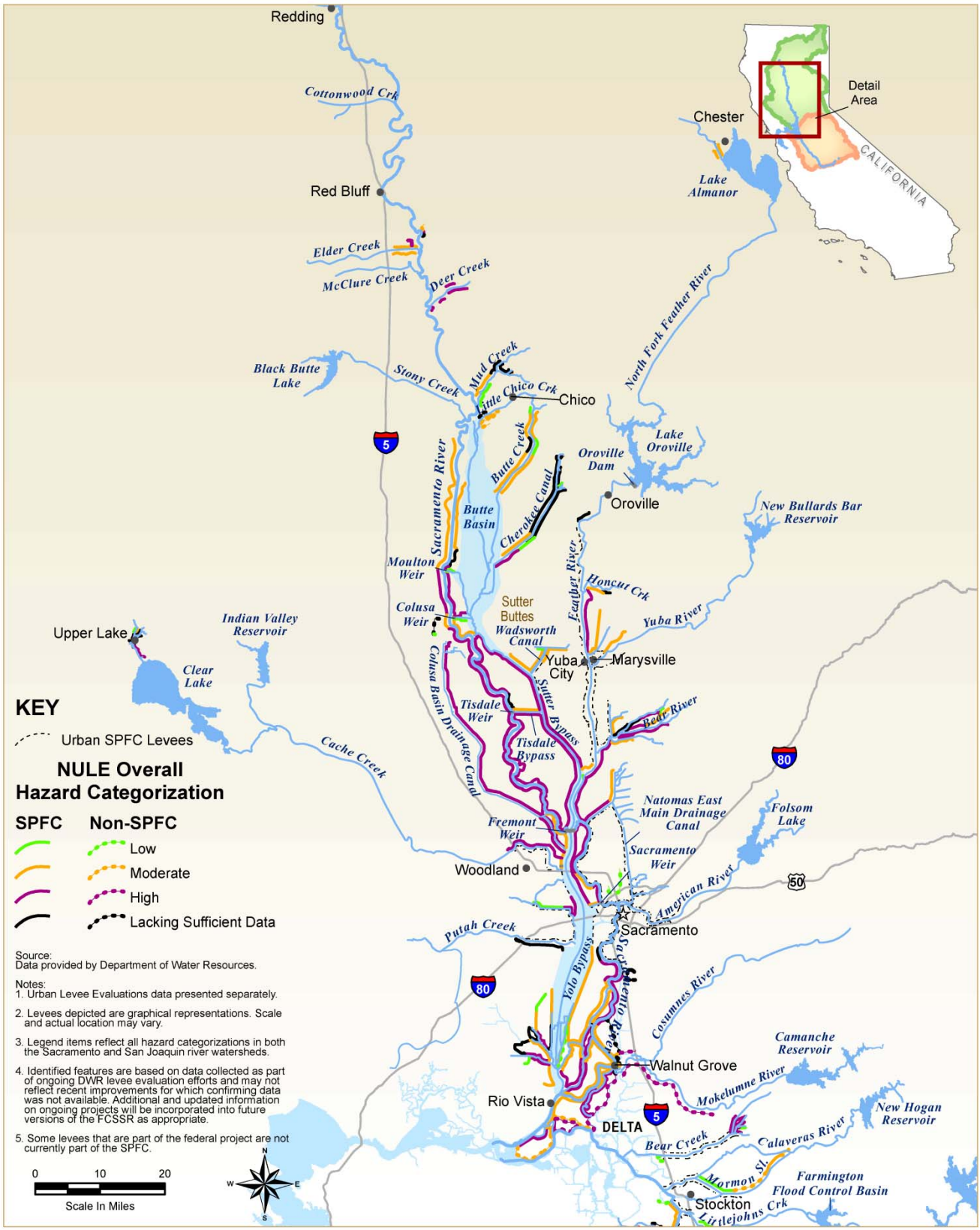


Figure 3-6. North NULE Overall Hazard Categorizations in Sacramento River Watershed

