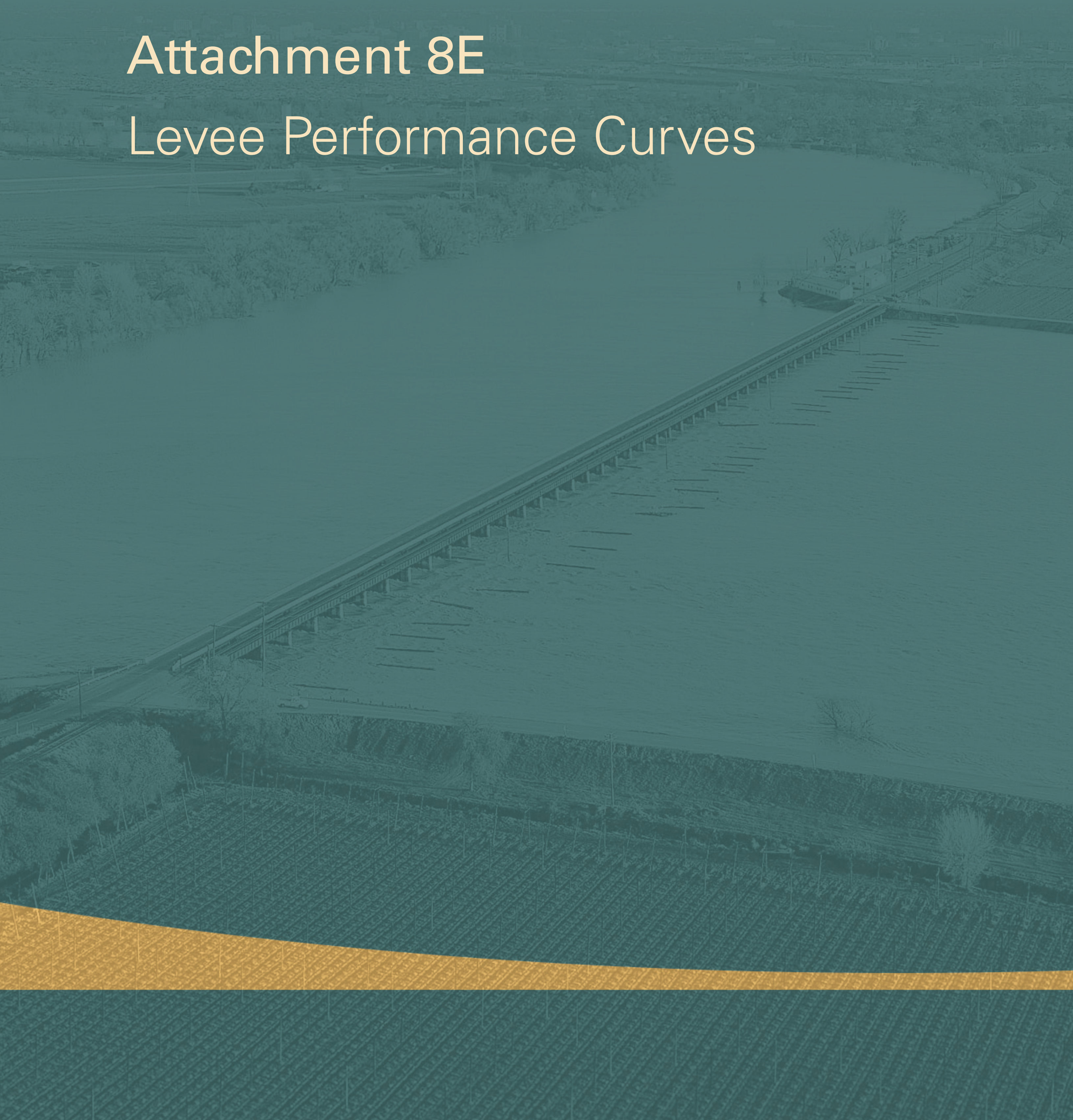
Attachment 8E

Levee Performance Curves



CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE
CALIFORNIA

2012 Central Valley Flood Protection Plan

Attachment 8E: Levee Performance Curves

June 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

This section provides the purpose of this attachment, background information (including planning areas, goals, and approaches), an overview levee performance curves, and report organization.

1.1 Purpose of this Attachment

The hydraulic and economic analysis of the State Plan of Flood Control (SPFC) facilities for the Central Valley Flood Protection Plan (CVFPP) is based on analysis methodologies and computer models developed for the 2002 Sacramento-San Joaquin River Basins Comprehensive Study (Comprehensive Study) conducted by the U.S. Army Corps of Engineers (USACE) and the California Department of Water Resources (DWR) between 1998 and 2002 (2002). In that study, levee performance curves[1] were used to describe the ability of a given levee segment to withstand specified water surface elevations without breaching.

To reflect the most current levee conditions, new levee performance curves were developed using the recently generated data and preliminary evaluations from DWR's Urban Levee Evaluation (ULE) and Non-Urban Levee Evaluation (NULE) levee segments/reaches in the Sacramento River (North) and San Joaquin River (South) basins, in lieu of the Comprehensive Study levee performance curves. The new levee performance curves were based on geotechnical data and evaluations performed through summer 2011.

This attachment first describes the expert consultation process that resulted in equations and techniques for using ULE and NULE data/preliminary evaluations to develop levee performance curves. Next, the methodology used to develop the levee performance curves is described and applied using the ULE and NULE data/preliminary evaluations.

1.2 Background

As authorized by Senate Bill 5, also known as the Central Valley Flood Protection Act of 2008, DWR has prepared a sustainable, integrated flood management plan called the CVFPP, for adoption by the Central Valley

[1] The term levee performance curves and fragility curves are synonymous.

Flood Protection Board (Board). The 2012 CVFPP provides a systemwide approach to protecting lands currently protected from flooding by existing facilities of the SPFC, and will be updated every 5 years.

As part of development of the CVFPP, a series of technical analyses were conducted to evaluate hydrologic, hydraulic, geotechnical, economic, ecosystem, and related conditions within the flood management system and to support formulation of system improvements. These analyses were conducted in the Sacramento River Basin, San Joaquin River Basin, and Sacramento-San Joaquin Delta (Delta).

The DWR Levee Evaluations Program includes the ULE Project, covering State-federal Project (project) and appurtenant non-project levees in highly populated areas, and the NULE Project, which covers the remaining project and appurtenant non-project levees. The ULE Project includes approximately 470 miles of project and non-project levees protecting populations of 10,000 people or more, and the NULE Project includes 1,620 miles of project and non-project levees protecting populations of fewer than 10,000 people. Non-project levees are considered appurtenant and are included in the DWR Levee Evaluations Program when these levees protect part of an overflow basin partially protected by project levees or may impact the performance of project levees.

1.3 CVFPP Planning Areas

For planning and analysis purposes, and consistent with legislative direction, two geographical planning areas were important for CVFPP development (Figure 1-1):

- **SPFC Planning Area –** This area is defined by the lands currently receiving flood protection from facilities of the SPFC (see *State Plan of Flood Control Descriptive Document* (DWR, 2010)). The State of California’s (State) flood management responsibility is limited to this area.

- **Systemwide Planning Area –** This area includes the lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System (California Water Code Section 9611). The SPFC Planning Area is completely contained within the Systemwide Planning Area, which includes the Sacramento River Basin, San Joaquin River Basin, and Delta regions.

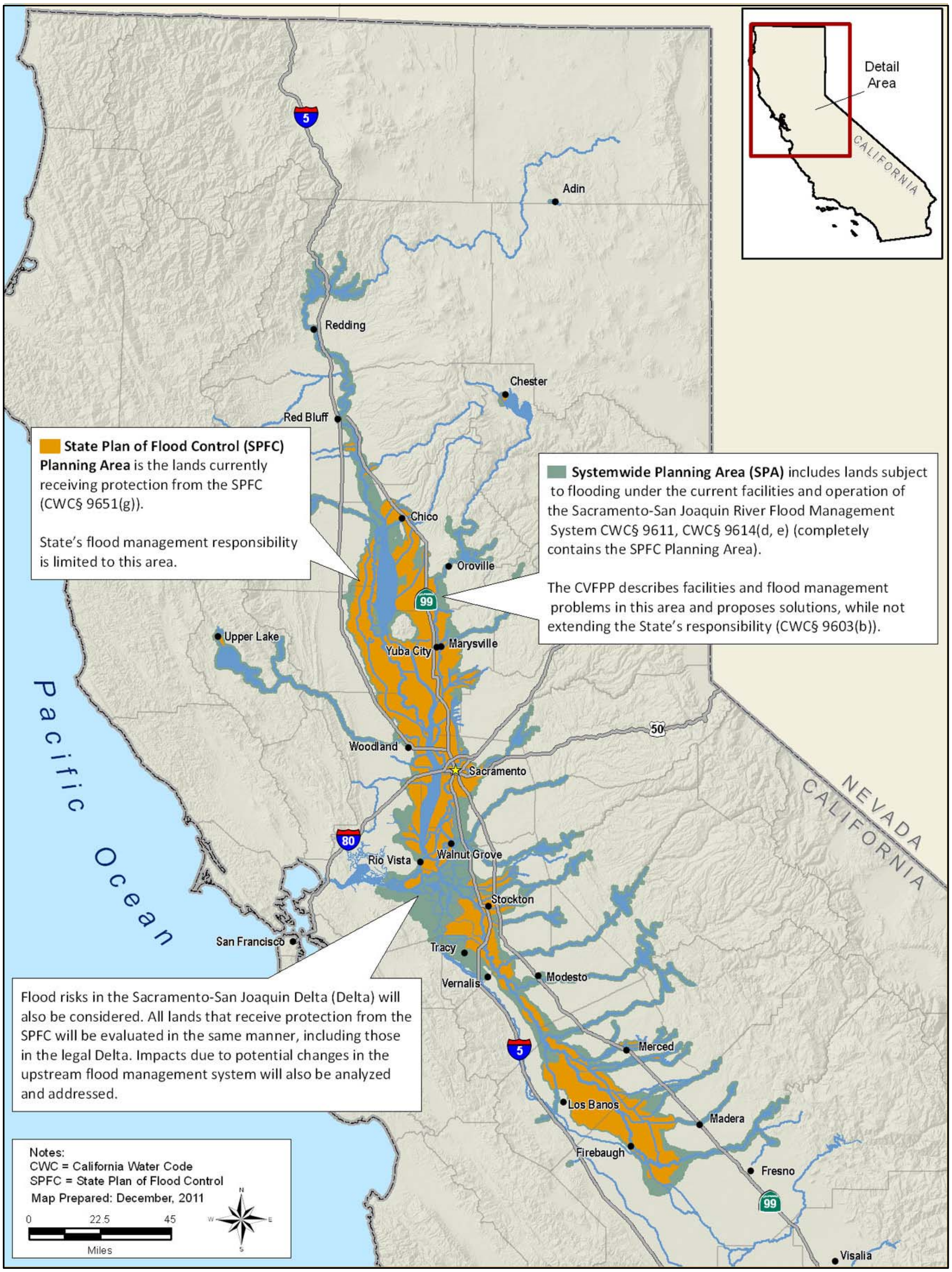


Figure 1-1. Central Valley Flood Protection Plan Planning Areas

Planning and development for the CVFPP occurs differently in these planning areas. The CVFPP focused on SPFC facilities; therefore, evaluations and analyses were conducted at a greater level of detail within the SPFC Planning Area than in the Systemwide Planning Area.

The newly developed levee performance curves are used to support geotechnical levee reliability for hydraulic models of the Sacramento and San Joaquin rivers and major tributaries contained within the SPFC Planning Area. Levee performance curves located within the Stockton Area are discussed in Attachment 8C: Riverine Channel Evaluations.

1.4 2012 CVFPP Planning Goals

To help direct CVFPP development to meet legislative requirements and address identified flood-management-related problems and opportunities, a primary and four supporting goals were developed:

- **Primary Goal –** Improve Flood Risk Management
- **Supporting Goals**:
  - Improve Operations and Maintenance
  - Promote Ecosystem Functions
  - Improve Institutional Support
  - Promote Multi-Benefit Projects

The work described in this attachment is related to the primary goal of improving flood risk management. The levee performance curves help to understand and model the way SPFC levees react to floodwaters and what improvements to the levees may be required to provide desired levels of protection.

