4.0 Levee Status

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

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

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

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

- High flood flows in 1986 severely stressed levees to the point that a levee failure in Linda (and several other near failures) occurred, demonstrating that the SPFC facilities could not be assumed to be as reliable as previously thought.

- Investigations found that several reaches of levee had geotechnical problems, mostly relating to stability, seepage, and piping potential (described in Section 4.2). These conditions stemmed from the time of construction and were present when the facilities were turned over by USACE to the Board for O&M. Remedial levee reconstructions and improvements are required for the SPFC to function at its original intended design level.

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

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

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

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

Flood events in 1995 and 1997 reemphasized that the levee system needed additional levee reconstructions and improvements to achieve the desired level of flood protection. As a result of poor performance with respect to levee under-seepage during the 1997 flood, the USACE Sacramento District convened a panel of experts that recommended modifications to

USACE levee under-seepage evaluations and design. The USACE Sacramento District adopted most of the panel's recommendations, and issued new guidance in *Engineering Technical Letter 1110-2-569 Design Guidance for Underseepage* (2005) and the *Geotechnical Levee Practice Standard Operating Procedures for the USACE Sacramento District* (2008).

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

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

Table 4-2. Levee Status Factors Data Summary

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

Note:
[1] NULE hazard assessment includes under-seepage and through-seepage. ULE hazard assessment includes a steady state seepage analysis of both under-seepage and through-seepage.

Key:
DWR = California Department of Water Resources
FCSSR = Flood Control System Status Report
NULE = Non-Urban Levee Evaluations
ULE = Urban Levee Evaluations

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

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

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

4.1 Levee Geometry Check

Although physical processes such as erosion may alter levee geometry, many SPFC levees do not comply with current minimum geometry criteria because levee geometry criteria used at the time of construction varied. Before congressional authorization of flood control projects in the Central Valley, levees were constructed to variable geometry criteria by local interests. After congressional authorization, USACE improved levee geometry in some locations before turning flood control projects over to the Board for O&M. Minimum levee geometry criteria have previously been specified by various USACE and State guidance documents, such as USACE *Design and Construction of Levees Engineering Manual 1110-2-1913* (2000), Title 23. Waters Division 1. Central Valley Flood Protection Board California Code of Regulations, 1953 *Memorandum of Understanding Respecting the Sacramento River Flood Control Project* (USACE and Board, 1953) and USACE Sacramento District *Geotechnical Levee Practice Standard Operating Procedures REFP10L0* (2008).

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

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

The DWR *Interim Levee Design Criteria for Urban and Urbanizing Areas in the Sacramento-San Joaquin Valley Version 4* (2010d) includes criteria for urban levee geometry. The Board is also currently updating levee geometry criteria.

4.1.1 Status Evaluation Methodology

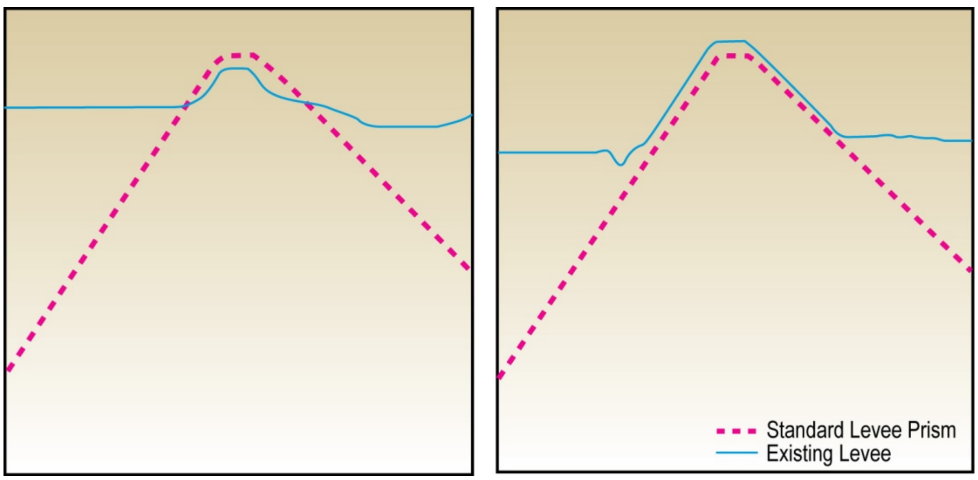
The DWR Levee Evaluations Program conducted a levee geometry check of ULE and NULE levees that compared existing levee geometry at regular cross-section intervals with a standard levee design prism.

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

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

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

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



Levee Cross Section That Deviates from Standard Levee Design Prism

Levee Cross Section That Conforms to Standard Levee Design Prism

Figure 4-1. Levee Cross Section Geometry Check Illustrations

Urban Levee Evaluations Project

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

- Meets Criteria (M)
- Marginal (MG)
- Does Not Meet Criteria (DNM)
- Lacking Sufficient Data (LD)

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

Non-Urban Levee Evaluations Project

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

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

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

4.1.2 Limitations of Status Evaluations

ULE Project levee geometry check results presented in this section are preliminary and represent findings of the first of a multitiered process being applied by DWR to assess levee geometry inadequacies and erosion hazards, results of which will be incorporated into Geotechnical Evaluation Reports being prepared for individual ULE study areas (see Section 4.4.1 for more details). Although ULE levee geometry results are preliminary, they are presented in this section as a proxy for erosion analyses in the absence of additional erosion hazard analyses that will be conducted under the ULE Project. Levee geometry check results are an imperfect indicator of erosion hazard because a wide variety of factors in addition to erosion could cause a levee to have inadequate levee geometry.

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

The results shown in the figures do not reflect recent reclassification of certain ULE levee segments along Bear Creek near Stockton from urban to nonurban SPFC levees.

4.1.3 Results of Status Evaluations

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

Urban Levee Evaluations Project

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

Non-Urban Levee Evaluations Project

Results of the geometry check for NULE levees are shown in Figures 4-3 and 4-4. The percentages mapped are the percentage of each NULE levee segment that deviated from standard levee design prism geometry. Compliance with minimum levee geometry criteria varied across the

Sacramento and San Joaquin river watersheds. Results suggest that the San Joaquin river watershed and Sacramento River have the highest percentage of levees that conform to standard levee design prism geometry. Further, levees along the bypasses and along the tributary streams to the Sacramento River in the northern Sacramento River watershed have the lowest percentage of NULE levee segments that conform to standard levee design prism geometry. Results elsewhere along NULE levees are variable.