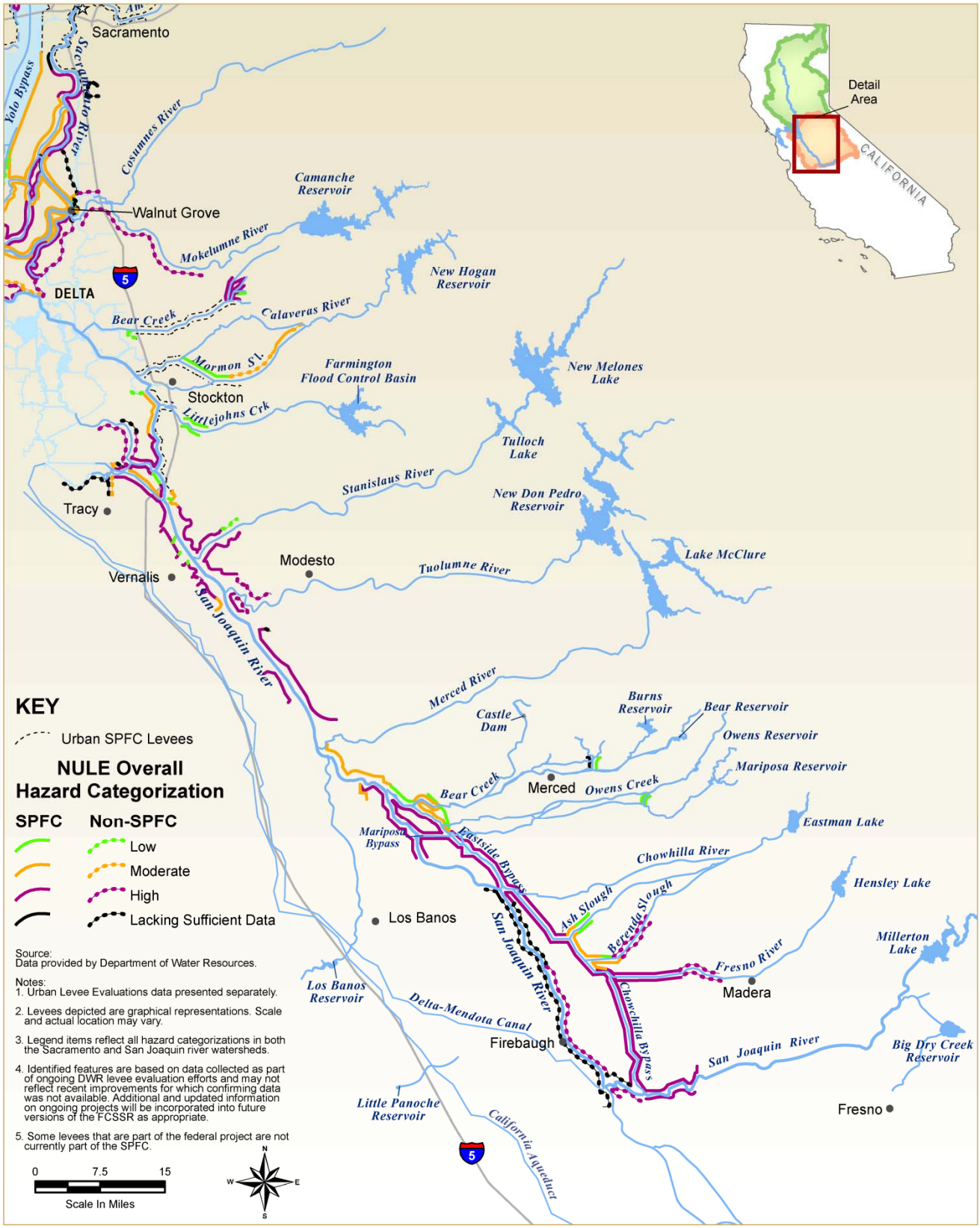


Figure 3-7. South NULE Overall Hazard Categorizations in San Joaquin River Watershed

3.3.3 Urban and Non-Urban Levee Evaluations Methodology Summary

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

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 in assigning a ULE overall hazard classification using the ULE Overall Levee Segment Hazard Classification Decision Tree (see Figure 3-3). For the NULE Project, NULE levee segments were evaluated for four geotechnical failure modes (under-seepage, 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 in assigning NULE overall hazard categorization using the NULE Overall Levee Segment Hazard Categorization Decision Tree (see Figure 3-5).