1.5 2012 CVFPP Planning Approaches

In addition to **No Project**, three fundamentally different approaches to flood management were initially compared to explore potential improvements in the Central Valley. These approaches are not alternatives; rather, they bracket a range of potential actions and help explore tradeoffs in costs, benefits, and other factors important in decision making. The approaches are as follows:

- **Achieve SPFC Design Flow Capacity –** Address capacity inadequacies and other adverse conditions associated with existing SPFC facilities, without making major changes to the footprint or operation of those facilities.

- **Protect High Risk Communities –** Focus on protecting life safety for populations at highest risk, including urban areas and small communities.

- **Enhance Flood System Capacity –** Seek various opportunities to achieve multiple benefits through enhancing flood system storage and conveyance capacity.

Comparing these approaches helped identify the advantages and disadvantages of different combinations of management actions, and demonstrated opportunities to address the CVFPP goals to different degrees.

Based on this evaluation, a **State Systemwide Investment Approach** was developed that encompasses aspects of each of the approaches to balance achievement of the goals from a systemwide perspective, and includes integrated conservation elements. Figure 1-2 illustrates this plan formulation process.

The levee performance curves developed from the ULE and NULE data describe the No Project condition of the levees. Each of the approaches described above would require modifications or improvements to levees with levee performance curves that result in levels of protection lower than desired for a given location in the particular approach.

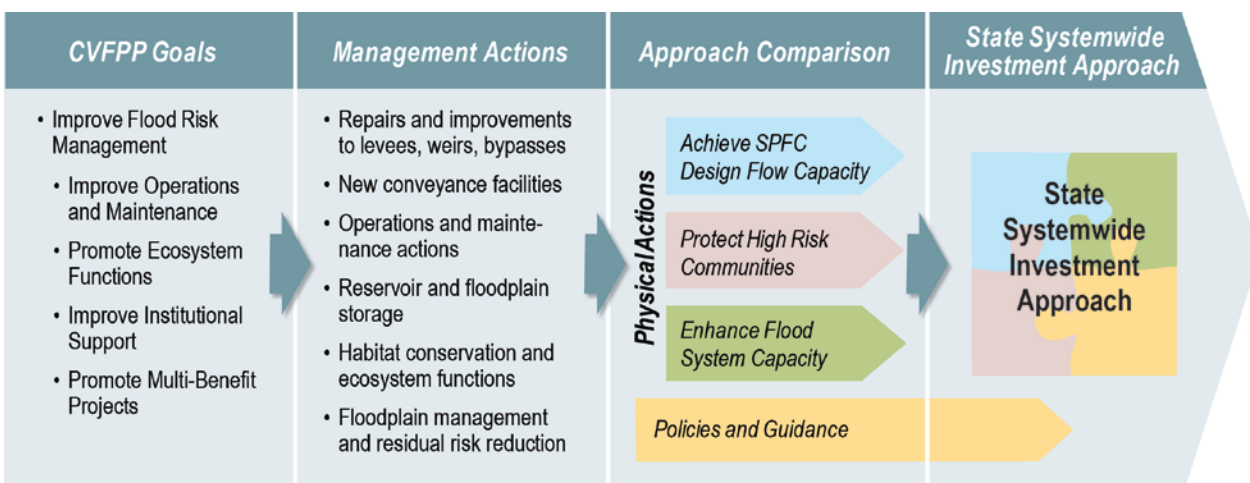


Figure 1-2. Formulation Process for State Systemwide Investment Approach

1.6 Levee Performance Curves

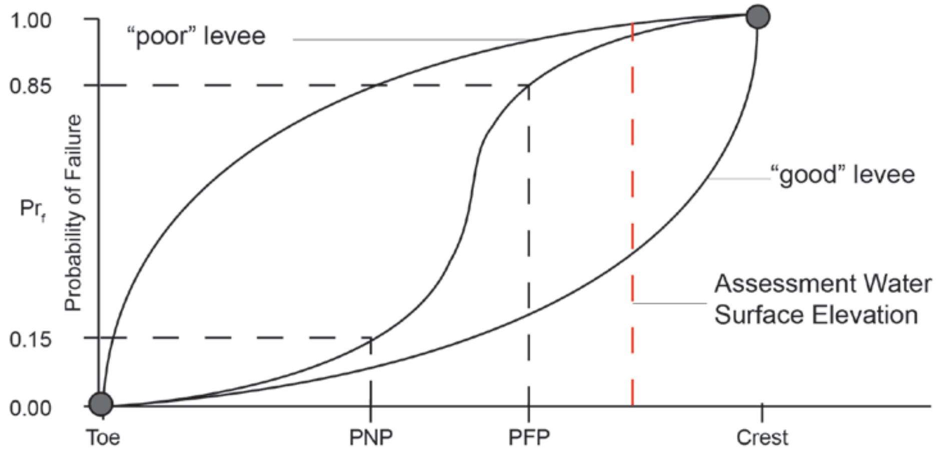
Levee performance curves developed for the CVFPP provide relationships between river water surface elevation (stage) and the probability that the levee segment will fail when exposed to that water surface elevation without human intervention (floodfighting). In this application, “failure” is defined as a levee breach in which water from the waterside of the levee is allowed to flow in an uncontrolled manner to the landside of the levee, potentially resulting in loss of life, personal injury, property damage, and economic loss. The approach used to develop levee performance curves herein generally follows a process similar to that described in the USACE Manual Engineering Technical Letter (ETL) 1110-2-556 (USACE, 1999).

Figure 1-3 provides three example levee performance curves. The probability of failure is plotted on the vertical (dependent) axis and water surface elevation is plotted on the horizontal (independent) axis. Probability of failure is shown on the vertical or dependent axis because probability of failure is a function the channel stage. The range of water surface elevations of interest begin at the landside toe of a levee, below which the probability of failure is assumed to be zero, to the levee crest, where the probability of failure is assumed to be 100 percent because of overtopping.

The three example levee performance curves shown in Figure 1-3 represent the performance of a “poor” levee, a “good” levee, and a “generic” levee. The performance for the good levee shows a low probability of failure until higher water levels are reached and is concave upward, while the performance curve for the poor levee shows a high probability of failure even at low water surface elevations, and is concave downward (convex). The performance curve for the generic levee includes elements of both the poor and the good levees and follows a characteristic levee performance curve “s” shape.

An assessment water surface elevation is also shown in Figure 1-3. The ULE Project has performed geotechnical evaluations for a number of water surface elevations (e.g., 100- and 200-year flood levels). For the NULE Project, geotechnical assessments have been completed that consider likely levee performance at only a single design or assessment water surface elevation (typically the 1955/1957 water surface profile) (Kleinfelder, 2010 and URS, 2010b). For areas that require further study, additional NULE Project work may include geotechnical evaluations as for those areas as needed.

Figure 1-3 also shows the probable non-failure point (PNP) and probable failure point (PFP), representing 15 percent and 85 percent probabilities of failure, respectively. Previous studies developing levee performance curves for Central Valley levees (e.g., Comprehensive Study, USACE, 2002) have made use of these terms, but they are not used in developing the levee performance curves for the CVFPP. The PFP, or 85 percent probability of failure, however, is used to set the levee failure elevation for use in the hydraulic models.



Key:
Crest = levee crest
PFP = probable failure point
PNP = probable nonfailure point
Toe = levee toe

Figure 1-3. Conceptual Levee Performance Curve Examples

1.7 Report Organization

Organization of this document is as follows:

- Section 1 introduces and describes the purpose of this attachment. It also provides an overview of levee performance curves.
- Section 2 provides a summary of results and findings.
- Section 3 describes the methodology used to develop the levee performance curves.
- Section 4 describes the results in more detail.
- Section 5 contains references for the sources cited in this document.
- Section 6 lists acronyms and abbreviations used in this document.

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2.0 Levee Performance Curve Locations

A total of 307 new levee performance curves were developed using ULE and NULE data and methodologies described in Section 3. Levee performance curves were grouped according their location within the SPFC Planning Area. The SPFC Planning Area is separated into different impact areas. An impact area is a unique, contiguous floodplain located along a stream or waterway. Most impact areas in the SPFC Planning Area are protected by levees. At least one levee performance curve was developed for each of the impact areas, where levees are present, in the SPFC Planning Area. Many of the impact areas have more than one levee. Tables 2-1 and 2-2 show the number of levee performance curves developed for each impact area and the methodology used (ULE/NULE), and Figures 2-1 and 2-2 map the locations of the levee performance curves for the Sacramento River Basin and San Joaquin River Basin, respectively.

Table 2-1. Levee Performance Curve Summary for Sacramento River Basin

Impact Area	Name	Number of Levee Performance Curves	Methodology
SAC01	Woodson Bridge East	0	N/A
SAC02	Woodson Bridge West	0	N/A
SAC03	Hamilton City	1	NULE[1]
SAC04	Capay	1	NULE[1]
SAC05	Butte Basin	10	NULE
SAC06	Butte City	1	NULE
SAC07	Colusa Basin North	5	NULE Anomalous[2]
SAC08	Colusa	1	NULE
SAC09	Colusa Basin South	4	NULE Anomalous[2]
SAC10	Grimes	1	NULE
SAC11	RD 1500 West	2	NULE
SAC12	Sycamore Slough	1	NULE[1]
SAC13	Knight's Landing	1	NULE[1]
SAC14	Ridge Cut (North)	3	NULE
SAC15	Ridge Cut (South)	3	NULE
SAC16	RD 2035	6	ULE
SAC17	East of Davis	3	ULE

Table 2-1 Levee Performance Curve Summary for Sacramento River Basin (contd.)

Impact Area	Name	Number of Levee Performance Curves	Methodology
SAC18	Upper Honcut	1	NULE[1]
SAC20	Gridley	1	ULE
SAC21	Sutter Buttes East	3	NULE[1]
SAC22	Live Oak	1	ULE
SAC23	Lower Honcut	2	NULE[1]
SAC24	Levee District No. 1	6	NULE
SAC25	Yuba City	2	ULE Anomalous Hazard[2]
SAC26	Marysville	3	ULE Anomalous Hazard[2]
SAC27	Linda-Olivehurst	3	NULE Anomalous Hazard[1,2]
SAC28	RD 384	2	ULE
SAC29	Best Slough	8	NULE Anomalous Hazard [2]
SAC30	RD 1001	5	NULE
SAC32	RD 70-1660	5	NULE
SAC33	Meridian	1	NULE
SAC34	RD 1500 East	1	NULE
SAC35	Elkhorn	7	NULE
SAC36	Natomas	4	NULE Anomalous Hazard[2]
SAC37	Rio Linda	1	NULE[1]
SAC38	West Sacramento	1	ULE
SAC39	RD 900	1	ULE
SAC40	Sacramento North	2	ULE
SAC41	RD 302	1	NULE
SAC42	RD 999	3	NULE
SAC43	Clarksburg	1	NULE
SAC44	Stone Lake	3	NULE Anomalous Hazard[2]
SAC45	Hood	1	NULE
SAC46	Merritt Island	2	NULE
SAC47	RD 551	2	NULE
SAC48	Courtland	1	NULE
SAC49	Sutter Island	3	NULE
SAC51	Locke	2	NULE
SAC52	Walnut Grove	1	NULE
SAC53	Tyler Island	1	NULE
SAC54	Andrus Island	8	NULE Anomalous Hazard[2]

Table 2-1 Levee Performance Curve Summary for Sacramento River Basin (contd.)