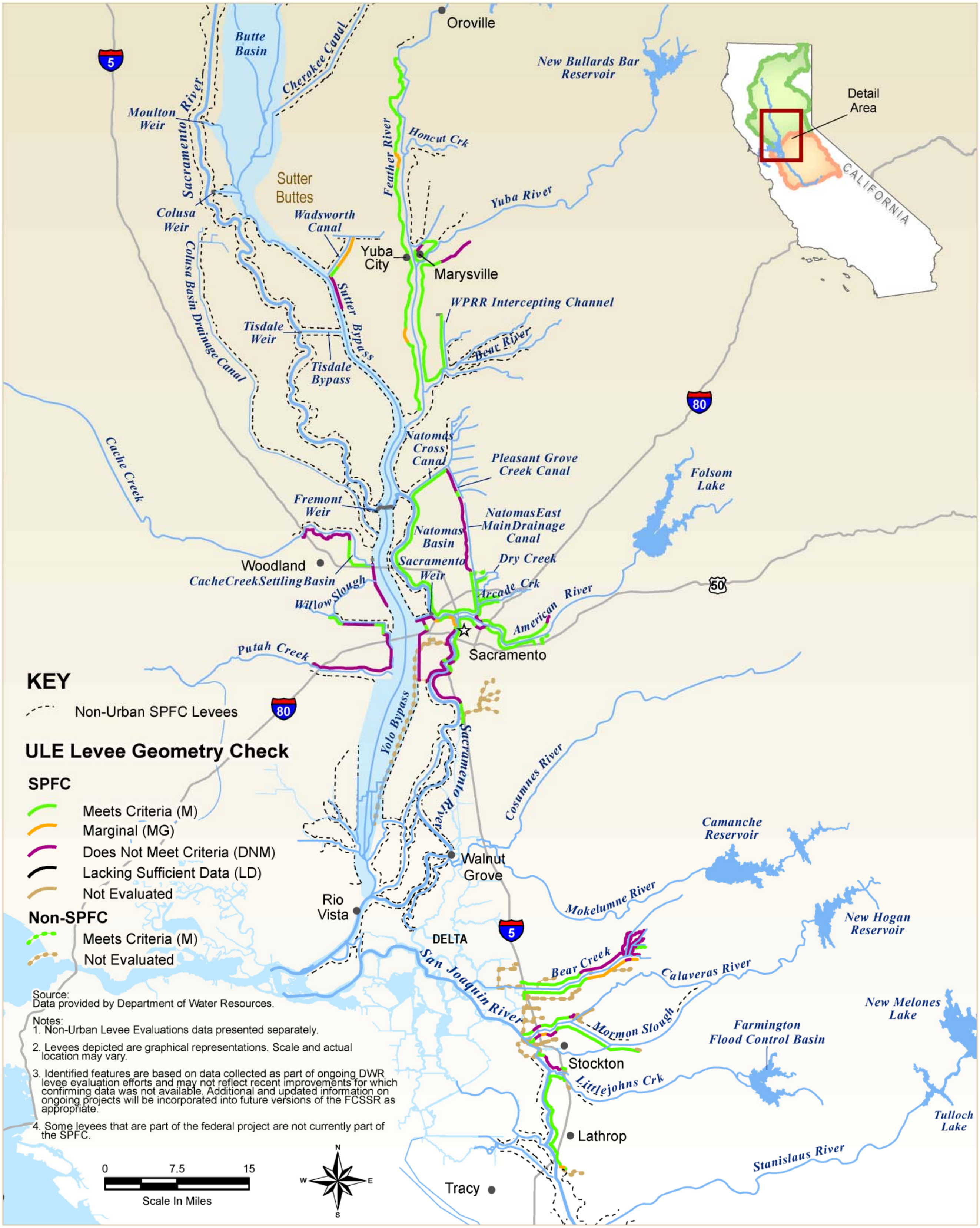


Figure 4-2. ULE Levee Geometry Check

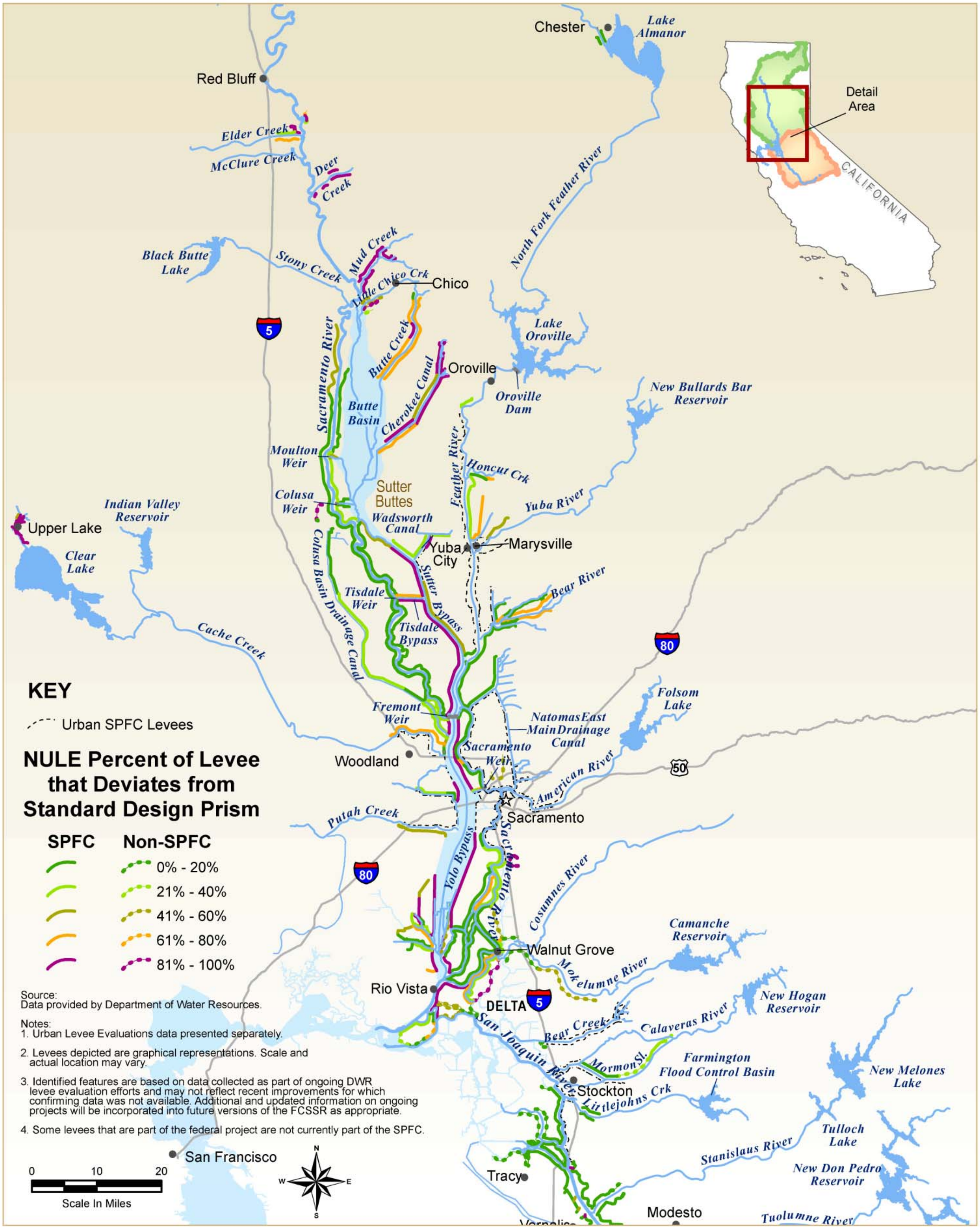


Figure 4-3. NULE Levee Geometry Check in Sacramento River Watershed

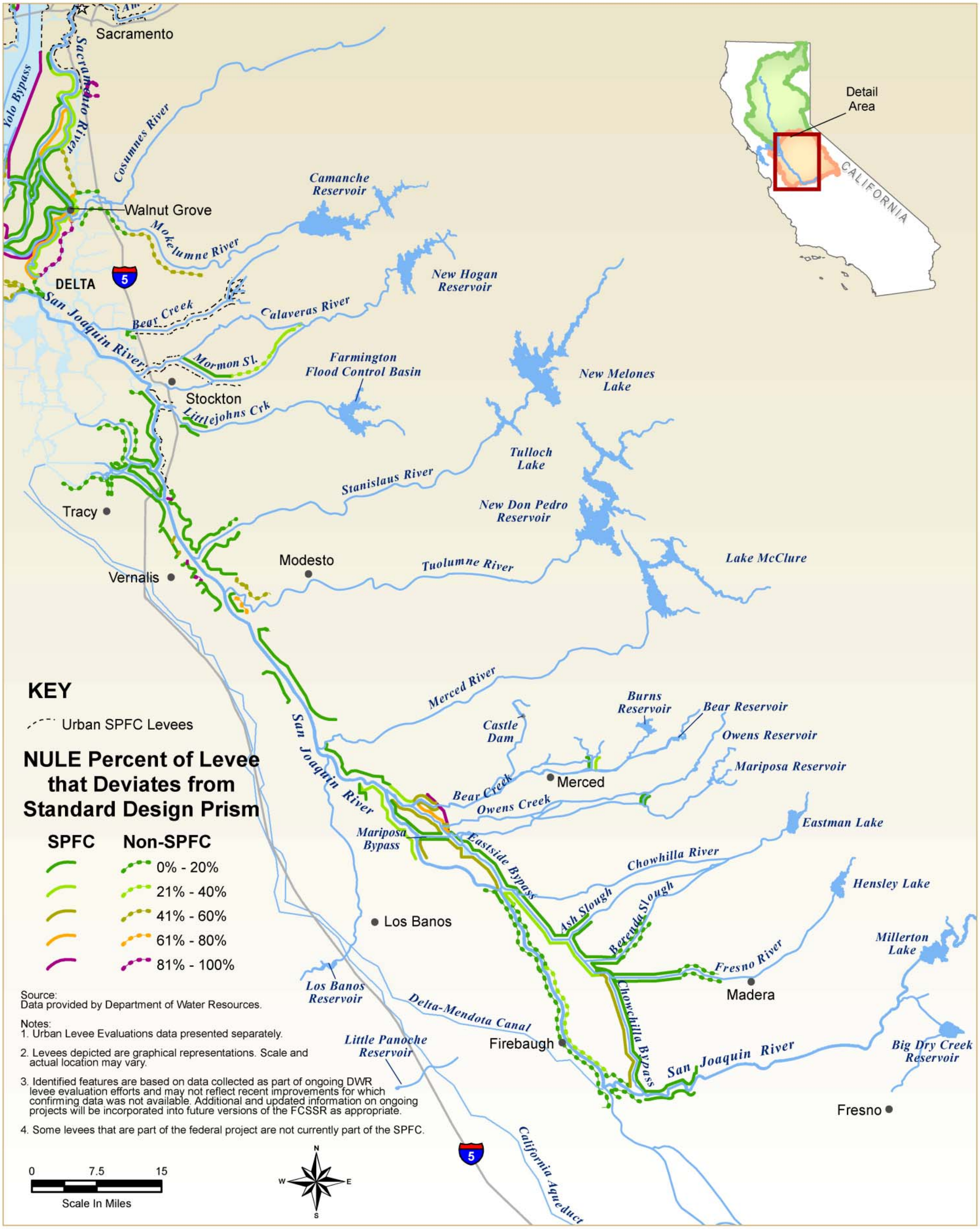


Figure 4-4. NULE Levee Geometry Check in San Joaquin River Watershed

4.2 Seepage

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

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

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

Most recently, USACE has been updating seepage criteria in *Engineering Manual 1110-2-1913 Engineering and Design – Design and Construction of Levees* (USACE, 2000); further updates to USACE seepage criteria are expected. The DWR *Interim Levee Design Criteria for Urban and Urbanizing Areas in the Sacramento-San Joaquin Valley Version 4* (DWR, 2010d) contain more rigorous seepage design criteria than the current USACE guidance. This is because USACE guidance applies to all levees, and the DWR interim levee design criteria only apply to levees protecting urban and urbanizing areas.

4.2.1 Status Evaluation Methodology

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

Urban Levee Evaluations Project

As mentioned, levee performance for the ULE project was evaluated against hazard classifications relative to established levee design criteria To assess seepage along ULE levees, DWR performed a quantitative analysis that assessed under-seepage and through-seepage concurrently. A steady state seepage computer model used for this effort (SEEP/W) incorporated existing and new geotechnical data and analyses from borings drilled at regular intervals along the entire urban levee system. The model estimates an exit gradient for under-seepage at the design water surface elevation and allows assessment of potential through-seepage conditions, which are then compared against accepted criteria, as specified in the USACE *Design and Construction of Levees Engineering Manual 1110-2-1913* (USACE, 2000) and the DWR *Interim Levee Design Criteria for Urban and Urbanizing Areas in the Sacramento-San Joaquin Valley Version 4* (DWR, 2010d).

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

- Meets Criteria (M)
- Marginal (MG)
- Does Not Meet Criteria (DNM)
- Lacking Sufficient Data (LD)

Non-Urban Levee Evaluations Project

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

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

- Low
- Moderate
- High
- Lacking Sufficient Data

4.2.2 Limitations of Status Evaluations

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

Urban Levee Evaluations Project

The steady state seepage hazard classifications presented in this FCSSR for the ULE levees are based on analyses of preliminary data collected as part of the ULE Project, and do not reflect data collected from supplemental field explorations performed in 2009 and 2010. Data from these efforts will enhance levee seepage analytical results because the efforts were focused on data gaps identified based on results of the initial data collection effort, as presented in this FCSSR. Thus, results presented here may change based on the outcomes of supplemental investigations and analyses. New information will be incorporated into Geotechnical Evaluation Reports being prepared for each individual study area.

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

Non-Urban Levee Evaluations Project

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

4.2.3 Results of Status Evaluations

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

Urban Levee Evaluations Project

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

Non-Urban Levee Evaluations Project

Results of the NULE under-seepage and through-seepage hazard categorizations are shown in Figures 4-6 through 4-9. Figures 4-6 and 4-7 show the under-seepage hazard categorizations for NULE levees in the Sacramento and San Joaquin river watersheds, respectively. Figures 4-6 and 4-7 show that approximately one-third of SPFC NULE levees in the Sacramento River watershed and almost two-thirds in the San Joaquin River watershed have a high under-seepage hazard. Figures 4-8 and 4-9 show through-seepage hazard categorizations for NULE levees in the two watersheds. In general, through-seepage is less prevalent than under-seepage; approximately one-eighth of SPFC NULE levees in the Sacramento River watershed and approximately half in the San Joaquin River watershed have a high through-seepage hazard.