As mentioned, levee geometry was considered in the ULE overall hazard classifications as a proxy for assessing the erosion failure mode because the ULE erosion analyses have not yet been completed and the collected geometry data represents the initial step in that analysis. Freeboard was considered in the ULE overall hazard classifications, but not in the 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.

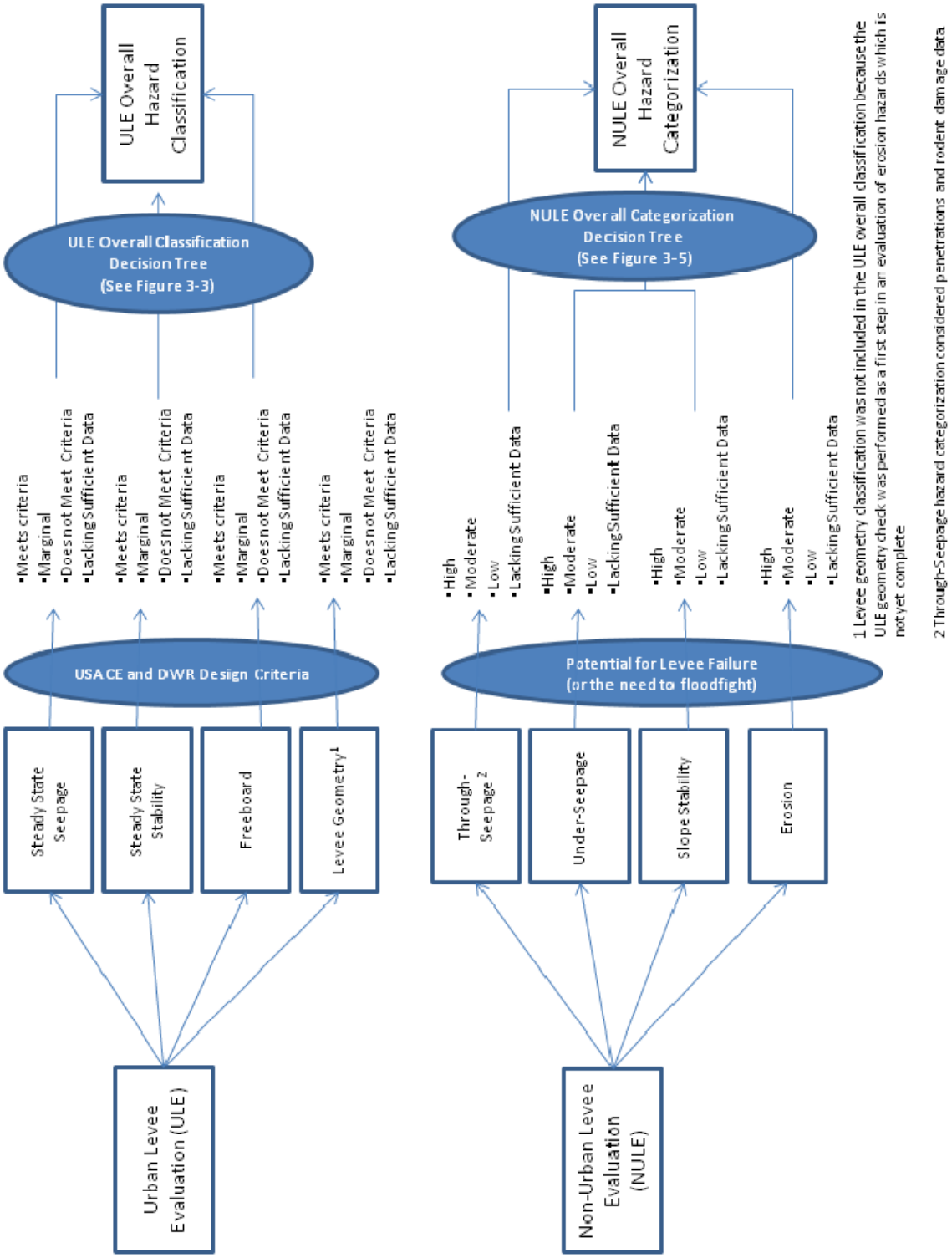


Figure 3-8. Process for ULE Overall Hazard Classifications and NULE Overall Hazard Categorizations