Impact Area	Name	Number of Levee Performance Curves	Methodology
SAC55	Ryer Island	5	NULE Anomalous Hazard[2]
SAC56	Prospect Island	N/A	TOL
SAC57	Twitchell Island	1	NULE
SAC58	Sherman Island	8	NULE Anomalous Hazard[2]
SAC59	Moore	6	NULE Anomalous Hazard[2]
SAC60	Cache Slough	1	NULE
SAC61	Hastings	1	NULE
SAC62	Lindsey Slough	3	NULE
SAC63	Sacramento South	1	ULE

Notes:
[1] Additional evaluations were required; initial ULE/NULE Project evaluations did not evaluate/assess levees in this impact area.
[2] A short anomalous section within the impact area had a lower levee performance curve than surrounding levees. Used data that resulted in the most conservative (highest hazard) levee performance curve.
Key:
N/A = not applicable – no levee
No. = number
NULE = Non-Urban Levee Evaluations
RD = Reclamation District
TOL = top of levee
ULE = Urban Levee Evaluations

Table 2-2. Levee Performance Curve Summary for San Joaquin River Basin

Impact Area	Name	Number of Levee Performance Curves	Methodology
SJ01	Fresno	0	N/A
SJ02	Fresno Slough East	3	NULE
SJ03	Fresno Slough West	1	NULE[1]
SJ04	Mendota	1	NULE[1]
SJ05	Chowchilla Bypass	2	NULE
SJ06	Lone Willow Slough	6	NULE
SJ07	Mendota North	1	NULE
SJ08	Firebaugh	1	NULE[1]
SJ09	Salt Slough	3	NULE
SJ10	Dos Palos	Used SJ09[3]	NULE
SJ11	Fresno River	5	NULE
SJ12	Berenda Slough	6	NULE
SJ13	Ash Slough	2	NULE
SJ14	Sandy Mush	6	NULE

Table 2-2. Levee Performance Curve Summary for San Joaquin River Basin (contd.)

Impact Area	Name	Number of Levee Performance Curves	Methodology
SJ15	Turner Island	3	NULE
SJ16	Bear Creek	2	NULE
SJ17	Deep Slough	4	NULE
SJ18	West Bear Creek	2	NULE
SJ19	Fremont Ford	1	NULE
SJ20	Merced River	0	N/A
SJ21	Merced River North	3	NULE Anomalous Hazard[2]
SJ22	Orestimba	2	NULE Anomalous Hazard[2]
SJ23	Tuolumne South	2	NULE
SJ24	Tuolumne River	1	NULE
SJ25	Modesto	0	N/A
SJ26	3 Amigos	3	NULE
SJ27	Stanislaus South	2	NULE
SJ28	Stanislaus North	4	NULE
SJ29	Banta Carbona	4	NULE
SJ30	Paradise Cut	1	NULE
SJ31	Stewart Tract	6	NULE Anomalous Hazard[2]
SJ32	East Lathrop	1	NULE[1]
SJ33	Lathrop/ Sharpe	1	NULE[1]
SJ34	French Camp	1	NULE[1]
SJ35	Moss Tract	1	NULE[1]
SJ36	Roberts Island	5	NULE
SJ37	Rough and Ready Island	1	ULE
SJ38	Drexler Tract	2	NULE[1]
SJ39	Union Island	1	NULE
SJ40	Southeast Union Island	3	NULE
SJ41	Fabian Tract	1	NULE
SJ42	RD 1007	1	NULE[1]
SJ43	Grayson	1	NULE

Notes:
[1] Additional evaluations were required; initial ULE/NULE Project evaluations did not evaluate/assess levees in this impact area.
[2] A short anomalous section within the impact area had a lower levee performance curve than surrounding levees. Used data that resulted in the most conservative (highest hazard) levee performance curve.
[3] SJ10 is part of SJ09; therefore, SJ10 used the same levee performance curve as SJ09.

Key:
N/A = not applicable – no levee
NULE = Non-Urban Levee Evaluation
RD = Reclamation District
ULE = Urban Levee Evaluations

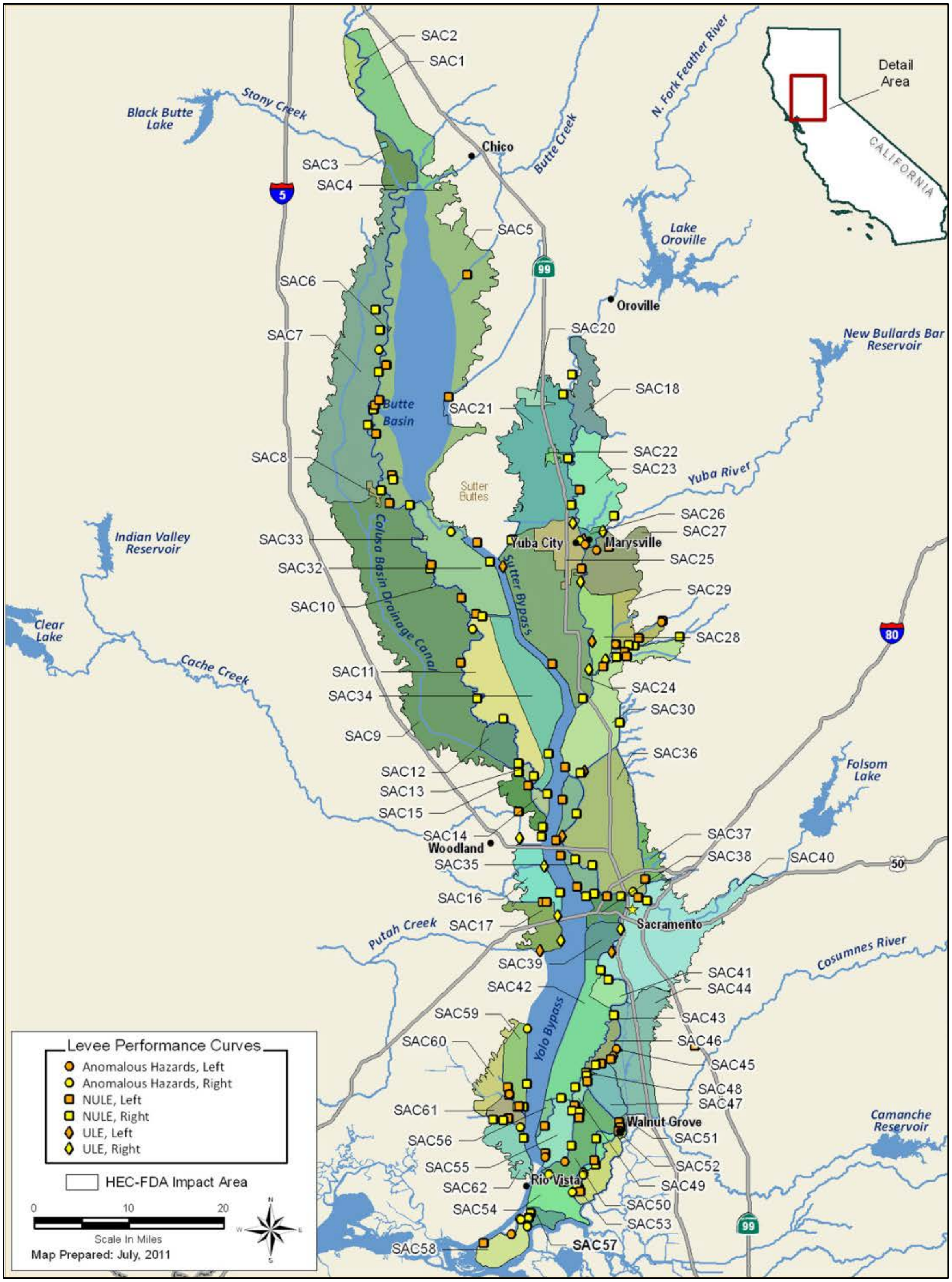


Figure 2-1. Levee Performance Curve Locations, Sacramento River Basin

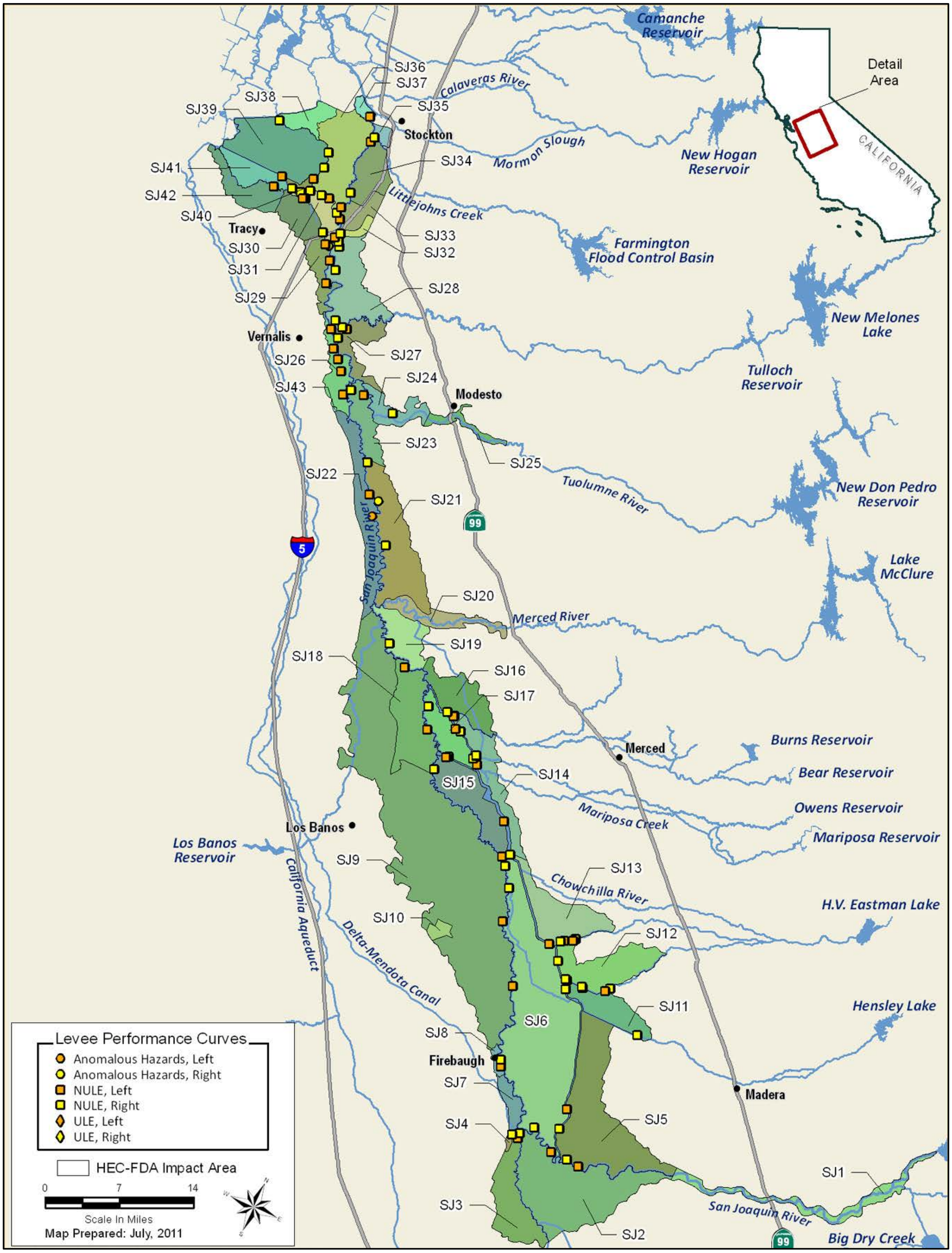


Figure 2-2. Levee Performance Curve Locations, San Joaquin River Basin

3.0 Methodology

This section describes the methodology used to develop levee performance curves, a description of the sources of the data, and a detailed description of the process for developing levee performance curves for both ULE and NULE Project segments.

Note that the detailed description of the process for developing levee performance curves is first described for NULE Project segments. This is because some of the data developed for the NULE levee performance curves were used in the ULE assessment, as additional ULE work has yet to be completed.

3.1 Developing Levee Performance Curve Methodology Overview

The methodology used to develop levee performance curves included review of the data, formulation of a levee expert panel, and a sensitivity analysis.

3.1.1 Data Review

To begin the task of developing levee performance curves, two levee evaluation teams, one in the north study area and one in the south study area, were formed. These teams reviewed the data collected and conclusions drawn during preparation of the NULE Geotechnical Assessment Report (GAR), and the hazard maps developed to support the ULE study areas in the *Flood Control System Status Report* (FCSSR) (DWR, 2011) (URS, 2010a). Each team compiled and summarized key performance events relevant to preparation of levee performance curves, such as information related to historical levee failures and estimates of the water surface elevation during these events, using readily available records.

Based on review and compilation of this information, a standard set of levee performance curves was developed for application to ULE and NULE levee segments. The approach used to develop levee performance curves generally follows a process similar to that described in *USACE Manual ETL 1110-2-556* (USACE, 1999).