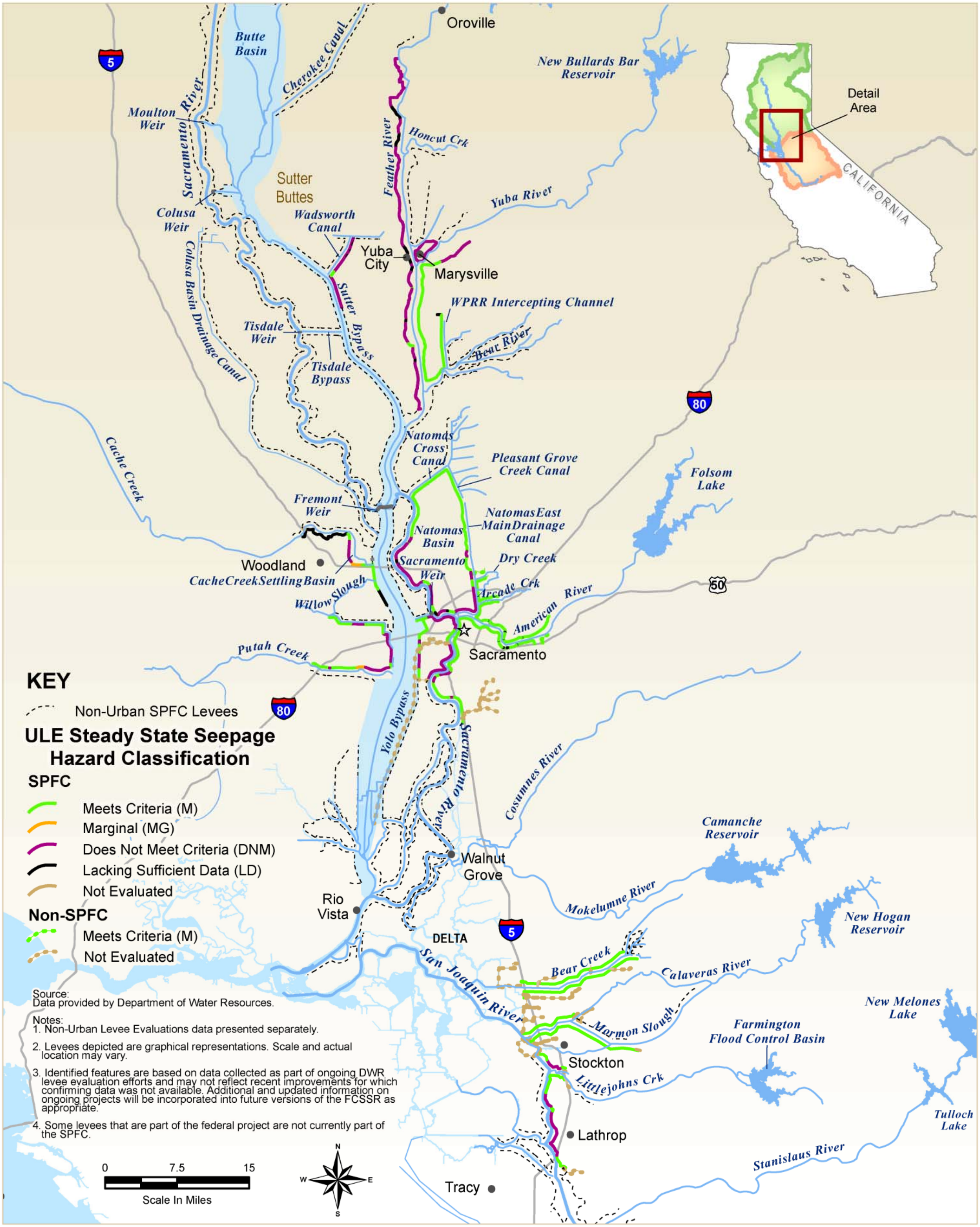


Figure 4-5. ULE Steady State Seepage Hazard Classifications

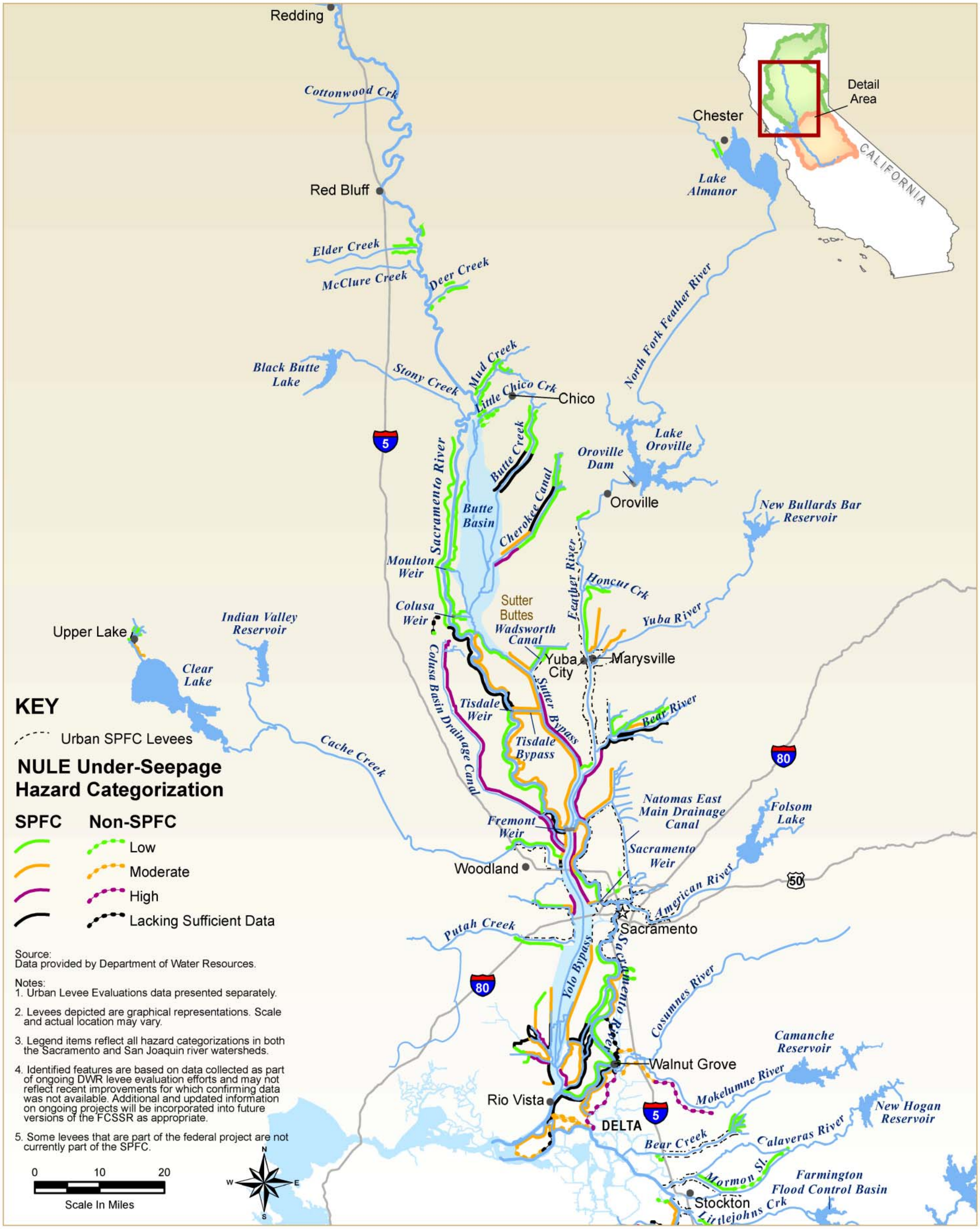


Figure 4-6. NULE Under-Seepage Hazard Categorizations in Sacramento River Watershed

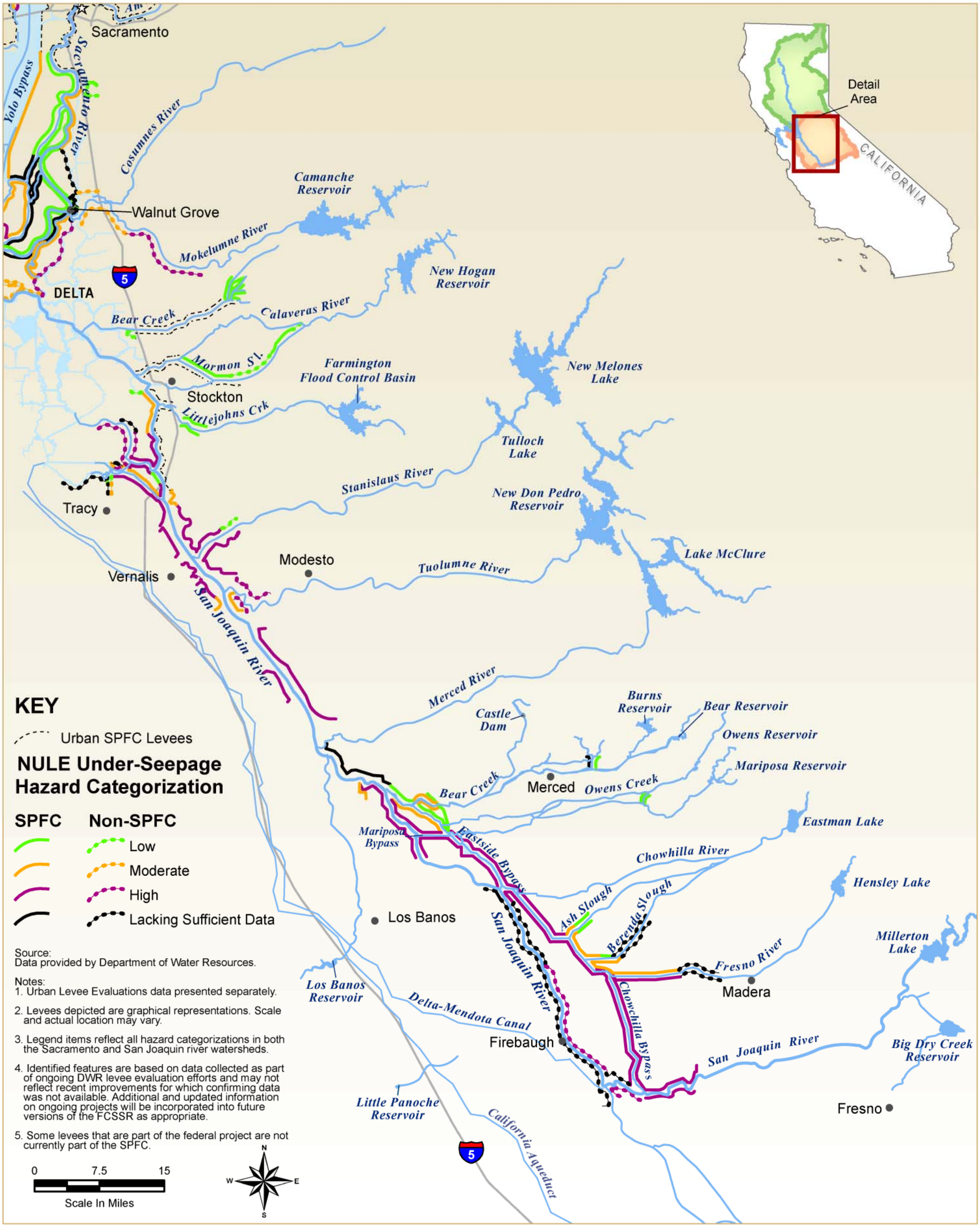


Figure 4-7. NULE Under-Seepage Hazard Categorizations in San Joaquin River Watershed

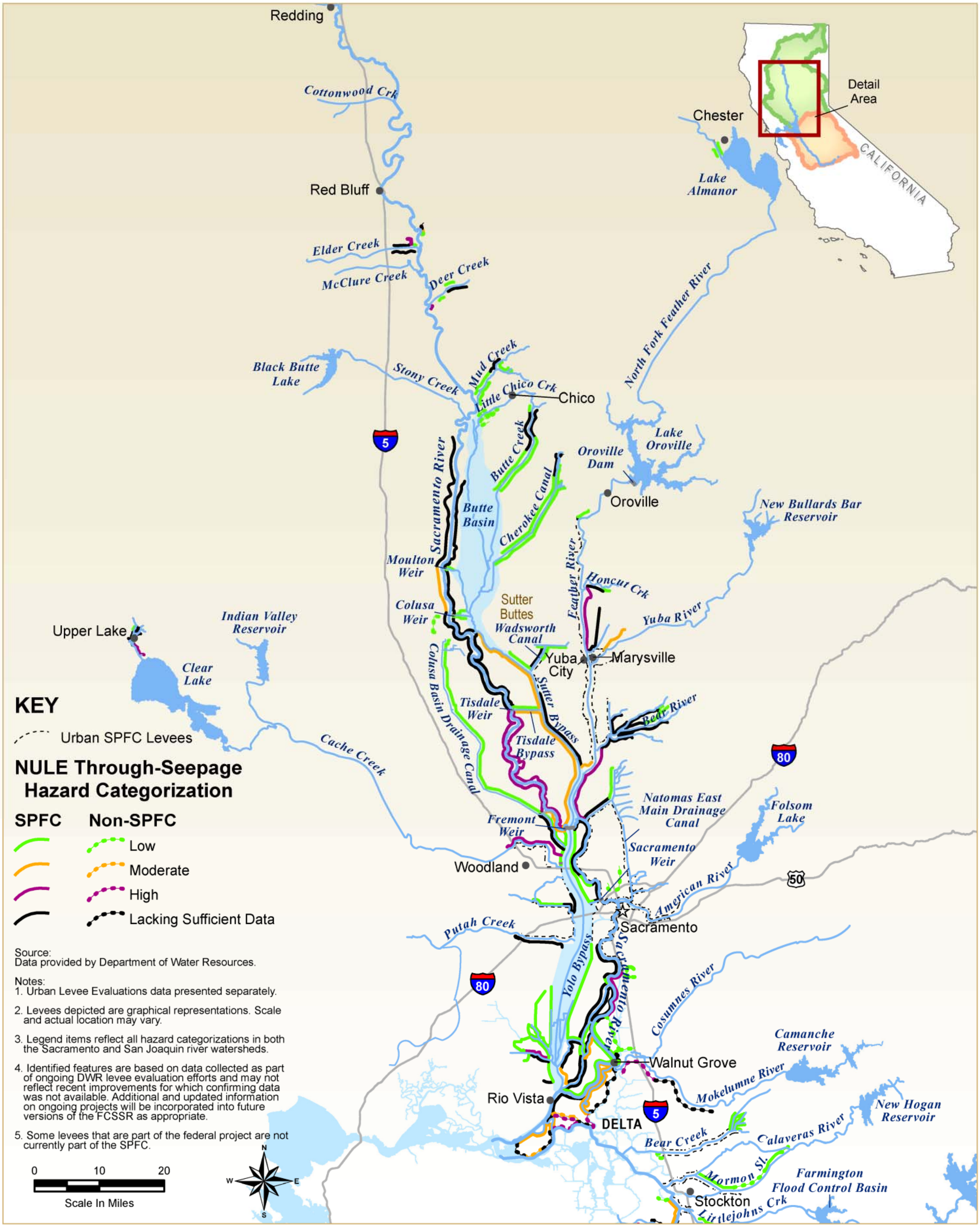


Figure 4-8. NULE Through-Seepage Hazard Categorizations in Sacramento River Watershed