3.1.2 Levee Expert Panel

A levee Expert Panel was formed to provide technical expertise, advice, and review (Table 3-1). This panel met multiple times, from fall 2010 through spring 2011, during the development of the levee performance curve methodology. The comments and suggestions of the levee Expert Panel were incorporated in the development of two separate levee performance curve tools (Excel workbooks), one for ULE levees and one for NULE levees. These tools incorporated and made use of data generated during earlier ULE and NULE work, and provided the user options for generating levee performance curves.

Table 3-1. Levee Expert Panel

Name	Organization
David Ford (facilitator)	David Ford Consulting Engineers
Ray Costa	Consultant to DWR
Mike Inamine	DWR
Steve Verigen	GEI
Les Harder	HDR
Scott Anderson	Kleinfelder
Pat Dell	Neil O. Anderson and Associates
Ram Kulkarni	URS Corporation
Michael Ramsbotham	USACE
Ed Ketchum	USACE

Key:
DWR = California Department of Water Resources
USACE = U.S. Army Corps of Engineers

3.1.3 Sensitivity Analysis

A sensitivity analysis was performed to evaluate the effect on estimated damage from varying parameters in the levee performance curve tool. Additionally, preliminary hydraulic modeling was conducted using a complete set of preliminary levee performance curves to evaluate (1) how these draft levee performance curves worked in the context of the existing hydraulic model, and (2) the number of levee failures predicted using the model and preliminary levee performance curves. These results were used to assess how well the results from the models approximated general historical flood conditions. Refinement of the preliminary ULE and NULE levee performance curve tools followed the sensitivity analysis and preliminary hydraulic modeling.

3.2 Sources of Levee Performance Data

The ULE Project has subdivided levees into reaches that are typically on the order of thousands of feet long. The NULE Project has assessed individual levee segments, which are generally two to five miles long, but were as long as 25 miles at some locations. Results of the ULE and NULE projects are summarized in the FCSSR (DWR, 2011).

3.2.1 Urban Levee Evaluations Project

The ULE Project evaluated 470 miles of levees. Based on an initial phase of field explorations, laboratory testing, and subsequent geotechnical analysis, levees in each urban study area were subdivided into reaches, typically 1,000 feet to 3,000 feet long. For the ULE study areas, the ULE teams reviewed data and analysis results from the ULE Technical Review Memoranda (URS, 2007-2010); Phase 1 Geotechnical Data Reports (URS, 2008-2009); Phase 1 Geotechnical Evaluation Reports (URS, 2008); and where already prepared, Supplemental Geotechnical Data Reports (URS, 2010c). Each team compiled and summarized key performance events relevant to preparation of levee performance curves, such as information related to historical levee failures and estimates of the water surface elevation during these events, using readily available records.

3.2.2 Non-Urban Levee Evaluations Project

During the geotechnical assessment for the NULE Project, existing data were assessed to assign hazard categories to 1,620 mile of levees and results were provided in the GARs (URS, 2010b; Kleinfelder, 2010), as follows:

- **Low (A) –** When water reaches the assessment water surface elevation, there is a low likelihood of either levee failure or the need to floodfight to prevent levee failure.

- **Moderate (B) –** When water reaches the assessment water surface elevation, there is a moderate likelihood of either levee failure or the need to floodfight to prevent levee failure.

- **High (C) –** When water reaches the assessment water surface elevation, there is a high likelihood of either levee failure or the need to floodfight to prevent levee failure.

- **Lacking Sufficient Data (LD) –** Currently lacking sufficient data regarding past performance or hazard indicators.

Floodfight refers to actions taken to prevent geotechnical levee failure, not actions to prevent overtopping.

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

The categorization was done for each of four failure modes: under-seepage, stability, through-seepage, and erosion.

3.3 Levee Performance Curves for NULE Levee Segments

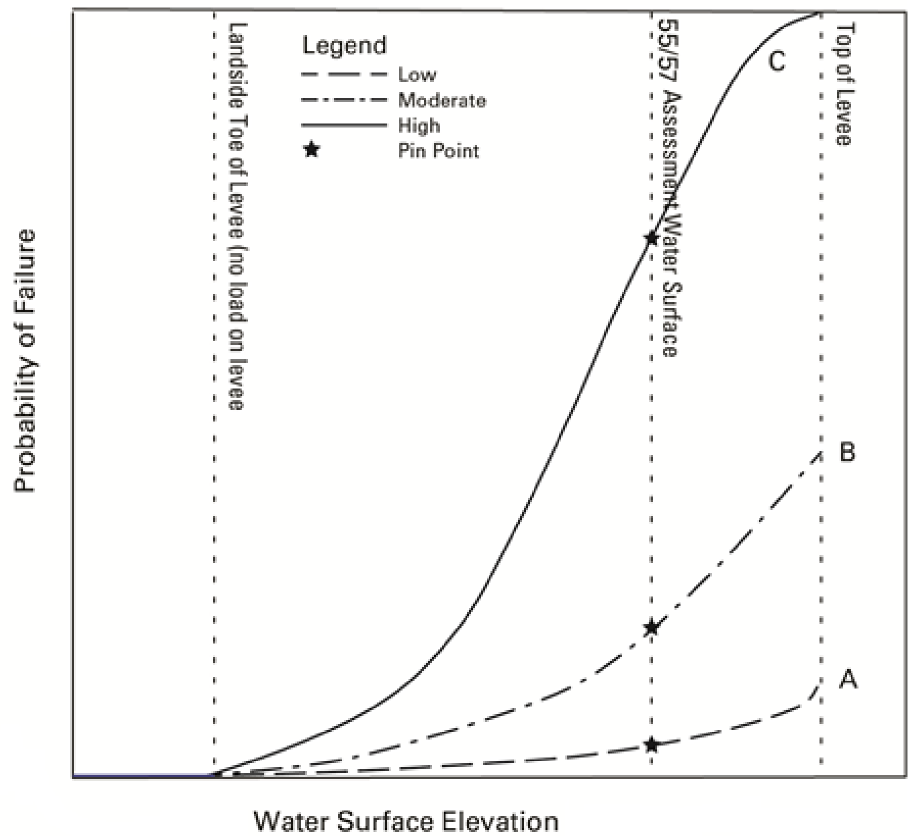
During the geotechnical assessment for the NULE Project, existing data were collected and used to categorize the levees. As described above, each levee segment was categorized as Low (A), Moderate (B), High (C), or Lacking Sufficient Data (LD), and the levee was cumulatively categorized as a whole. The categorization was done for each of four failure modes: under-seepage, stability, through-seepage, and erosion. It is important to note that the categorization was performed for only one water level, the assessment water surface elevation, which, where available, was the 1955/1957 water surface. All NULE categorizations and results are, therefore, for the single assessment water surface elevation. To produce levee performance curves for each NULE segment, levee performance curves were developed for each failure mode. These independent failure mode levee performance curves were then mathematically combined to produce the cumulative or overall levee performance curve for the segment or reach. Thus, two levees with similar failure mode categorizations and similar topographic profiles had very similar levee performance curves.

Topographic information necessary for levee performance curve development included levee crest elevation, levee toe elevation, and assessment water surface elevation. Topographic data used for developing levee performance curves were based on two sources: levee center line survey data obtained from the California Levee Database (CLD), and project-specific light detection and ranging (LiDAR) surveys.

Few additional data were used to generate the NULE levee performance curves; however, abundant data on past performance and past floodwater levels collected during the geotechnical assessment were used to calibrate and review the parameters selected in developing the levee performance curves.

To make use of the failure mode categorizations assigned in NULE to each segment, it was necessary to assign a probability of failure at the assessment water surface elevation for the Low (A), Moderate (B), and High (C) categories. These probability of failure values were not explicitly included in the NULE GAR (URS, 2010b), and part of the efforts expended in this task involved discussions and sensitivity analyses to constrain the values used for each category. Based on review of the sensitivity analysis and input from the levee Expert Panel, the values for each category, at the assessment water surface elevation, were Low (A), 0.5 percent; Moderate (B), 2 percent; and High (C), 16 percent. These points, which define the levee performance curve at the assessment water surface elevation, are called the "pin points." Figure 3-1 shows an example of three schematic levee performance curves for each hazard category (Low (A), Moderate (B) and High (C) curves) for a single failure mode. The pin points are where each curve intersects the assessment water surface elevation and represents the probability of failure at the assessment water surface elevation for each category. It is important to note that the values used here for the pin-point probabilities are for the purposes of this levee performance curve effort; they should not be retroactively imposed on the NULE GAR.

Thus, for NULE levee performance curves, three water surface elevations were used to define the levee performance curves: (1) the levee toe elevation, at which the probability of failure is assumed to be zero, (2) the levee crest elevation, at which overtopping would occur and the probability of failure is set to 100 percent, and (3) the pin-point at the assessment water surface elevation (Figure 3-1). The NULE levee performance curve Excel tool fitted a simple curve through these three points for each failure mode using the assigned probability of failure at the assessment water surface elevation. Below the assessment water surface elevation, the curve was fitted using a "concavity factor" that ranges between zero and 1, with zero yielding a curve of constant slope of no concavity, and 1 yielding a curve that is concave upward and very steep at the assessment water surface elevation. For this analysis, a concavity factor of 0.5 was used for all levee performance curves based on the results of the sensitivity analyses. The levee performance curves are extended above the assessment water surface elevation based on their slope as they approach the assessment water level. Low (A) and Moderate (B) curves extend at constant slope (although the example in Figure 3-1 shows a curving line), and High (C) curves roughly mirror the shape of the curve below the assessment water surface elevation. The same probability values are used for every Low (A), Moderate (B), or High (C) pin-point (e.g., all Moderate (B) levee performance curves were assigned a probability of failure of 2 percent at the assessment water surface elevation, independent of the failure mode, the size of the levee, or other differences in levees). For levee segments categorized LD, pin-point values between those of Low (A) and Moderate (B), or Moderate (B) and High (C) were used, depending on the nature of the LD categorization (e.g., LD (Low (A) or Moderate(B)) vs. LD (Moderate(B) or High(C))).



Note: Values in figure are not to scale

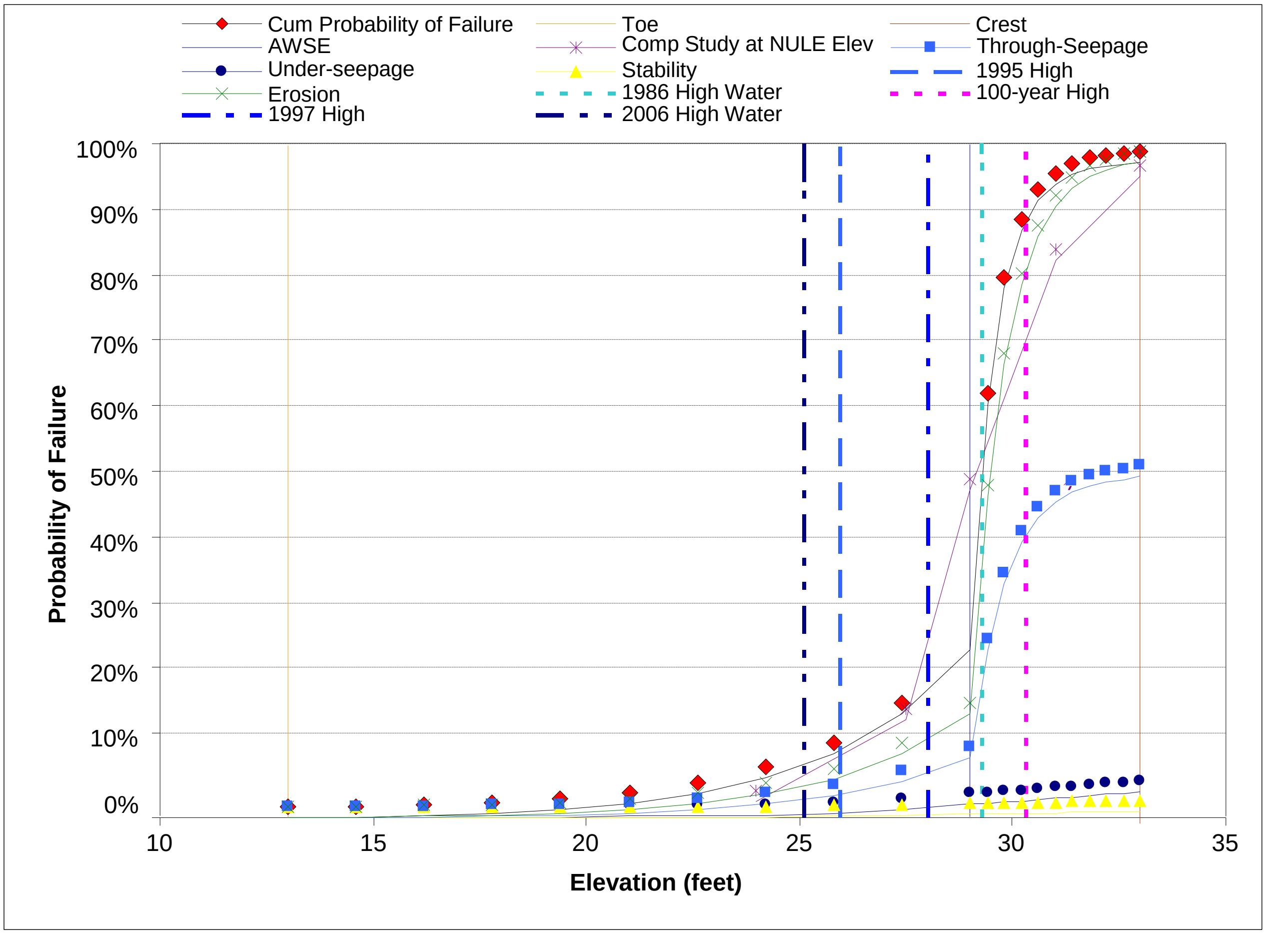
Figure 3-1. Conceptual NULE Levee Performance Curves for Hazard Categories Low (A), Moderate (B), and High (C)

Past flood information (water surface elevation and record of performance) can be used to calibrate or validate levee performance curves for individual segments. Basin-wide compilations of past performance were used as guidance in constraining the chosen pin-point probability values. The four individual failure mode levee performance curves were mathematically combined using the conventional probabilistic summing expression:

$$Cumulative\ Pf = 1 - (1 - Pf(underseepage)) * (1 - Pf(stability)) * (1 - Pf(through\ seepage)) * (1 - Pf(erosion))$$

Figure 3-2 shows an example of output generated by the NULE levee performance curve Excel tool. Individual failure modes for this example levee segment were categorized as Moderate (B) for under-seepage; Low (A) for stability; LD (Moderate (B) or High (C)) for through-seepage; and High (C) for erosion in the GAR. The example levee's landside toe is at elevation 13 feet, the crest is at elevation 33 feet, and the assessment water surface was at elevation 29 feet, or 4 feet below the levee crest. The dark blue line with circles shows the levee performance curve for under-seepage, the yellow line is stability, the light blue line with squares is through-seepage, and the green line is erosion. The black line shows the combined or cumulative levee performance curve when the failure mode levee performance curves are summed using the expression above. Also shown are vertical lines depicting the assessment water surface elevation and water surface elevations for a number of historical high-water events. The magenta lines show the levee performance curves used in the Comprehensive Study (USACE, 2002). The solid line shows the Comprehensive Study curve at the levee crest elevation used in the NULE Program, which was estimated based on LiDAR and CLD information. The dashed magenta curve shows the Comprehensive Study curve tied to the elevation used in the Comprehensive Study.

When levee locations were identified where elevations used in the Comprehensive Study hydraulic models were different from the top-of-levee elevations used in the ULE and NULE projects, which are based on more recent and better constrained topographic data, the ULE and NULE elevations were used.



Note: These curves represent a levee segment with the following hazard categories from the GAR: Moderate (B) for under-seepage, Low (A) for stability, LD (Moderate (B) or High (C)) for through-seepage, and High (C) for erosion.
Key:
AWSE = assessment water surface elevation
Cum = cumulative
Elev = elevation
NULE = Non-Urban Levee Evaluations

Figure 3-2. Example NULE Levee Performance Curve

Note that the levee performance curves for the failure modes categorized A (stability) and B (under-seepage) extend above the assessment water surface to the elevation of the levee crest at nearly a constant slope. This means that this example levee is not expected to fail because of either of these failure modes, even when the water surface reaches the levee crest. The failure mode levee performance curves for through-seepage and erosion have the more classic “s”-shaped curves, as does the combined or cumulative levee performance curve. This example levee performance curve shows that there is little probability of the levee failing at low water levels, and that the cumulative probability of failure at the assessment water surface elevation is about 25 percent.

3.4 Levee Performance Curves for ULE Levee Segments

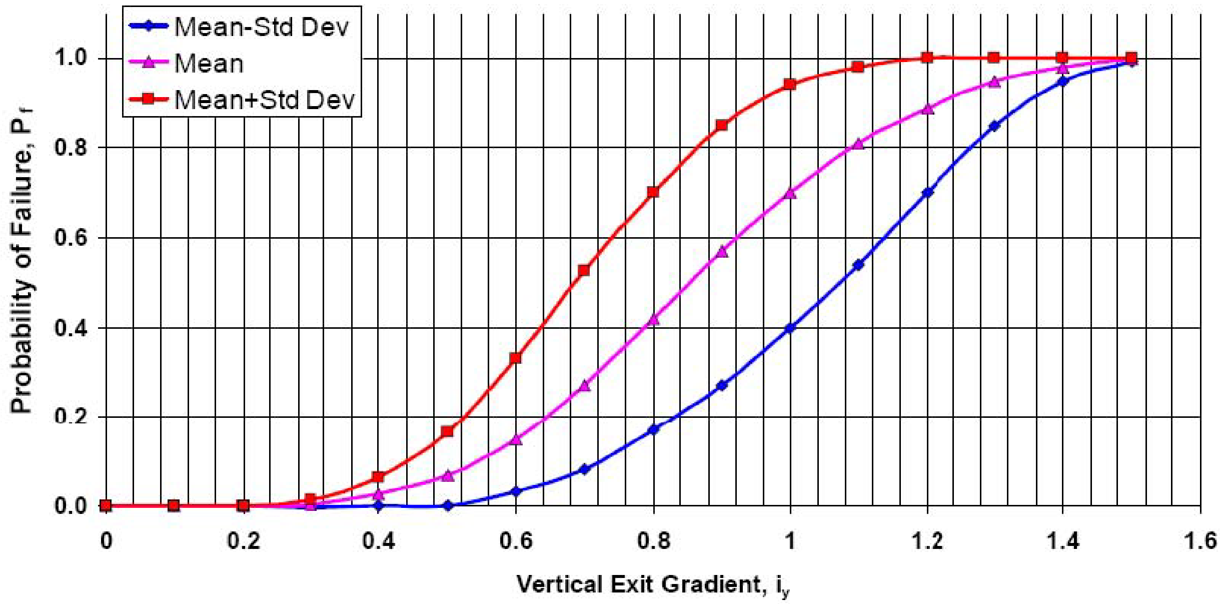
To support the 2012 CVFPP modeling, representative reaches and corresponding cross sections within individual urban study areas were selected for development of levee performance curves. A cumulative ULE levee performance curve for each of these selected cross sections was prepared based on the individual curves for the same four failure modes: assessed in the NULE program (under-seepage, stability, through-seepage, and erosion).

For steady-state under-seepage and steady-state stability, historical data and field and laboratory geotechnical data collected in the initial phase of the ULE Project were used as input to calculate average vertical exit gradients (i) and stability factors of safety (FS) for various flood elevations for each respective cross-section location.

To establish the relationships between i and probability of failure (P_f) and between stability FS and P_f, input from the levee Expert Panel and program-specific information were used to generate classic "s"-shaped curves (see Figure 3-3) (note that Figure 3-3 is a generic example). For this study, the following control points were used to develop the applicable "s" curves:

- Under-seepage i=0.5, P_f =1 percent and i=0.9, P_f =50 percent
- Stability FS=1.4, P_f =1 percent and FS=1.0, P_f =50 percent

Using these relationships for under-seepage and stability, and correlating them to specific results at various river water surface elevations, levee performance curves for under-seepage and stability were then developed using the same concavity factor (0.5) used in development of the NULE levee performance curves. Figures 3-4 and 3-5 show examples of ULE levee performance curves for the under-seepage and stability failure modes.



Source: DWR, 2007

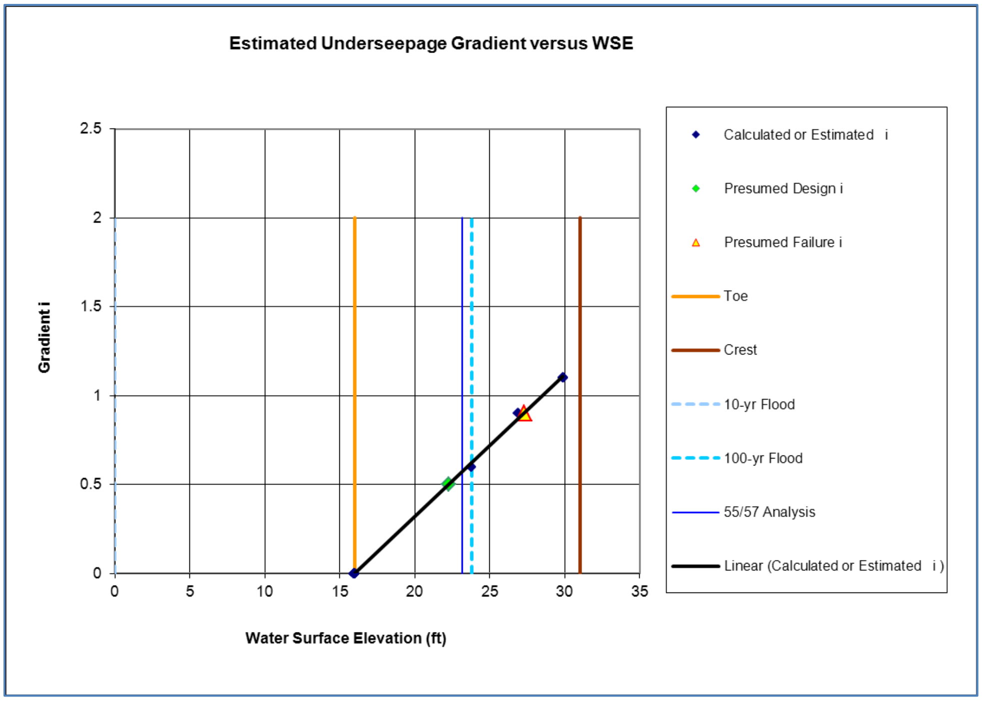
Figure 3-3. Relationship Between Vertical Exit Gradient and Probability of Failure

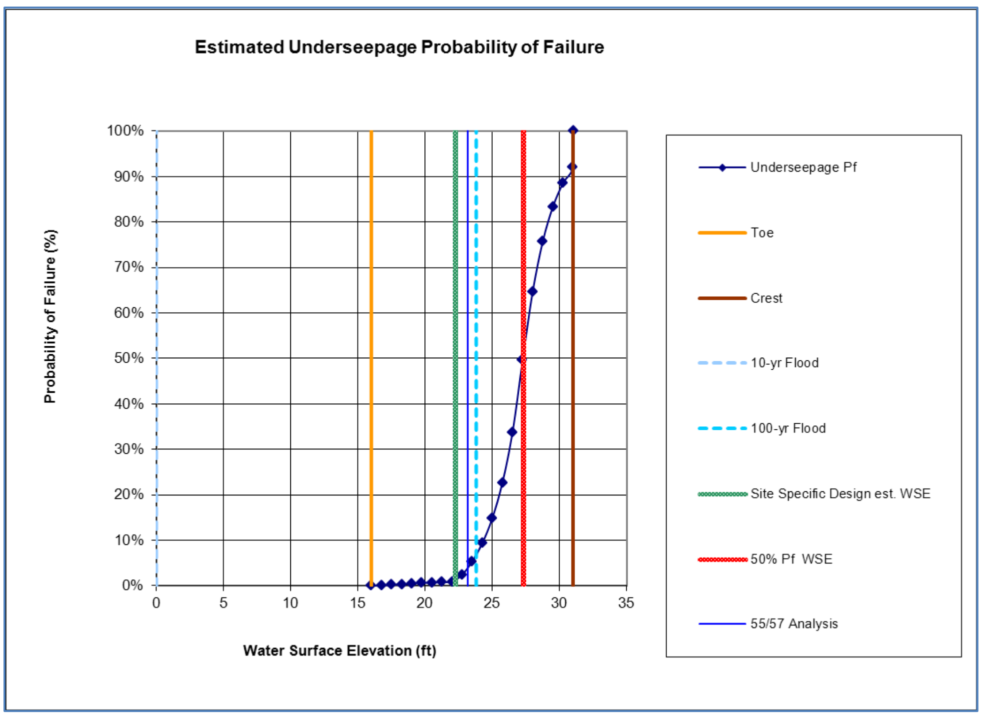
To develop ULE levee performance curves for through seepage, a failure model was developed for landside levee slopes that are composed of erodible materials, typically silts and sands. If these soils are present, then a failure assessment based on the height of seepage "breakout" above the landside toe of the levee was used. The height of seepage breakout above the landside toe was identified from the seepage analyses, which therefore relates the height of seepage breakout to the water surface elevation (flood elevation). The levee performance curve model relates the probability of failure to the height of seepage breakout where erodible materials are present – the higher the breakout, the higher the probability of failure. Figure 3-6 shows the relationship used relating breakout probability of failure versus flood elevation.