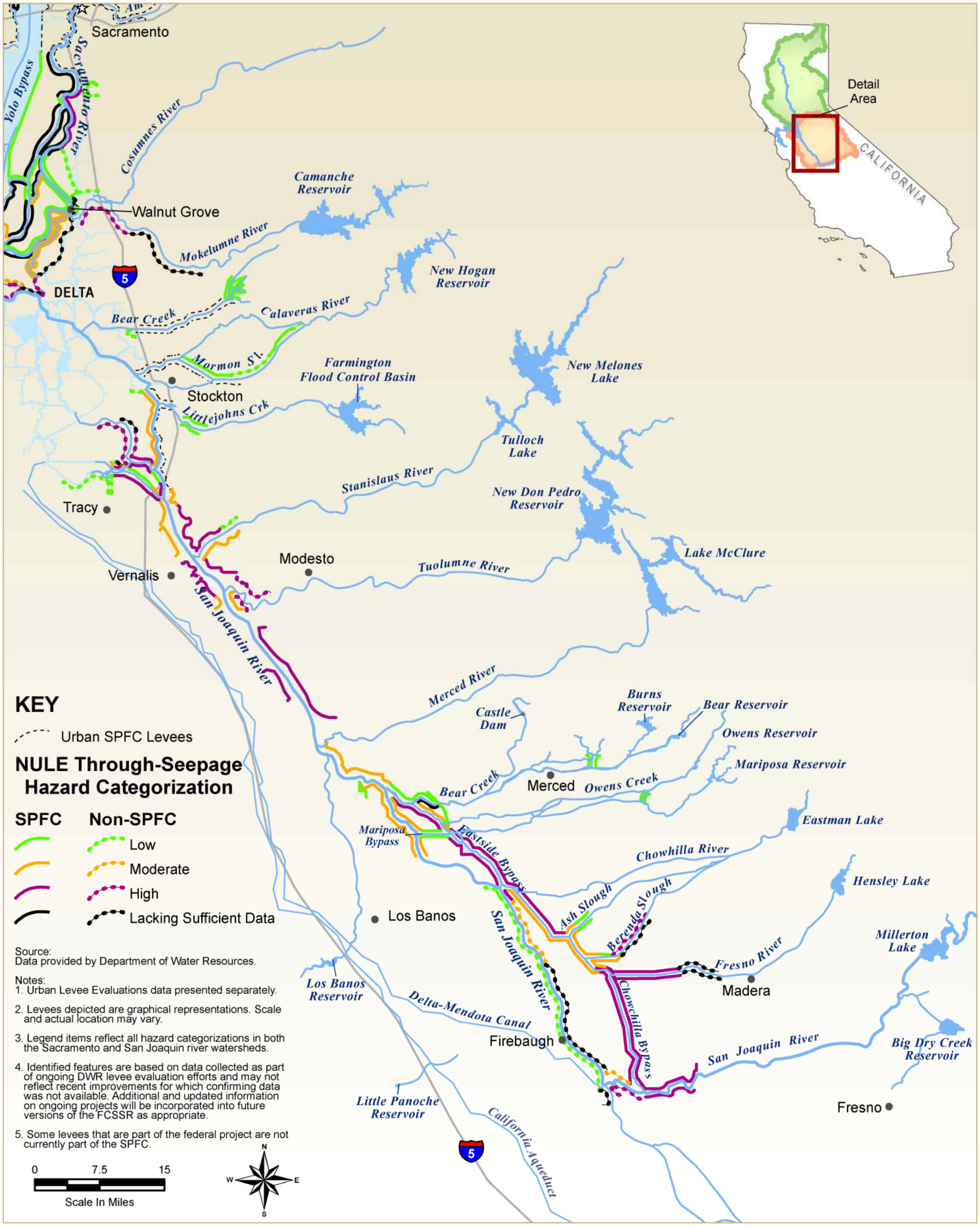


Figure 4-9. NULE Through-Seepage Hazard Categorizations in San Joaquin River Watershed

4.3 Structural Instability

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

4.3.1 Status Evaluation Methodology

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

Urban Levee Evaluations Project

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

- Meets Criteria (M)
- Marginal (MG)
- Does Not Meet Criteria (DNM)
- Lacking Sufficient Data (LD)

Non-Urban Levee Evaluations Project

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

- Low
- Moderate
- High
- Lacking Sufficient Data

4.3.2 Limitations of Status Evaluations

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

Urban Levee Evaluations Project

The hazard classifications presented in this FCSSR for the ULE Project levees are based on analyses of preliminary data collected as part of the project, and do not reflect data collected from supplemental field explorations performed in 2009 and 2010. Data from these efforts will enhance levee slope stability analytical results because the efforts were focused on data gaps identified based on results of the initial data collection effort, as presented in this FCSSR. Thus, results presented here may change based on the outcomes of supplemental investigations and analyses. New information will be incorporated into Geotechnical Evaluation Reports being prepared for each individual study area.

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

Non-Urban Levee Evaluations Project

As mentioned, the hazard categories provided in the NULE *Geotechnical Assessment Reports for the North NULE Study Area and South NULE*

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

4.3.3 Results of Status Evaluations

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

Urban Levee Evaluations Project

Results of the ULE Project steady state stability hazard classifications are shown in Figure 4-10. Based on these results, an estimated one-fifth of SPFC ULE levees do not meet geotechnical criteria for slope stability at the design water surface elevation. In general, SPFC ULE levees in the San Joaquin river watershed, along the American River, and along rehabilitated reaches of the Natomas basin and east of the Feather River meet slope stability criteria. Results along the remaining SPFC ULE levees vary.

Non-Urban Levee Evaluations Project

Slope stability hazard categories are shown in Figures 4-11 and 4-12. As shown, there is generally a higher slope stability hazard for levees in the Sacramento River watershed compared to the San Joaquin River watershed. Approximately one-eighth of SPFC NULE levees in the Sacramento River watershed and 1 percent in the San Joaquin River watershed have a high slope stability hazard.

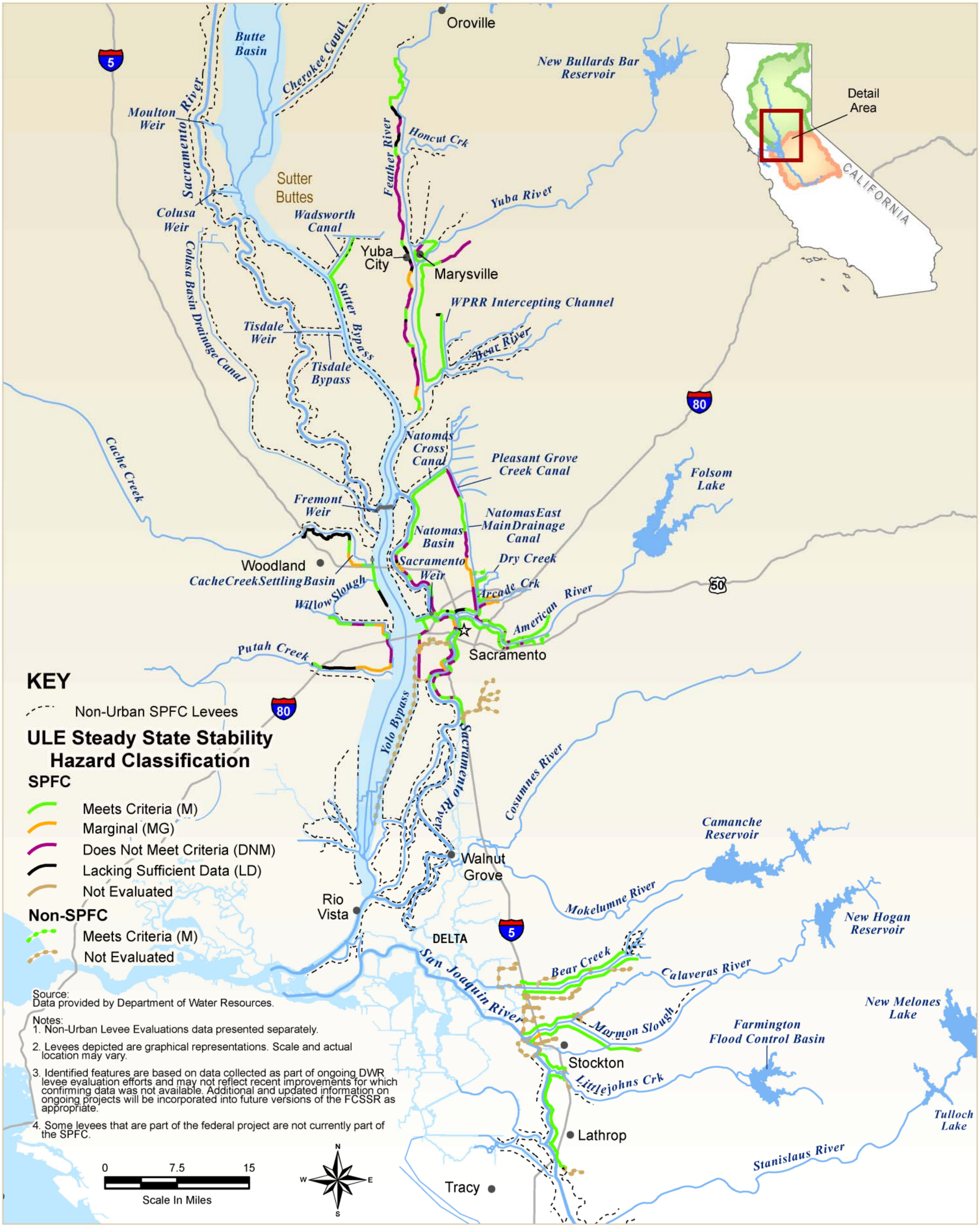


Figure 4-10. ULE Steady State Stability Hazard Classifications

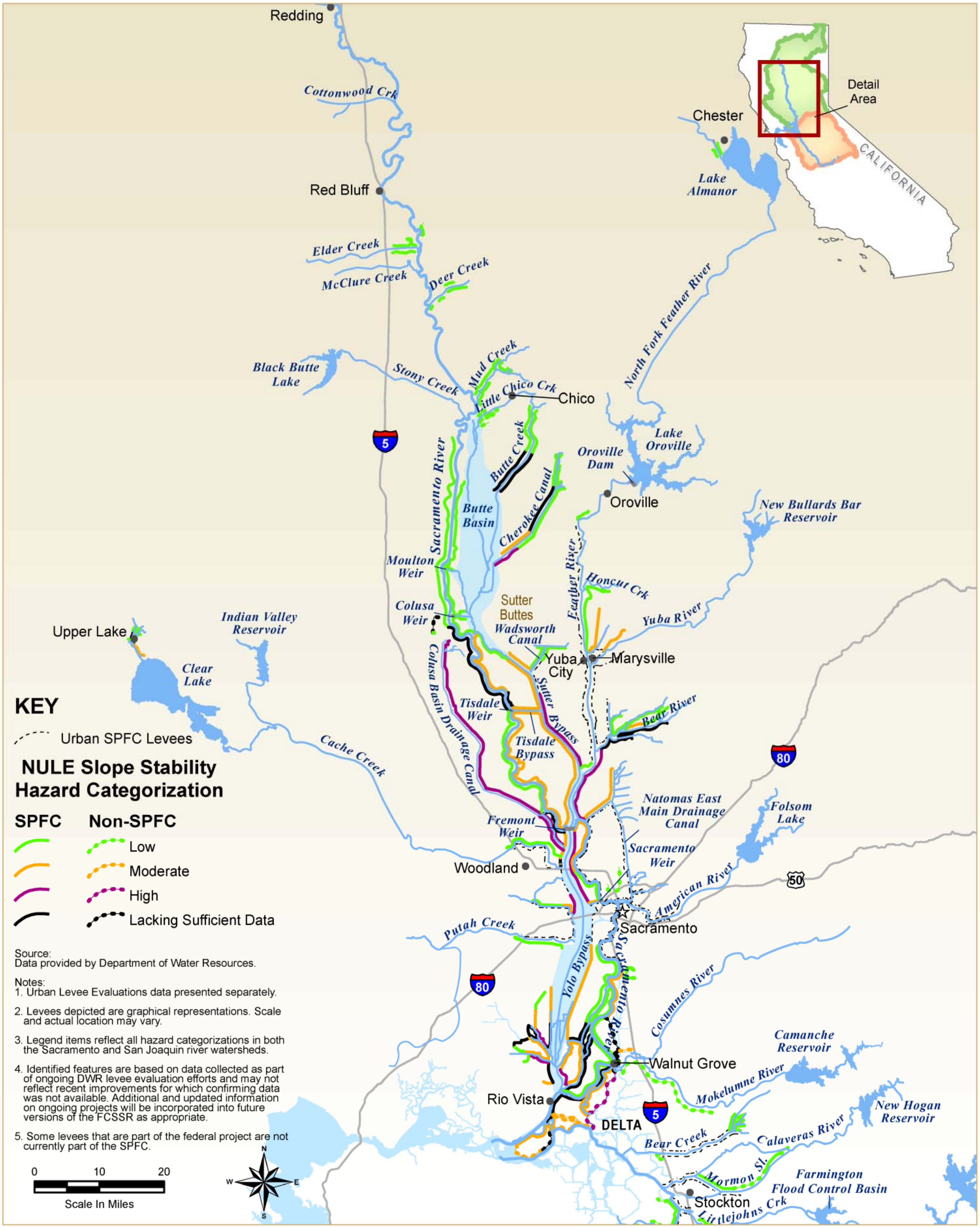


Figure 4-11. NULE Slope Stability Hazard Categorizations in Sacramento River Watershed