For the erosion failure mode, because a formal erosion analysis is not yet available (this work is planned for the final ULE Geotechnical Evaluation Reports), a more qualitative assessment was performed resulting in an erosion A, B, or C classification for each ULE reach for which a levee performance curve was developed. The erosion levee performance curve developed in NULE described in Section 3.3 was then used in the ULE assessment.

The final step was to mathematically combine (using Equation 1) the four failure modes into one cumulative levee performance curve for each selected cross section. Figure 3-7 provides an example cumulative ULE levee performance curve.

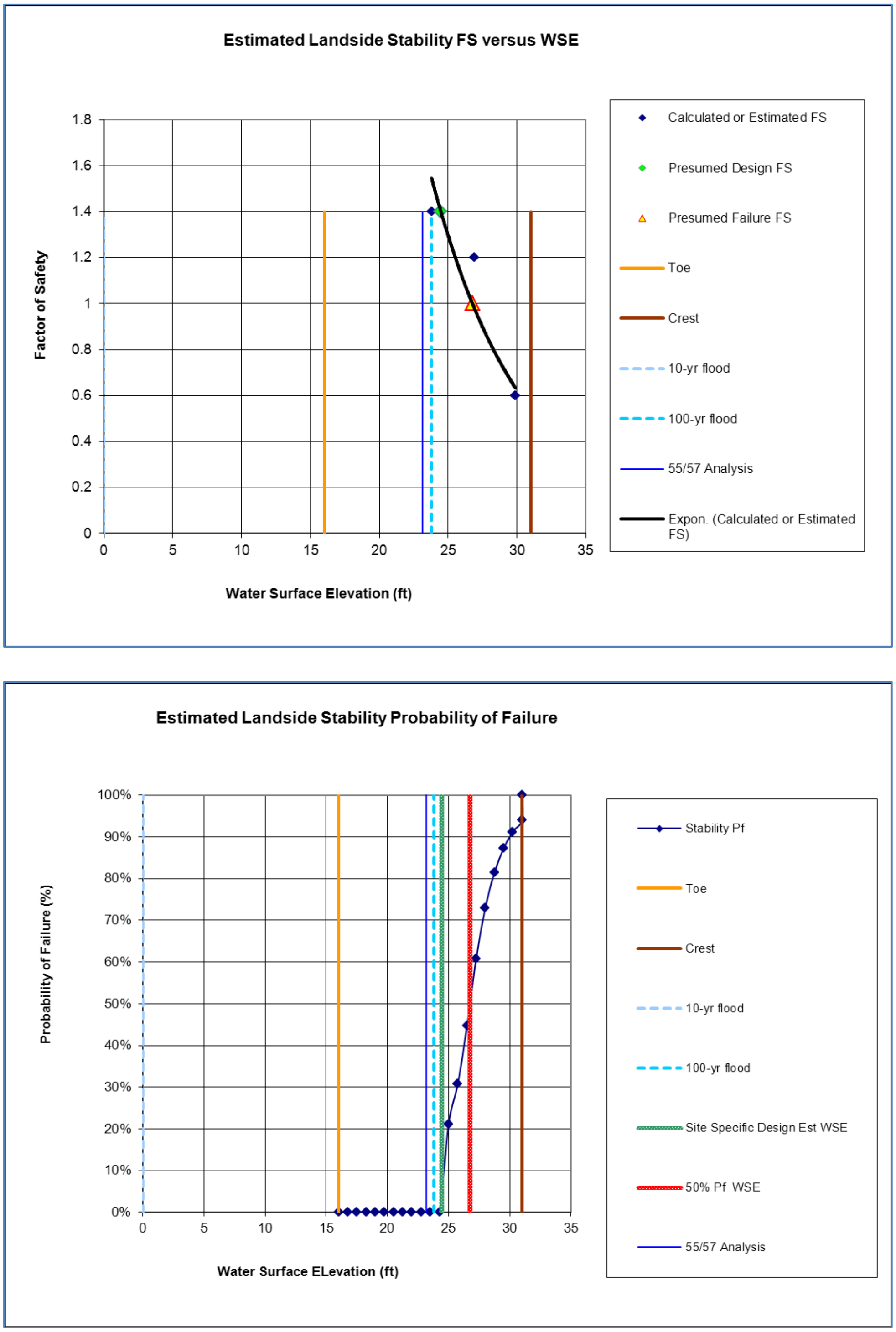
An informal review of ULE levee performance curves was provided by some ULE team Task Managers who were responsible for the ULE study area in question where each cross section is located.





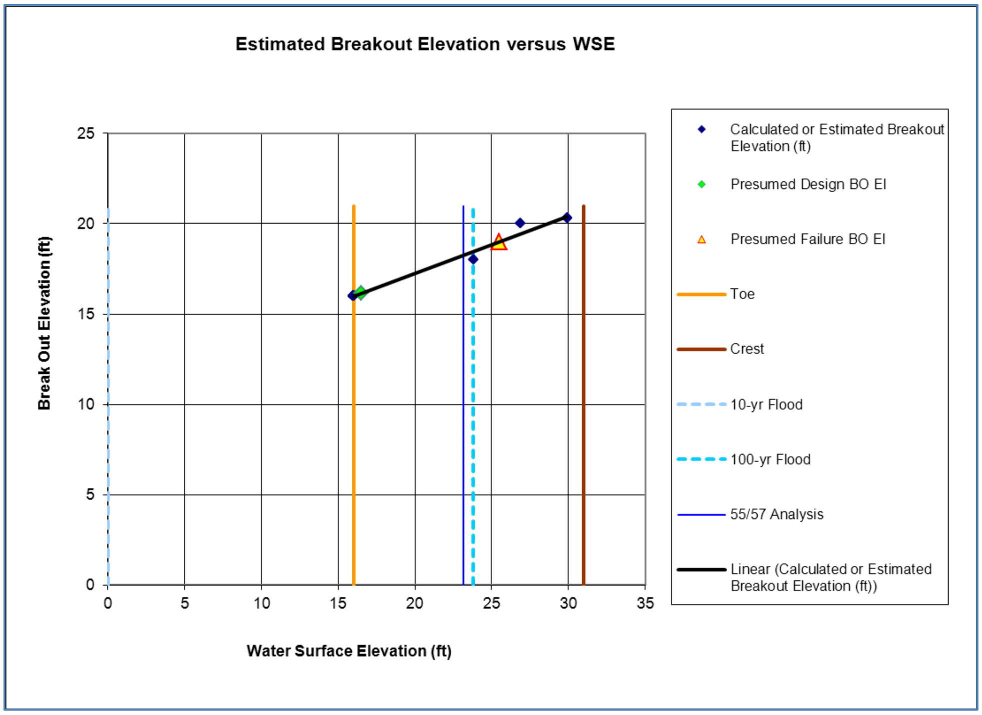
Key:
55/57 = 55/57 assessment water surface elevation
ft = feet
i = vertical exit gradient
P_f = probability of failure
WSE = water surface elevation
yr = year

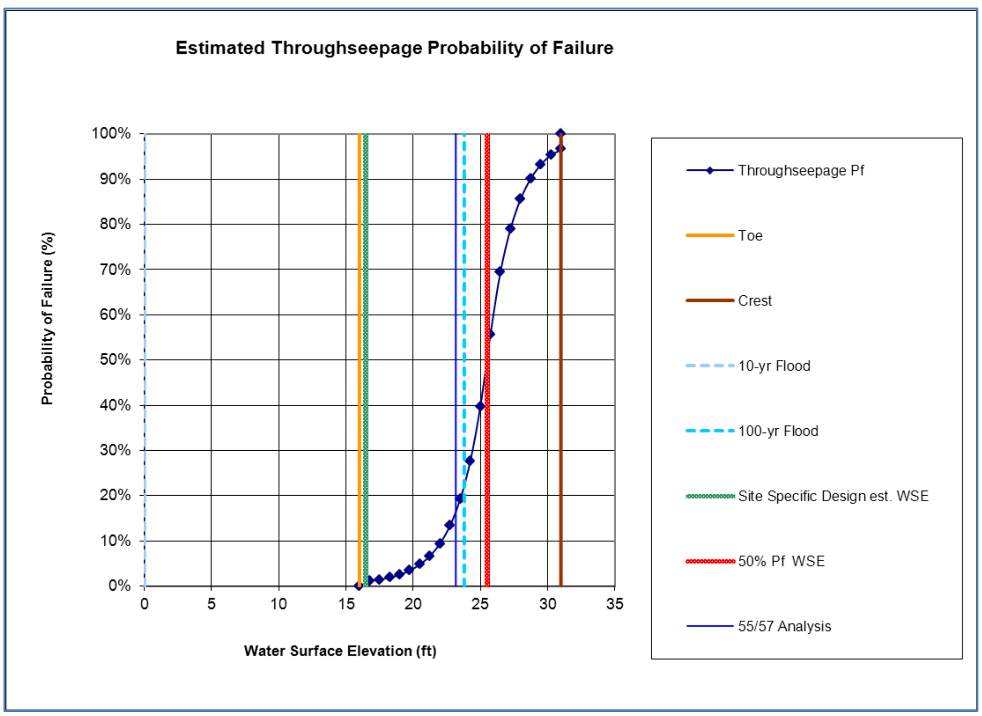
Figure 3-4. Example ULE Under-Seepage Levee Performance Curves



Key:
55/57 = 55/57 assessment water surface elevation
FS = factor of safety
ft = feet
i = vertical exit gradient
P_f = probability of failure
WSE = water surface elevation
yr = year

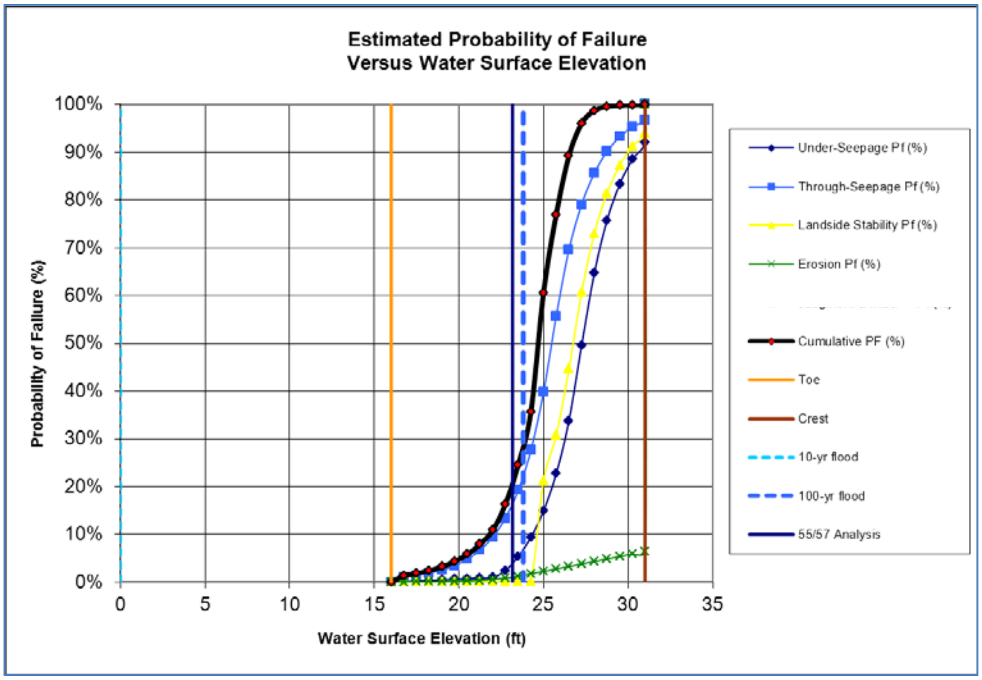
Figure 3-5. Example ULE Stability Levee Performance Curves





Key:
55/57 = 55/57 assessment water surface elevation
BO = breakout
El = failure elevation
ft = feet
i = vertical exit gradient
P_f = probability of failure
WSE = water surface elevation
yr = year

Figure 3-6. Example ULE Through-Seepage Levee Performance Curves



Key:
55/57 = 55/57 assessment water surface elevation
ft = feet
P_f = probability of failure
yr = year

Figure 3-7. Example ULE Levee Performance Curves (with failure mode and combined curves)

3.5 Anomalous Hazards

Levee performance curves for anomalous hazards were also developed. Anomalous hazards were identified in the preliminary ULE analysis and NULE GAR as isolated locations distinct from the overall levee segment for which the following apply:

- Geotechnical conditions are different from the remainder of the segment (reach).
- The current scope of levee assessment approaches used in ULE and NULE Phase 1 do not lend themselves to further detailed analyses of the hazard at these sites (e.g., analyses of structures, penetrations, encroachments).
- In many cases, the anomalous conditions are associated with observations of past poor performance.
- Available information in the area with anomalous conditions suggests that the levee may be susceptible to failing in one of the four failure

modes assessed in NULE Phase 1 (under-seepage, instability, through-seepage, or erosion).