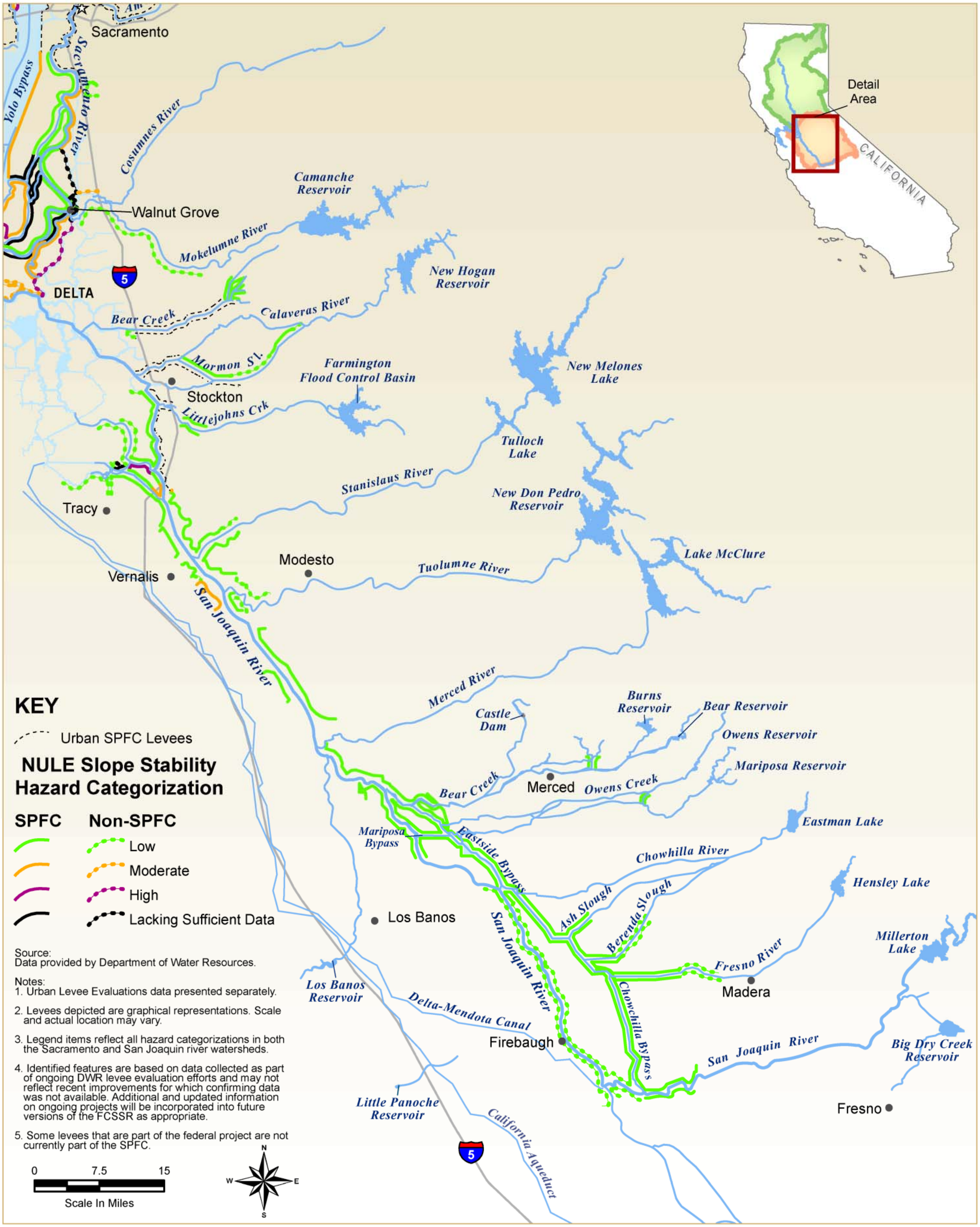


Figure 4-12. NULE Slope Stability Hazard Categorizations in San Joaquin River Watershed

4.4 Erosion

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

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

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

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

4.4.1 Status Evaluation Methodology

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

Urban Levee Evaluations Project

For the FCSSR, the levee geometry check described in Section 4.1 serves as a preliminary proxy for levee erosion problems. This is primarily because erosion-specific levee hazard assessments for SPFC ULE levees are underway and results are not available for this document. After erosion analyses are completed using a multitiered evaluation process, the information will be reported in various Geotechnical Evaluation Reports and future versions of the FCSSR. It is anticipated that the multitiered evaluation process will consider levee geometry, potential for wind-wave action, and past erosion history as part of the first tier analysis. ULE levee segments that appear to have potentially moderate or high erosion hazard based on the first tier analysis will be assessed under second tier analyses, when levee surface materials and river flow velocities will be compared, wave shear stress will be evaluated, and a field reconnaissance will be conducted to verify past performance. ULE levee segments that appear to have potentially moderate or high erosion hazard based on the second tier analyses will be assessed under a third tier analysis, which will classify levees as having a low, moderate, or high erosion hazard.

Non-Urban Levee Evaluations Project

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

- Low
- Moderate
- High
- Lacking Sufficient Data

4.4.2 Limitations of Status Evaluations

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

Urban Levee Evaluations Project

At present, the ULE Project has not completed evaluations specifically for erosion hazards of ULE Project levees. However, because the levee geometry evaluation performed for the ULE Project (described in Section 4.1.3) may indicate potential erosion hazards, it may be considered a proxy for erosion hazards, as mentioned. Because inadequate levee geometry may occur from a variety of conditions, including erosion, the results of that geometry check should be considered a conservative evaluation of the potential hazards associated with erosion. A more specific evaluation of erosion hazards, as described in Section 4.4.1, will be provided in the Geotechnical Evaluation Reports being prepared by DWR for each individual study area as part of the ULE Project.

Non-Urban Levee Evaluations Project

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

4.4.3 Results of Status Evaluations

Results of levee erosion hazard assessments for the ULE and NULE projects are summarized below. For additional information on levee inspection results, historical erosion occurrences, recent remedial actions, ongoing and planned repairs and improvements, and other actions to improve future evaluations, see Appendix A, Section A-5. Also, USACE periodic inspection results on levee erosion/bank caving for 10 USACE levee systems are included in Appendix A, Section A-1.

Urban Levee Evaluations Project

As mentioned, the ULE Project has not completed hazard assessments specifically for levee erosion. However, the levee geometry evaluation performed for the ULE Project, described in Section 4.1, is a proxy for potential erosion hazards.

Non-Urban Levee Evaluations Project

Estimates of NULE levee erosion hazard categorizations for the Sacramento River and San Joaquin river watersheds are shown in Figures 4-13 and 4-14, respectively. Approximately one-seventh of SPFC NULE levees in the Sacramento River watershed were categorized as having a high erosion hazard. NULE levee segments with high erosion hazard in the Sacramento River watershed are predominantly located in the area between the City of Sacramento and the Bear River in Yuba County.

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

Figure 4-13. NULE Erosion Hazard Categorizations in Sacramento River Watershed

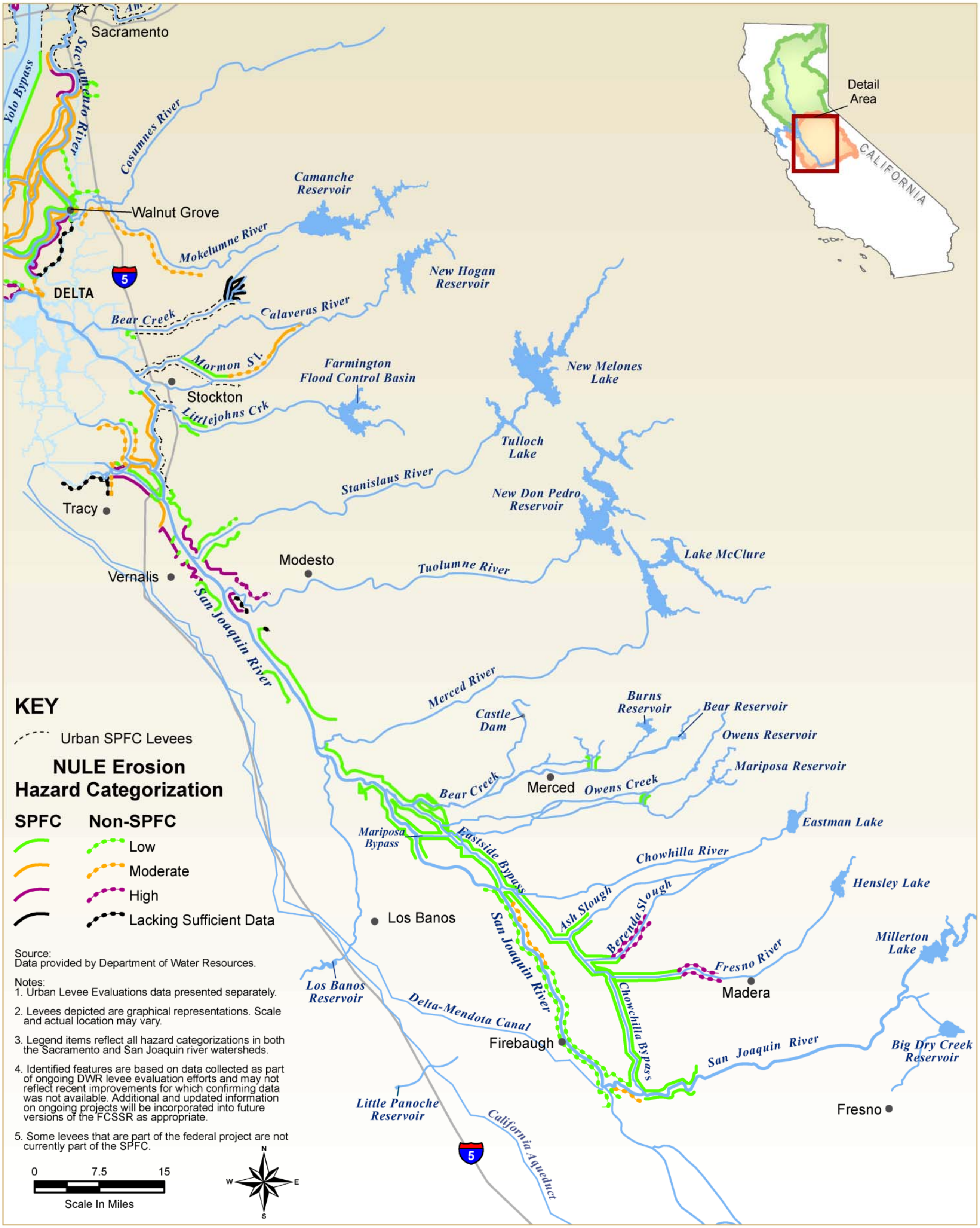


Figure 4-14. NULE Erosion Hazard Categorizations in San Joaquin River Watershed

4.5 Settlement

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

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

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

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

4.5.1 Status Evaluation Methodology

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

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

Inspection Rating	Rating Descriptions
Acceptable (A)	The road is in all-weather condition. There are no ruts, potholes, or other depressions on the levee, except minor depressions caused by levee settlement. The levee crown, embankments, and access road crowns are well established and drain properly without any ponded water.
Minimally Acceptable (M)	Some minor depressions in the levee crown, embankment, or access roads that will not pond water and do not threaten the integrity of the levee, or some additional road material may be necessary.
Unacceptable (U)	There are depressions greater than 6 inches deep that will pond water, endangering the integrity of the levee, or significant additional road material is needed.

Source: DWR, 2010b

4.5.2 Limitations of Status Evaluations

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

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

4.5.3 Results of Status Evaluations

Minimally Acceptable and Unacceptable levee crown surface/depressions/rutting inspection ratings from the *2009 Annual Inspection Report* (DWR, 2010b) are shown in Figures 4-15 and 4-16.

DWR inspections identified four locations of localized levee settlement that affect the integrity of levees (i.e., ratings of Unacceptable).

For additional information on levee sinkhole and subsidence data collected by the NULE Project, recent, ongoing, and planned repairs and improvements, and ongoing actions to improve future evaluations, see Appendix A, Section A-6. Also, USACE periodic inspection results for levee settlement and depressions/rutting for 10 USACE levee systems are included in Appendix A, Section A-1.