Anomalous hazards are not related to the potential for overtopping (e.g., low spots in a levee crown at a bridge or ramp) as overtopping is not included as a failure mode in ULE and NULE.

As mentioned, additional levee performance curves were developed for anomalous hazard locations identified by the ULE teams and in the NULE GAR. Groups of anomalous hazards and suggested modifications to parent segment category ratings for NULE are listed in Table 3-2. Anomalous conditions for ULE generally followed the methods described in Section 3.4 above.

In some cases, the anomalous hazard rating and parent segment category rating are identical. The anomalous hazard will still impact the hydraulic and damage models by adding an additional potential breakout location within the segment.

Table 3-2. Anomalous Hazard Groups and Suggested Modifications to Parent Segment Category Ratings

Anomalous Hazard Group	Suggested Modifications to Rating
Erosion coincident with constructed features	Increase erosion rating to C
Poor past performance coincident with a penetration (usually through-seepage)	Increase through-seepage rating to C
Large siphon	Increase under-seepage rating to C
Site of past breach that has been repaired and has had either (1) poor performance since repair, or (2) an adjacent landside hole (e.g., scour pool, which shortens flow path)	Increase under-seepage and through-seepage ratings to C
Soft foundations resulting from buried sloughs or the like, with associated indicators of stability problems	Increase stability rating to C
Landside holes (adjacent or near to levee) associated with boils or other poor performance	Increase under-seepage rating to C
Permanent unrepaired breach	Use new topography and assign all failure modes a category of C
Significant encroachment/transition in levee geometry	Increase impacted failure mode to C
Documented geotechnical conditions at specific anomalous hazard locations	Increase other failure mode ratings

Note:
C = When water reaches assessment water surface elevation, there is a high likelihood of either levee failure or the need to floodfight to prevent levee failure.

3.6 Capabilities of HEC-FDA

The risk analysis capabilities provided by the USACE Hydrologic Engineering Center Flood Damage Assessment (HEC-FDA) program are used in the CVFPP, and as described in Attachment 8F: Flood Damage Analysis. Because the levee performance curves are important input data for the HEC-FDA model, this section briefly describes the capabilities and uses of HEC-FDA.

The HEC-FDA program can be used to perform an integrated hydrologic engineering, risk, and economic analysis during formulation and evaluation of flood risk management plans.

The use of risk analysis procedures for formulating and evaluating flood damage reduction measures is described in USACE Engineer Manual 1110-2-1619 (1996) and Engineer Regulation 1105-2-101 (2006). These documents describe how to quantify uncertainty in discharge-exceedence probability, stage-discharge relationships, and stage-damage functions and incorporate uncertainty into economic and engineering performance analyses. The program applies Monte Carlo simulation, a numerical analysis procedure that computes the expected value of damage while explicitly accounting for uncertainty in the basic parameters used to determine flood inundation damage. One of those basic parameters is the levee performance curve.

HEC-FDA assists in formulating and evaluating flood risk management plans using these procedures to calculate damage-stage-uncertainty information at damage reach index locations. Expected annual damage and flood risk are computed in the evaluation portion of the program.

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4.0 Results

This section presents the levee performance curves and describes the limitations in using these curves.

4.1 Summary

This section presents the levee performance curves developed using the techniques described above for use in systemwide SPFC hydraulic (UNET) and economic damage (HEC-FDA) modeling and for preparing the 2012 CVFPP. Table 4-1 contains only the levee performance curves at the HEC-FDA index points for the Sacramento River Basin and Table 4-2 contains only the levee performance curves at the HEC-FDA index points for the San Joaquin River Basin.

The ULE Excel tool for developing levee performance curves should only be used on a reach-by-reach basis. The NULE Excel tool allows the user to modify certain parameters and rapidly generate a new set of levee performance curves for all NULE segments.

Table 4-1. Sacramento River Basin Levee Performance Curves

ID		SAC1	SAC2	SAC3		SAC4		SAC5		SAC6	
Name		Woodson Bridge East	Woodson Bridge West	Hamilton City		Capay		Butte Basin		Butte City	
Toe Elevation[3]		1	1	145.5		135.4		52.6		52.6	
AWSE				151.0		142.1		66.1		66.1	
Crest Elevation[3]				154.0		145.1		69.1		69.1	
Type of Project (ULE or NULE)				NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	2	2	145.47	0	135.38	0	52.59	0	52.59	0
				146.02	0	136.05	0	53.94	0	53.94	0
				146.57	0	136.72	0	55.29	0	55.29	0
				147.12	1	137.38	1	56.64	1	56.64	1
				147.67	1	138.05	1	57.99	1	57.99	1
				148.22	2	138.72	2	59.34	2	59.34	2
				148.77	4	139.39	4	60.69	3	60.69	3
				149.32	6	140.06	6	62.04	6	62.04	6
				149.87	10	140.72	10	63.39	9	63.39	9
				150.42	16	141.39	16	64.74	15	64.74	15
				150.97	25	142.06	25	66.09	24	66.09	24
				151.27	63	142.36	63	66.39	63	66.39	63
				151.57	81	142.66	81	66.69	80	66.69	80
				151.87	90	142.96	90	66.99	89	66.99	89
				152.17	94	143.26	94	67.29	94	67.29	94
				152.47	97	143.56	97	67.59	97	67.59	97
				152.77	98	143.86	98	67.89	98	67.89	98
				153.07	99	144.16	99	68.19	99	68.19	99
				153.37	100	144.46	100	68.49	99	68.49	99
				153.67	100	144.76	100	68.79	100	68.79	100
				153.97	100	145.06	100	69.09	100	69.09	100
				-	-	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC7		SAC8		SAC9		SAC10		SAC11	
Name		Colusa Basin North		Colusa		Colusa Basin South		Grimes		RD 1500 West	
Toe Elevation[3]		84.6		58.6		46.6		46.6		36.6	
AWSE		97.6		67.6		57.4		57.4		48.2	
Crest Elevation[3]		101.6		70.6		61.4		61.4		53.7	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	84.61	0	58.58	0	46.60	0	46.60	0	36.63	0
		85.91	0	59.48	0	47.68	0	47.68	0	37.79	0
		87.21	0	60.38	0	48.76	0	48.76	0	38.95	0
		88.51	0	61.28	0	49.84	1	49.84	1	40.11	1
		89.81	0	62.18	0	50.92	2	50.92	2	41.27	1
		91.11	0	63.08	0	52.00	3	52.00	3	42.43	2
		92.41	1	63.98	1	53.08	5	53.08	5	43.59	3
		93.71	1	64.88	1	54.16	8	54.16	8	44.75	4
		95.01	2	65.78	2	55.24	13	55.24	13	45.91	7
		96.31	3	66.68	3	56.32	20	56.32	20	47.07	12
		97.61	6	67.58	4	57.40	32	57.40	32	48.23	20
		98.01	6	67.88	5	57.80	73	57.80	73	48.78	52
		98.41	7	68.18	5	58.20	88	58.20	88	49.33	71
		98.81	8	68.48	6	58.60	94	58.60	94	49.88	83
		99.21	8	68.78	6	59.00	97	59.00	97	50.43	90
		99.61	9	69.08	7	59.40	98	59.40	98	50.98	94
		100.01	10	69.38	7	59.80	99	59.80	99	51.53	97
		100.41	10	69.68	8	60.20	100	60.20	100	52.08	98
		100.81	11	69.98	8	60.60	100	60.60	100	52.63	99
		101.21	12	70.28	9	61.00	100	61.00	100	53.18	100
		101.61	100	70.58	100	61.40	100	61.40	100	53.73	100
		-	-	-	-	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC12		SAC13		SAC14		SAC15		SAC16	
Name		Sycamore Slough		Knights Landing		Ridge Cut (North)		Ridge Cut (South)		RD 2035	
Toe Elevation[3]		33.2		30.3		29.6		15.5		13.0	
AWSE		42.2		39.3		38.6		33.5		25.0	
Crest Elevation[3]		47.2		42.3		43.6		39.5		30.0	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Breach (percent)	33.16	0	30.35	0	29.56	0	15.51	0	12.97	0
		34.06	0	31.25	0	30.46	0	17.31	0	14.17	0
		34.96	0	32.15	0	31.36	0	19.11	0	15.37	0
		35.86	0	33.05	0	32.26	0	20.91	1	16.57	1
		36.76	0	33.95	0	33.16	0	22.71	1	17.77	2
		37.66	1	34.85	1	34.06	1	24.51	2	18.97	3
		38.56	1	35.75	1	34.96	1	26.31	3	20.17	5
		39.46	2	36.65	2	35.86	2	28.11	4	21.37	8
		40.36	3	37.55	3	36.76	3	29.91	7	22.57	13
		41.26	4	38.45	4	37.66	4	31.71	12	23.77	20
		42.16	7	39.35	7	38.56	7	33.51	20	24.97	32
		42.66	9	39.64	8	39.06	9	34.11	52	25.42	73
		43.16	10	39.94	9	39.56	10	34.71	71	25.87	88
		43.66	11	40.23	10	40.06	11	35.31	83	26.32	94
		44.16	13	40.52	11	40.56	13	35.91	90	26.77	97
		44.66	14	40.82	11	41.06	14	36.51	94	27.22	98
		45.16	16	41.11	12	41.56	16	37.11	96	27.67	99
		45.66	17	41.41	13	42.06	17	37.71	98	28.12	100
		46.16	19	41.70	14	42.56	19	38.31	99	28.57	100
		46.66	20	41.99	15	43.06	20	38.91	100	29.02	100
		47.16	100	42.29	100	43.56	100	39.51	100	29.47	100
		-	-	-	-	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC17		SAC18		SAC20		SAC21		SAC22	
Name		**East of Davis**		**Upper Honcut**		**Gridley**		**Sutter Buttes East**		**Live Oak**	
Toe Elevation[3]		26.0		0.00		77.7		77.7		77.7	
AWSE		31.6		0.00		83.2		83.2		83.2	
Crest Elevation[3]		37.2		0.00		88.7		88.7		88.7	
Type of Project (ULE or NULE)		ULE		NULE		ULE		ULE		ULE	
Water Surface Elevation (NGVD29) (feet)	**Associated Probability of Failure (breach) (percent)**	25.97	0	96.57	0	77.73	0	77.73	0	77.73	0
		26.53	0	97.00	0	78.28	17	78.28	17	78.28	17
		27.09	0	97.42	0	78.83	24	78.83	24	78.83	24
		27.65	0	97.84	1	79.38	33	79.38	33	79.38	33
		28.22	1	98.26	2	79.93	44	79.93	44	79.93	44
		28.78	1	98.68	3	80.48	57	80.48	57	80.48	57
		29.34	1	99.11	4	81.03	70	81.03	70	81.03	70
		29.90	1	99.53	7	81.58	82	81.58	82	81.58	82
		30.47	1	99.95	12	82.13	90	82.13	90	82.13	90
		31.03	1	100.37	19	82.68	95	82.68	95	82.68	95
		31.59	1	100.79	30	83.23	97	83.23	97	83.23	97
		32.15	2	101.09	74	83.78	99	83.78	99	83.78	99
		32.72	3	101.39	91	84.33	99	84.33	99	84.33	99
		33.28	4	101.69	97	84.88	100	84.88	100	84.88	100
		33.84	6	101.99	99	85.43	100	85.43	100	85.43	100
		34.40	9	102.29	100	85.98	100	85.98	100	85.98	100
		34.97	12	102.59	100	86.53	100	86.53	100	86.53	100
		35.53	16	102.89	100	87.08	100	87.08	100	87.08	100
		36.09	21	103.19	100	87.63	100	87.63	100	87.63	100
		36.65	28	103.49	100	88.18	100	88.18	100	88.18	100
		37.22	35	103.79	100	88.73	100	88.73	100	88.73	100
		37.23	100			88.74	100	88.74	100	88.74	100