Figure 4-15. 2009 Crown Surface/Depressions/Rutting Inspection Ratings in Sacramento River Watershed

Figure 4-16. 2009 Crown Surface/Depressions/Rutting Inspection Ratings in San Joaquin River Watershed

4.6 Penetrations

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


Penetrations can be potential pathways for seepage

In most cases, penetrations were not modified to meet criteria at the time a levee was constructed. Numerous old and sometimes abandoned penetrations were not installed using current criteria that regulate how penetrations can be placed through levees. These criteria are found in Code of California Regulations Title 23, Article 8, Section 123. Many penetrations were included as part of the flood control project and turned over to maintaining agencies for maintenance. The Board has a partially complete levee penetrations inventory indicating that more than 6,000 penetrations exist through SPFC levees; many existing penetrations are still unidentified. Documentation of historical abandonment of penetrations is limited.

As mentioned, penetrations can be potential pathways for seepage, and may contribute to levee failure. In some instances, if backfill surrounding penetrations is more permeable than levee soils, a seepage pathway can develop. Susceptibility to seepage is particularly acute from older penetrations, which are prone to corrosion or collapse. Metal pipes can corrode, creating holes and leaks. These penetrations can induce the levee embankment to erode, creating areas of weakness or internal voids. This internal erosion often remains hidden until a surface expression develops, such as a sinkhole or localized depression (see Section 4.5, “Settlement,” for discussion of localized depressions).

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

Damage to levee embankments from penetrations can contribute to seepage, stability, and settlement problems. If the phreatic surface[1] intersects an internal levee embankment cavity during a high water event, internal erosion may accelerate, and potential for development of a levee breach will increase. Levee seepage, stability, and settlement problems are discussed in Sections 4.2, 4.3, and 4.5, respectively.

4.6.1 Status Evaluation Methodology

DWR levee inspectors currently do not inspect penetrations in detail as part of their annual levee inspections. DWR has implemented a utility crossing inventory program that will identify, locate, and visually inspect existing penetrations over the next 3 to 5 years. As part of this effort, DWR is currently identifying and documenting existing penetrations and developing a rating system or criteria to incorporate penetrations into inspection ratings.

Because the utility crossing inventory program is currently under development, data presented in this report are limited to documentation of known penetrations from existing sources, and the FCSSR does not include assessing potential structural threats to levees. Data from DWR levee penetration logs, which list the number and approximate locations of pipes penetrating the levees, were supplemented by interviews with representatives from local agencies and landowners as part of the ULE and NULE projects.

4.6.2 Limitations of Status Evaluations

As mentioned, DWR is currently cataloging levee penetrations. Additional penetrations data, including data from DWR's Delta Levees Electro-Magnetic Anomaly Program, will be assessed under the ULE and NULE projects and incorporated into future updates of the FCSSR.

Efforts are also ongoing to develop criteria to evaluate risks associated with penetrations. Although records exist for many permitted penetrations, physical characteristics of the penetration (e.g., pipe dimension, material, use) were not documented consistently, and records stem from several different sources. Therefore, data presented here represent only a summary of the locations of known penetrations, and not an assessment of potential risks posed by those penetrations.

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

As discussed in Section 3.3.2, penetrations data were some of the qualitative data inputs incorporated in assigning a NULE through-seepage hazard categorization and therefore were also a consideration in the NULE overall hazard categorization. Penetrations data were not considered in assessing an overall hazard classification for ULE levees because ULE seepage hazards were assessed with numerical computer models incorporating site-specific geotechnical data from soil borings. Therefore, penetrations data presented in this FCSSR represent a compilation of NULE levee penetrations and only a partial compilation of ULE levee penetrations. Penetrations for ULE levees are being documented as part of the ULE Project; new data will be included in future updates of the FCSSR.

4.6.3 Results of Status Evaluations

Figures 4-17 and 4-18 show documented levee penetrations for the Sacramento and San Joaquin river watersheds, respectively. Data show that penetrations are prevalent throughout the entire levee system. As mentioned, the initial DWR inventory shows more than 6,000 penetrations through SPFC levees. In the Sacramento Valley, existing data include the greatest density of penetrations along the Sacramento River levees upstream from the Sutter Bypass and downstream from the City of Sacramento, with fewer penetrations documented along the Feather River levee system, along the smaller tributary stream levees, and along the bypass levees[2]. In the San Joaquin Valley, penetrations have been identified throughout the San Joaquin River levees between Stockton and Fresno.

For additional information on recent levee remedial actions, ongoing and planned remedial actions, and ongoing actions to improve future evaluations, see Appendix A, Section A-7.

[2] Since compilation of ULE levee penetrations is still ongoing, it is uncertain whether fewer penetrations exist in these areas or whether penetrations exist but have not been documented yet.

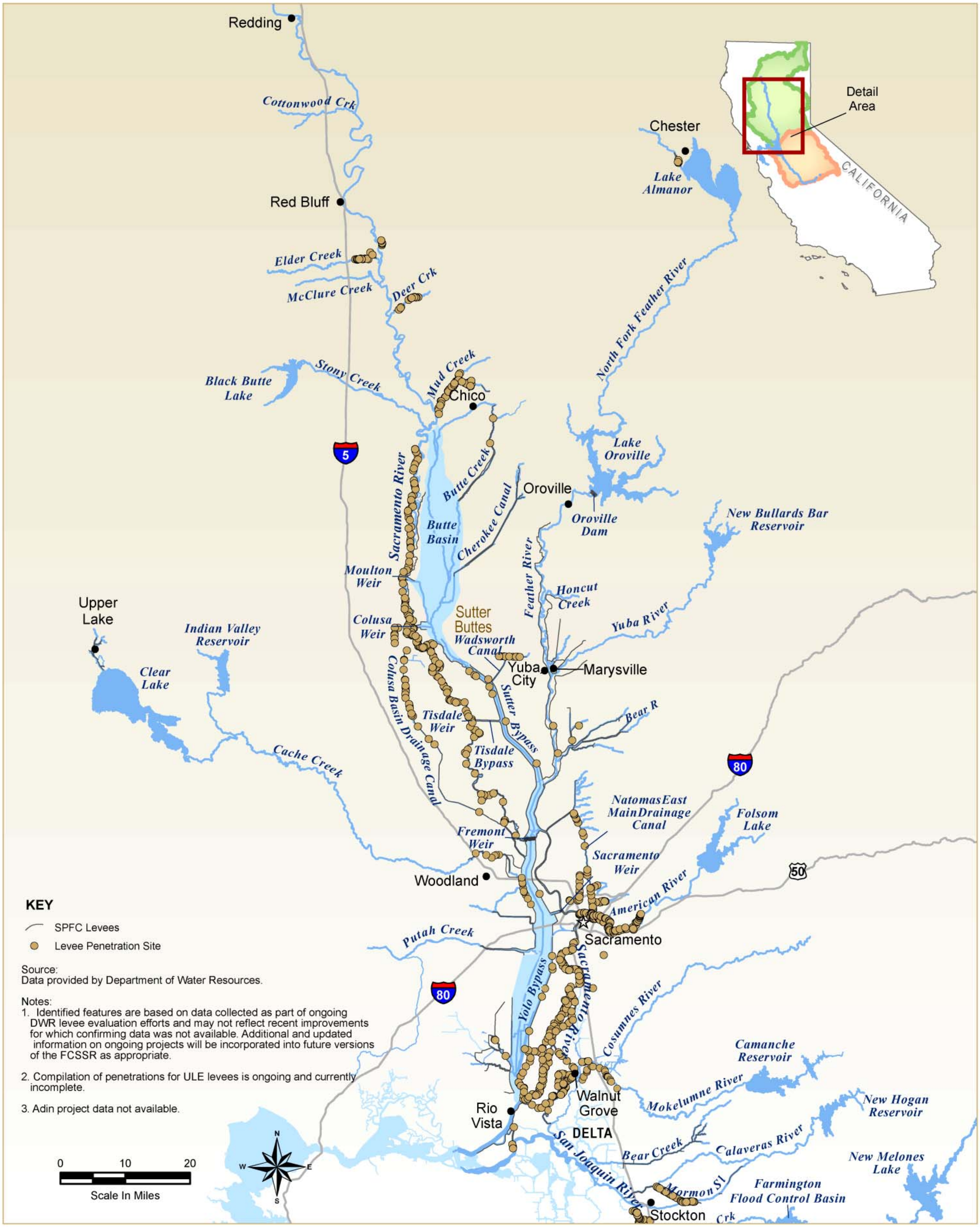


Figure 4-17. Levee Penetrations in Sacramento River Watershed

Figure 4-18. Levee Penetrations in San Joaquin River Watershed

4.7 Levee Vegetation

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

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

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

Over the last several years, USACE's enforcement of its policies regarding vegetation on levees has become more stringent. In April 2007, a Draft USACE White Paper provided specific guidance for USACE best management practices for vegetation management. USACE later issued the *Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures* (Engineering Technical Letter 1110-2-571) (2009b) on April 10, 2009. These guidelines limit growth (brush, weeds, or trees) to smaller than 2 inches in diameter.

In August 2007, DWR and the Board created the California Levees Roundtable, a partnership of maintaining agencies, USACE, FEMA, and resources agencies to generate procedures for vegetation management that are supported by the regulatory agencies and allow maintaining agencies to fulfill their public safety responsibilities. To address levee visibility and inspection issues presented by vegetation on levees, DWR adopted interim levee vegetation inspection criteria in fall 2007. These criteria are being used in the short term until they can be revised, using best available science. On February 27, 2009, the California Levees Roundtable issued a joint collaborative document titled *California Central Valley Flood System Improvement Framework* (California Levee Roundtable, 2009), which was intended to provide interim guidance on best vegetation management practices until the CVFPP is adopted.

4.7.1 Status Evaluation Methodology

DWR interim levee vegetation inspection criteria for visibility and accessibility form the primary basis in this report for identifying levee vegetation problems. *DWR Interim Levee Vegetation Criteria* (2007) comply with the standard contained in the *Central Valley Flood System Improvement Framework* document created in collaboration with USACE, DWR, and other agencies (California Levees Roundtable, 2009).

USACE levee vegetation standards limit uncontrolled vegetation growth (brush, weeds, or trees) to no greater than 2 inches in diameter on levee slopes or crowns, or within 15 feet of the landward toe. *DWR Interim Levee Vegetation Criteria* (2007) allow vegetation beyond 20 feet from the waterside hinge point; grass and weeds must be less than 12 inches in height, and trees must be trimmed 5 feet above ground or 12 feet above the crown road, with thinning to allow clear visibility and floodfight access. The *DWR Interim Levee Vegetation Criteria* (2007) can be found in Appendix A, Section A-8.

As described in Section 2.1.1, DWR visually inspects SPFC levees for levee vegetation and tree trimming/thinning at least two times per year and reports results annually. Table 4-4 shows DWR inspection rating descriptions for vegetation on earthen levees. Table 4-5 shows DWR inspection rating descriptions for trimming/thinning trees on earthen levees.

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

Inspection Rating	Rating Descriptions
Acceptable (A)	The levee has a good grass cover with no unwanted vegetation (brush, bushes, undesirable weeds) blocking visibility or access.
Minimally Acceptable (M)	Tall grass, weeds, or brush partially block visibility of or access to the levee and/or are within 10 feet of the landside toe.
Unacceptable (U)	Tall grass, weeds, or brush completely block visibility of or access to the levee and/or are within 10 feet of the landside toe.

Source: DWR, 2010b
Note:
See Appendix A-8, Figure A-31, for schematic showing *DWR Interim Vegetation Inspection Criteria for Standard Levees*, October 2007.

Table 4-5. Levee Inspection Rating Descriptions for Trimming/Thinning Trees on Earthen Levees

Inspection Rating	Rating Descriptions
Acceptable (A)	Any trees on the levee or the 10-foot landside toe easement are trimmed to at least 5 feet above the levee slope, and spaced to allow visibility and floodfight access. Trees adjacent to the levee crown or patrol road are trimmed at least 12 feet above ground.
Minimally Acceptable (M)	Moderate density of limbs, leaves, or the trees themselves is partially obstructing visibility and floodfight access to the levee slope and/or 10 feet beyond the landside toe.
Unacceptable (U)	Significant density of limbs, leaves, or the trees themselves is completely obstructing visibility and floodfight access to the levee slope and/or 10 feet beyond the landside toe.

Source: DWR, 2010b

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

To support maintaining agencies in reaching full compliance with the DWR interim vegetation inspection criteria by November 1, 2010, DWR conducted a follow-up evaluation of remaining levee vegetation problems identified in the DWR fall 2009 inspection. In July 2010, environmental scientists conducted site visits to all levee reaches rated as Unacceptable during the DWR fall 2009 inspection. The site visits documented continued improvements needed for levees to comply with the *DWR Interim Levee Vegetation Criteria* (2007).

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

4.7.2 Limitations of Status Evaluations

Reported levee vegetation conditions are based on inspections and assessments relative to the *DWR Interim Levee Vegetation Criteria* (2007), and not relative to USACE vegetation standards. Differences between DWR and USACE levee vegetation criteria are significant enough that comparison of DWR and USACE criteria would likely show more SPFC levees as noncompliant. Levee status evaluations do not yet have the benefit of a complete body of research to support a meaningful correlation between levee vegetation and geotechnical hazard to levees.

4.7.3 Results of Status Evaluations

Inspection results reflect vegetation and trimming/thinning trees levee inspection ratings from the *2009 Annual Inspection Report* (DWR, 2010b), updated by data collected from DWR's additional site visits in July 2010. Unacceptable and Minimally Acceptable inspection ratings are shown in Figures 4-19 through 4-22 for the Sacramento and San Joaquin River watersheds.

Although difficult to determine from the figures because of the scale of the maps, levee reaches with Unacceptable ratings include approximately 15 total miles of levees. Levees with Unacceptable ratings had brush and weeds, trees needing trimming/thinning, and approximately 111 elderberry shrubs requiring thinning or removal. Elderberry shrubs are host plants for the valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*), federally listed as threatened. Most of the Unacceptable ratings for levee vegetation and trimming/thinning of trees were located on the Sacramento River south of Sacramento, and in the Sacramento-San Joaquin Delta.

Additional information on recent, ongoing, and planned levee remedial actions, and ongoing actions to improve future evaluations of levee vegetation problems is included in Appendix A, Section A-8. Also, USACE periodic inspection results for levee vegetation growth (based on USACE levee vegetation inspection criteria) in 10 USACE levee systems are included in Appendix A, Section A-1.

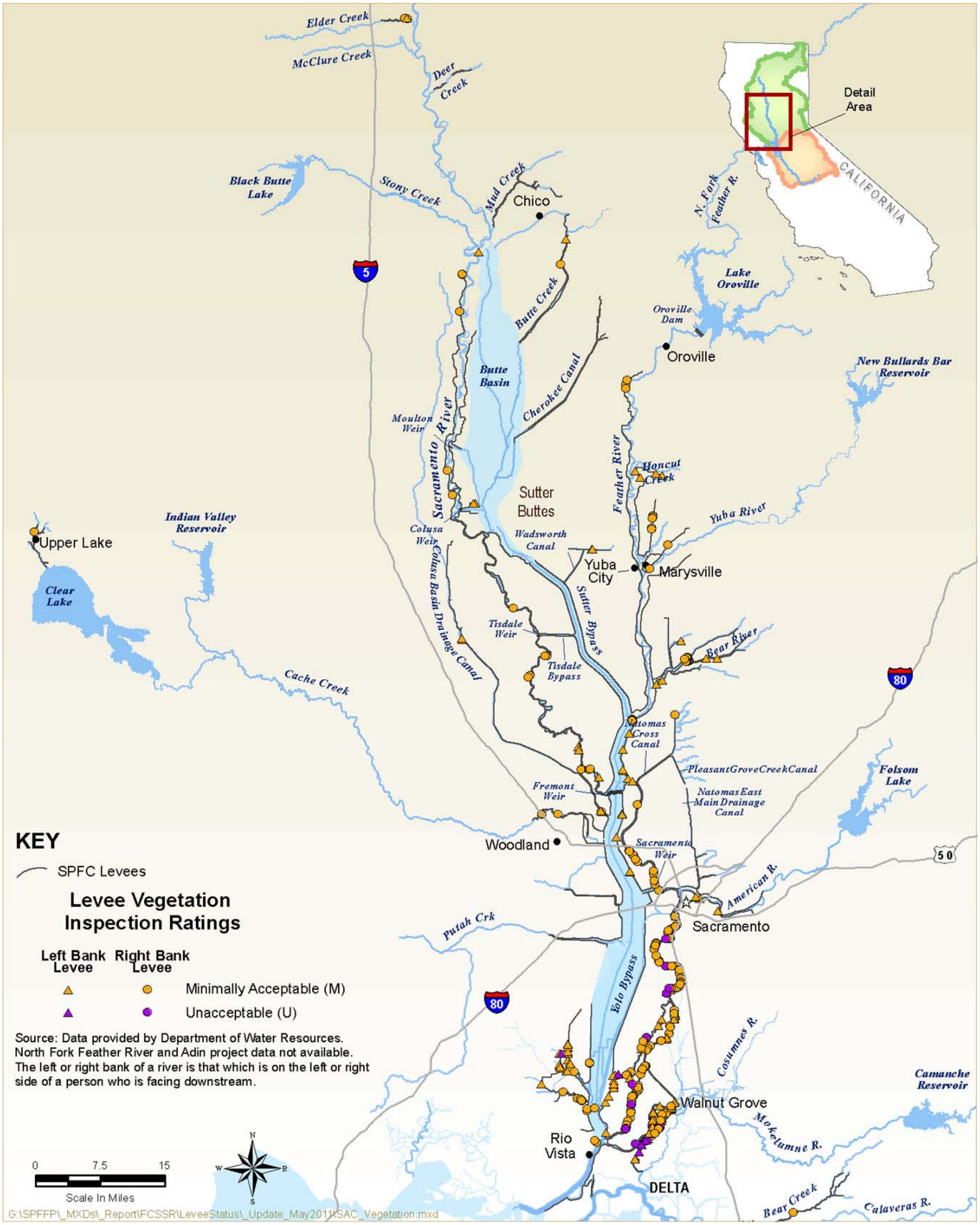


Figure 4-19. 2009 Levee Vegetation Inspection Ratings in Sacramento River Watershed

Figure 4-20. 2009 Levee Vegetation Inspection Ratings in San Joaquin River Watershed

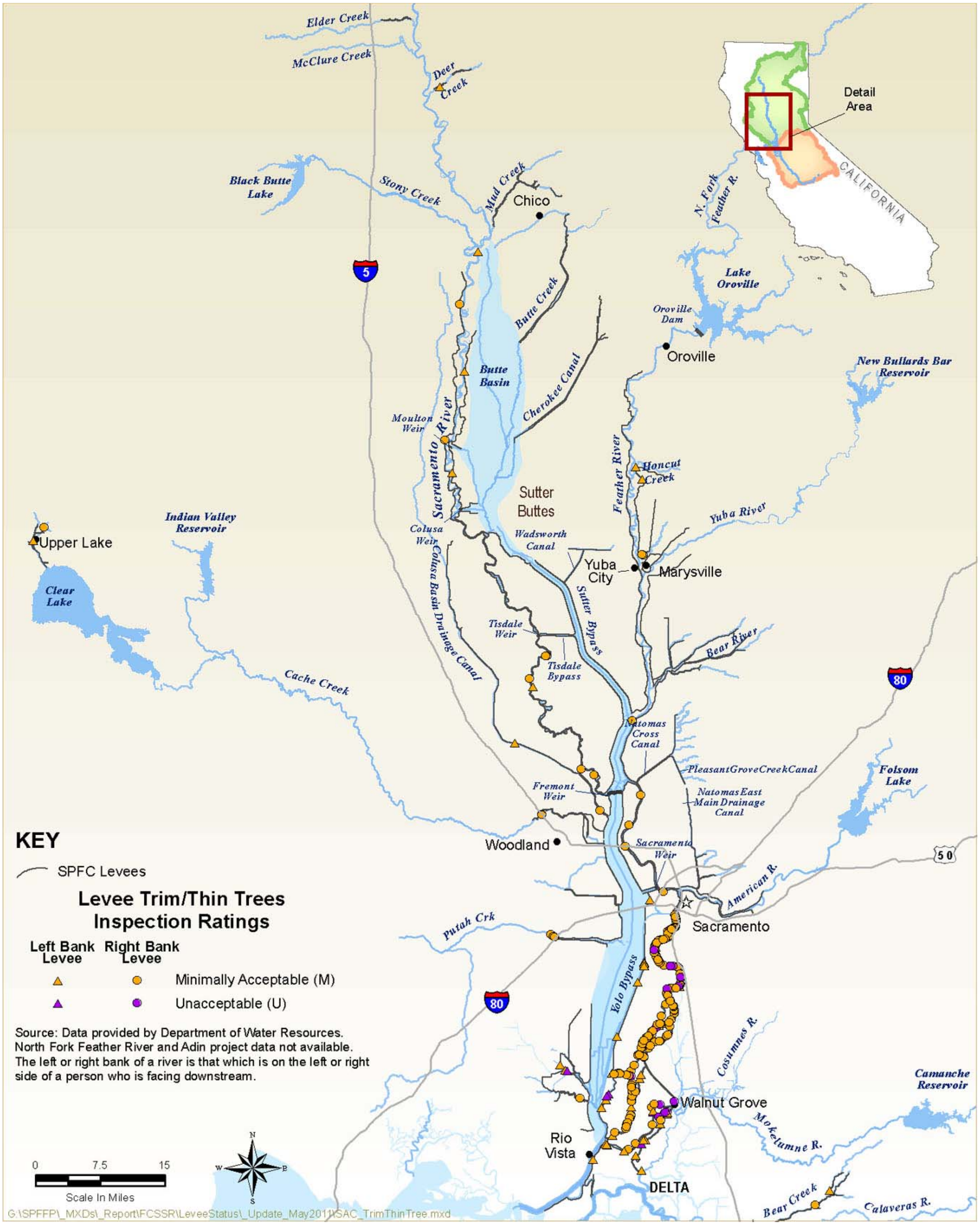


Figure 4-21. 2009 Trimming/Thinning Trees Inspection Ratings in Sacramento River Watershed

Figure 4-22. 2009 Trimming/Thinning Trees Inspection Ratings in San Joaquin River Watershed

4.8 Rodent Damage

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

Animal burrows can increase seepage through a levee

Burrowing animal (rodent) damage to SPFC levees can worsen because of deferred repairs or maintenance and other factors, such as land use adjacent to levees. While it is infeasible to eliminate all burrows from SPFC levees, maintaining agencies implement animal burrow control programs that reduce active burrowing and fill existing burrows. The specific type of control method used varies among maintaining agencies, and includes the following: grouting burrows, excavating and filling burrows, baiting, and others.

4.8.1 Status Evaluation Methodology

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

Statistical analysis was used to categorize levels of animal burrow hole persistence as the lower, middle, and upper third of the distribution (i.e., low, medium, and high persistence). Levels of persistence are described in Table 4-6. For more details on the study, refer to the *Assessment of Animal*

Burrow Hole Persistence on Project Levees Technical Memorandum (DWR, 2009b).

Table 4-6. Animal Burrow Hole Persistence Levels

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

Notes:
[1] The Animal Burrow Hole Persistence Study included 42 biannual DWR inspection records spanning 21 years, from 1984 to 2008. Records for 1988, 1990, 1991, and 1993 inspections were not available (DWR, 2009b).
[2] No Activity represents levee reaches for which no occurrences of documented burrowing activity were found in inspection reports, but for which documented occurrences were found elsewhere within the same levee unit.
[3] No Data represents entire levee units for which there were no data in the inspection reports. It is unknown whether the lack of data along these levee units was an indication of absence of activity or a reflection of problems observing animal activity in these areas.

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

4.8.2 Limitations of Status Evaluations

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

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

Some burrowing animals tend to be more damaging to levees (e.g., deeper penetrating burrows) than others; however, the type of burrowing animal in any particular area generally was not documented. The study did not address burrows and dens associated with large rodents, such as muskrats and beavers. These species usually do not burrow directly into levee slopes, but prefer to construct the entrances to their dens under water.

Records covering only 1,459 miles of approximately 1,600 total miles of SPFC levees contained information on burrowing activity. An additional 108 miles corresponded to entire levee units for which there were no data in the inspection reports ("No Data" level). It is unknown whether the lack of data along these levee units was an indication of absence of activity or a reflection of problems observing animal activity in these areas.

Animal persistence data were collected from levee inspections that are traditionally performed from a moving vehicle. For a variety of reasons, inspectors do not normally exit their vehicles to observe and document animal burrows. Visual inspection from a moving vehicle is not as effective for gathering information as foot surveys, and may lead to some underreporting of burrows. Certain maintenance measures, such as levee dragging, can also cover burrows on the surface, making underlying burrows difficult to observe during an inspection. Over time, this leads to levees that appear to lack any burrows on the surface, but instead may have internal burrows within the levee embankment.[3]

4.8.3 Results of Status Evaluations

Figures 4-23 and 4-24 show results for the DWR Animal Burrow Hole Persistence Study for the Sacramento and San Joaquin river watersheds, respectively (DWR, 2009b). More than one-third of the 1,459 miles of SPFC levees studied had high persistence (at least eight reported incidences of burrowing activity over the 21-year study span of inspection results).

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

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

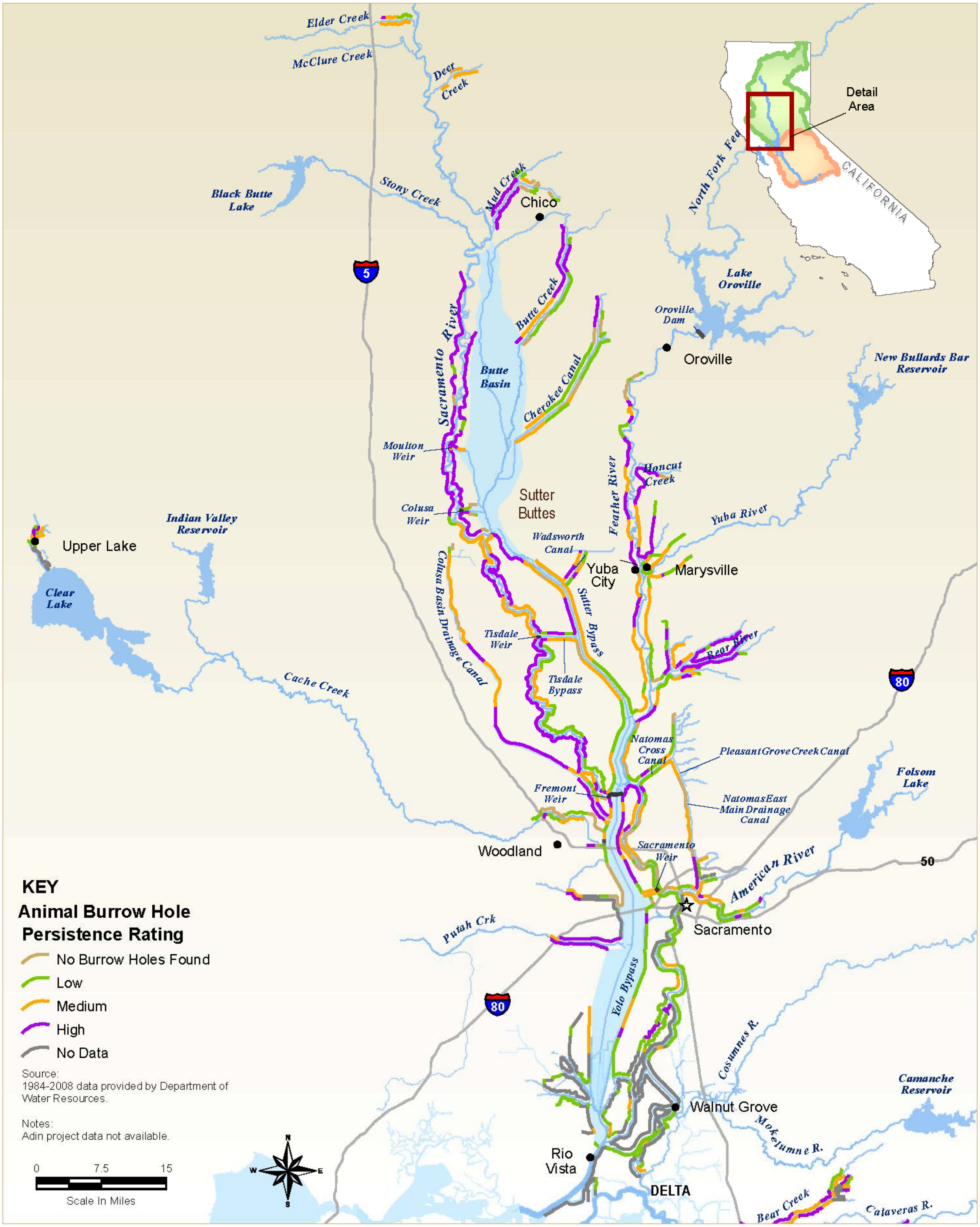


Figure 4-23. Animal Burrow Hole Persistence in Sacramento River Watershed

Figure 4-24. Animal Burrow Hole Persistence in San Joaquin River Watershed

4.9 Encroachments

Encroachments are any obstruction or physical intrusion by construction of works or devices, planting or removal of vegetation, or caused by any other means, for any purpose, into a flood control project, waterway area of the flood control project, or area covered by an adopted plan of flood control (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. Standard procedure is for the Board to obtain USACE approval before issuing an encroachment permit. More than 18,000 encroachment permits have been issued by the Board since its inception. A permit may be for a single encroachment or multiple encroachments. Many current encroachments are properly maintained. However, numerous permitted encroachments are not properly maintained, and numerous unpermitted encroachments exist on or within SPFC levee rights-of-way.

Encroachments can interfere with floodfighting, inspection, and maintenance

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

DWR is updating its *Interim Levee Design Criteria for Urban and Urbanizing Areas in the Sacramento-San Joaquin Valley Version 4* (DWR, 2010d) to include encroachment criteria for urban levee design.

4.9.1 Status Evaluation Methodology

DWR visually inspects SPFC levees for encroachments at least two times per year, and reports results annually. Table 4-7 shows DWR inspection rating descriptions for encroachments on earthen levees, used for annual inspections in 2009.

Table 4-7. Levee Inspection Rating Descriptions for Encroachments on Earthen Levees

Inspection Rating	Rating Descriptions
Acceptable (A)	No trash or debris present. No excavation, structures, or other encroachments threaten levee integrity. No encroachments obstruct visibility or access to the levee or landside toe easement.
Minimally Acceptable (M)	Minimal trash or debris present. Minor excavation, structure, or other encroachments pose minor threat to levee integrity.
Unacceptable (U)	Significant trash or debris present. Major excavation, structure, or other encroachments pose major threat to levee integrity.
Partially Obstructing (PO)	An encroachment (permitted or nonpermitted) partially obstructs visibility and access to the levee and/or 10 feet beyond landside toe.
Completely Obstructing (CO)	An encroachment (permitted or nonpermitted) completely obstructs visibility and access to the levee and/or 10 feet beyond landside toe.

Source: DWR, 2010b

DWR documents and rates three types of encroachments:

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

Encroachments that threaten levee integrity and those that are inappropriately placed on a levee are included in the overall ratings, and may need to be remediated by the maintaining agencies, if not permitted by the Board. Encroachments that obstruct visibility and access may be beyond the current authority of maintaining agencies to remediate because the encroachments may be Board-permitted, or have other associated factors that prevent maintaining agencies from taking action. DWR inspectors record the location, length, and type of encroachments that obstruct visibility and/or access. Partially Obstructing (PO) and Completely Obstructing (CO) encroachments are not included in the overall ratings (A, M, and U).

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

4.9.2 Limitations of Status Evaluations

Although efforts are underway to create a GIS database of historical encroachment permits, current inspection reporting does not distinguish between permitted or nonpermitted encroachments. It is also difficult for inspectors to determine whether observed encroachments are located within existing easement or right-of-way boundaries. A more thorough evaluation of encroachment status would include a complete inventory of permitted and nonpermitted encroachments and associated documentation, along with project-specific hydraulic modeling to assess the potential impact of encroachments on water surface elevation and levee integrity.

4.9.3 Results of Status Evaluations

The *2009 Annual Inspection Report* encroachment inspection ratings are shown in Figures 4-25 through 4-28 for the Sacramento and San Joaquin river watersheds, respectively (DWR, 2010b).

Minimally Acceptable and Unacceptable ratings are shown in Figures 4-25 and 4-26. Inspection results include 536 encroachment sites identified as minor threats to levee integrity (i.e., Minimally Acceptable) and 15 encroachment sites identified as major threats to levee integrity (i.e., Unacceptable). Encroachment sites may consist of multiple individual encroachments.[4]

Partially Obstructing and Completely Obstructing ratings are shown in Figures 4-27 and 4-28. Inspection results include 354 encroachment sites found to partially obstruct visibility and access to levees and 869 encroachment sites found to completely obstruct visibility and access.

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

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

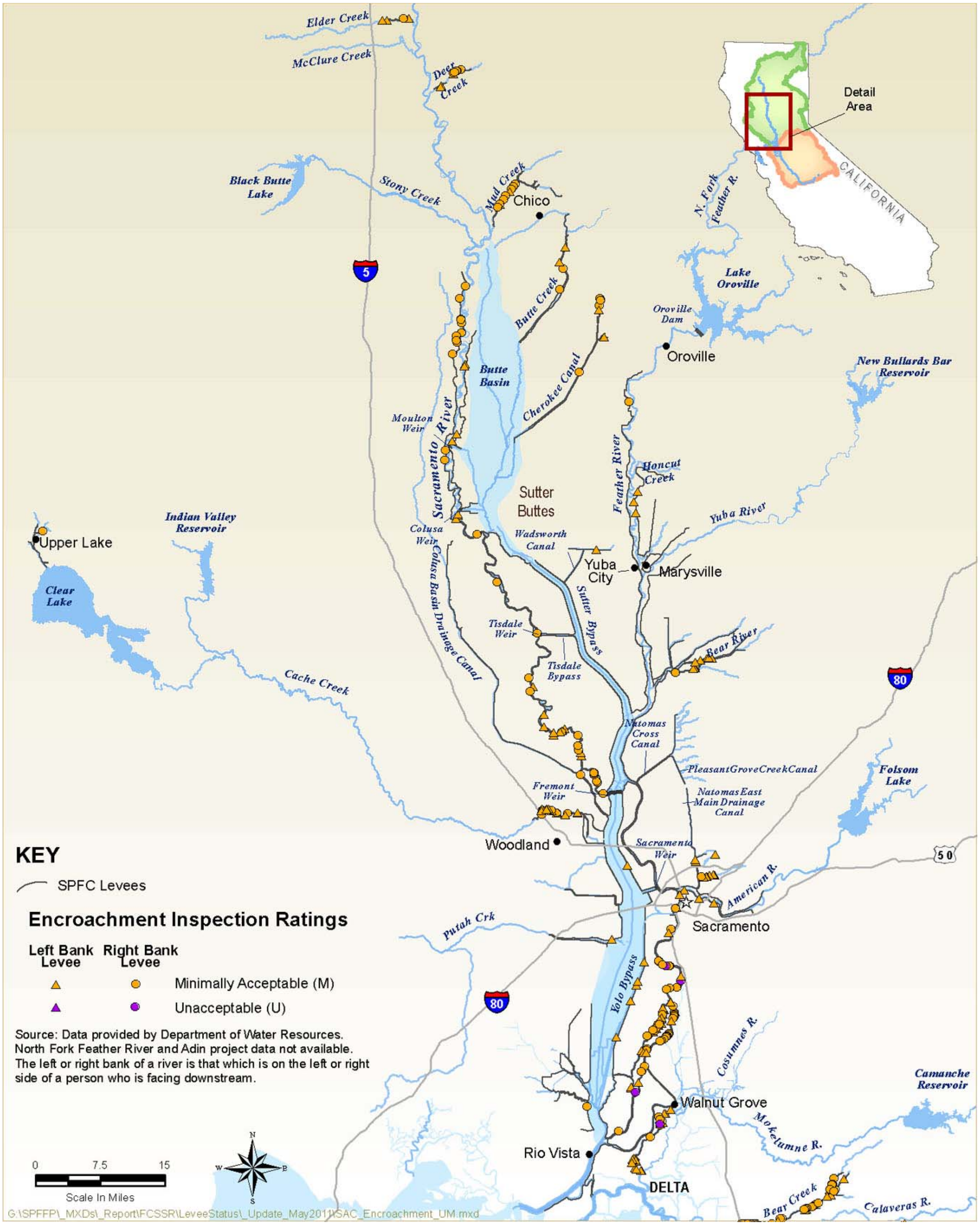


Figure 4-25. 2009 Encroachment Inspection Ratings in Sacramento River Watershed (Threats to Levee Integrity)

Figure 4-26. 2009 Encroachment Inspection Ratings in San Joaquin River Watershed (Threats to Levee Integrity)

Figure 4-27. 2009 Encroachment Inspection Ratings in Sacramento River Watershed (Obstructions to Visibility and Access)

Figure 4-28. 2009 Encroachment Inspection Ratings in San Joaquin River Watershed (Obstructions to Visibility and Access)