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC23		SAC24		SAC25		SAC26		SAC27	
Name		Lower Honcut		Levee Dist. #1		Yuba City		Marysville		Linda-Olivehurst	
Toe Elevation[3]		68.7		49.2		63.7		65.7		67.7	
AWSE		81.7		53.7		74.0		77.7		75.2	
Crest Elevation[3]		85.7		56.7		84.2		89.7		82.7	
Type of Project (ULE or NULE)		NULE		NULE		ULE		ULE		ULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	68.73	0	49.16	0	63.72	0	65.73	0	67.73	0
		70.03	0	49.61	0	64.74	0	66.93	1	68.48	0
		71.33	0	50.06	0	65.77	1	68.13	1	69.23	0
		72.63	1	50.51	0	66.79	1	69.33	2	69.98	0
		73.93	2	50.96	0	67.82	1	70.53	2	70.73	0
		75.23	3	51.41	0	68.84	3	71.73	2	71.48	0
		76.53	4	51.86	1	69.87	11	72.93	2	72.23	0
		77.83	7	52.31	1	70.89	22	74.13	2	72.98	0
		79.13	12	52.76	2	71.92	55	75.33	4	73.73	0
		80.43	19	53.21	3	72.94	77	76.53	7	74.48	0
		81.73	30	53.66	4	73.97	91	77.73	12	75.23	0
		82.13	74	53.96	5	74.99	97	78.93	21	75.98	0
		82.53	91	54.26	6	76.02	99	80.13	36	76.73	0
		82.93	97	54.56	7	77.04	100	81.33	60	77.48	1
		83.33	99	54.86	8	78.07	100	82.53	81	78.23	1
		83.73	100	55.16	10	79.09	100	83.73	92	78.98	1
		84.13	100	55.46	11	80.12	100	84.93	97	79.73	1
		84.53	100	55.76	12	81.14	100	86.13	99	80.48	2
		84.93	100	56.06	13	82.17	100	87.33	100	81.23	2
		85.33	100	56.36	14	83.19	100	88.53	100	81.98	2
		85.73	100	56.66	(100)	84.22	100	89.73	100	82.73	3
		-	-	-	-	84.23	100	89.74	100	82.74	100

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC28		SAC29		SAC30		SAC32		SAC33	
Name		RD 384		Best Slough		RD 1001		RD 70-1660		Meridian	
Toe Elevation[3]		44.7		70.3		35.7		42.6		42.6	
AWSE		54.7		77.8		55.7		57.2		57.2	
Crest Elevation[3]		64.7		80.8		62.7		61.8		61.8	
Type of Project (UULE or NULE)		ULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	44.70	0	70.29	0	35.69	0	42.60	0	42.60	0
		45.70	0	71.04	0	37.69	0	44.07	0	44.07	0
		46.70	0	71.79	0	39.69	1	45.53	0	45.53	0
		47.70	0	72.54	1	41.69	1	47.00	1	47.00	1
		48.70	0	73.29	2	43.69	2	48.46	2	48.46	2
		49.70	0	74.04	3	45.69	4	49.93	3	49.93	3
		50.70	0	74.79	5	47.69	6	51.39	4	51.39	4
		51.70	1	75.54	7	49.69	11	52.86	7	52.86	7
		52.70	1	76.29	12	51.69	17	54.32	12	54.32	12
		53.70	1	77.04	20	53.69	27	55.79	19	55.79	19
		54.70	1	77.79	31	55.69	42	57.25	30	57.25	30
		55.70	1	78.09	72	56.39	86	57.71	74	57.71	74
		56.70	1	78.39	87	57.09	96	58.17	91	58.17	91
		57.70	1	78.69	94	57.79	99	58.63	97	58.63	97
		58.70	1	78.99	97	58.49	100	59.08	99	59.08	99
		59.70	1	79.29	98	59.19	100	59.54	100	59.54	100
		60.70	2	79.59	99	59.89	100	60.00	100	60.00	100
		61.70	2	79.89	99	60.59	100	60.46	100	60.46	100
		62.70	2	80.19	100	61.29	100	60.91	100	60.91	100
		63.70	3	80.49	100	61.99	100	61.37	100	61.37	100
		64.70	4	80.79	100	62.69	100	61.83	100	61.83	100
		64.71	100	-	-	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC34		SAC35		SAC36		SAC37		SAC38	
Name		RD 1500 East		Elkhorn		Natomas		Rio Linda		West Sacramento	
Toe Elevation[3]		18.6		8.5		23.3		19.5		24.5	
AWSE		42.8		28.0		32.9		30.4		32.5	
Crest Elevation[3]		48.1		31.5		38.9		41.4		40.5	
Type of Project (ULE or NULE)		NULE		NULE		NULE		ULE		ULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	18.59	0	8.47	0	23.26	0	19.47	0	24.46	0
		21.01	0	10.42	0	24.23	0	20.56	0	25.26	0
		23.43	0	12.37	0	25.20	0	21.66	0	26.06	0
		25.85	1	14.32	1	26.16	1	22.75	0	26.86	0
		28.27	1	16.27	2	27.13	1	23.85	0	27.66	1
		30.69	2	18.22	3	28.10	2	24.94	0	28.46	1
		33.11	3	20.17	4	29.07	3	26.04	0	29.26	1
		35.53	5	22.12	7	30.04	4	27.13	0	30.06	1
		37.95	8	24.07	12	31.00	7	28.23	0	30.86	1
		40.37	13	26.02	19	31.97	12	29.32	0	31.66	2
		42.79	21	27.97	30	32.94	20	30.42	0	32.46	2
		43.32	52	28.32	74	33.54	52	31.51	0	33.26	2
		43.85	71	28.67	91	34.14	71	32.61	1	34.06	8
		44.38	83	29.02	97	34.75	83	33.70	1	34.86	11
		44.91	90	29.37	99	35.35	90	34.80	1	35.66	15
		45.44	94	29.72	100	35.95	94	35.89	1	36.46	21
		45.97	96	30.07	100	36.55	97	36.99	2	37.26	29
		46.50	98	30.42	100	37.15	98	38.08	2	38.06	41
		47.03	99	30.77	100	37.76	99	39.18	3	38.86	57
		47.56	100	31.12	100	38.36	100	40.27	3	39.66	72
		48.09	100	31.47	100	38.96	100	41.37	3	40.46	81
		-	-	-	-	-	-	41.38	100	40.47	100

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC39		SAC40		SAC41		SAC42		SAC43	
Name		RD 900		Sacramento North		RD 302		RD 999		Clarksburg	
Toe Elevation[3]		17.5		25.5		10.5		12.5		11.5	
AWSE		27.5		34.0		26.5		27.5		23.0	
Crest Elevation[3]		37.5		42.5		30.5		31.5		28.5	
Type of Project (ULE or NULE)		ULE		ULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	17.46	0	25.46	0	10.50	0	12.49	0	11.53	0
		18.46	1	26.31	0	12.10	0	13.99	0	12.68	0
		19.46	1	27.16	0	13.70	0	15.49	0	13.83	0
		20.46	2	28.01	0	15.30	1	16.99	1	14.98	0
		21.46	2	28.86	0	16.90	1	18.49	1	16.13	0
		22.46	2	29.71	0	18.50	2	19.99	2	17.28	0
		23.46	3	30.56	1	20.10	4	21.49	3	18.43	1
		24.46	4	31.41	1	21.70	6	22.99	4	19.58	1
		25.46	6	32.26	1	23.30	10	24.49	7	20.73	2
		26.46	10	33.11	1	24.90	16	25.99	12	21.88	3
		27.46	18	33.96	5	26.50	25	27.49	19	23.03	5
		28.46	28	34.81	7	26.90	63	27.89	46	23.58	6
		29.46	43	35.66	10	27.30	81	28.29	60	24.13	7
		30.46	63	36.51	14	27.70	90	28.69	67	24.68	8
		31.46	82	37.36	19	28.10	94	29.09	72	25.23	9
		32.46	93	38.21	27	28.50	97	29.49	74	25.78	9
		33.46	98	39.06	39	28.90	98	29.89	76	26.33	10
		34.46	100	39.91	55	29.30	99	30.29	77	26.88	11
		35.46	100	40.76	70	29.70	99	30.69	77	27.43	12
		36.46	100	41.61	81	30.10	100	31.09	78	27.98	13
		37.46	100	42.46	88	30.50	100	31.49	100	28.53	100
		37.47	100	42.47	100	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC44		SAC45		SAC46		SAC47		SAC48	
Name		Stone Lake		Hood		Merritt Island		RD 551		Courtland	
Toe Elevation[3]		15.6		15.6		10.5		5.6		5.6	
AWSE		20.5		20.6		21.1		21.6		21.6	
Crest Elevation[3]		26.4		26.4		23.6		25.6		25.6	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	15.56	0	15.56	0	10.55	0	5.56	0	5.56	0
		16.06	0	16.06	0	11.60	0	7.16	0	7.16	0
		16.56	0	16.56	0	12.65	0	8.76	0	8.76	0
		17.06	1	17.06	1	13.70	1	10.36	1	10.36	1
		17.56	2	17.56	2	14.75	1	11.96	1	11.96	1
		18.05	3	18.05	3	15.80	2	13.56	2	13.56	2
		18.55	5	18.55	5	16.85	4	15.16	4	15.16	4
		19.05	8	19.05	8	17.90	6	16.76	6	16.76	6
		19.55	13	19.55	13	18.95	10	18.36	10	18.36	10
		20.05	20	20.05	20	20.00	16	19.96	16	19.96	16
		20.55	32	20.55	32	21.05	25	21.56	25	21.56	25
		21.13	76	21.13	76	21.30	63	21.96	63	21.96	63
		21.72	91	21.72	91	21.55	81	22.36	81	22.36	81
		22.30	97	22.30	97	21.80	90	22.76	90	22.76	90
		22.88	99	22.88	99	22.05	94	23.16	94	23.16	94
		23.46	100	23.46	100	22.30	97	23.56	97	23.56	97
		24.04	100	24.04	100	22.55	98	23.96	98	23.96	98
		24.62	100	24.62	100	22.80	99	24.36	99	24.36	99
		25.20	100	25.20	100	23.05	99	24.76	99	24.76	99
		25.79	100	25.79	100	23.30	100	25.16	100	25.16	100
		26.37	100	26.37	100	23.55	100	25.56	100	25.56	100
		-	-	-	-	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID	SAC49		SAC50		SAC51		SAC52		SAC53	
Name	Sutter Island		Grand Island		Locke		Walnut Grove		Tyler Island	
Toe Elevation[3]	4.6		-0.4		7.6		9.6		-2.4	
AWSE	16.1		12.4		15.0		14.5		9.6	
Crest Elevation[3]	22.6		17.8		20.1		22.6		11.6	
Type of Project (ULE or NULE)	NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet) / Associated Probability of Failure (breach) (percent)	4.58	0	-0.42	0	7.61	0	9.61	0	-2.38	0
	5.73	0	0.87	0	8.35	0	10.10	0	-1.18	0
	6.88	0	2.15	1	9.09	0	10.59	0	0.02	0
	8.03	1	3.44	1	9.83	0	11.08	0	1.22	1
	9.18	2	4.73	2	10.57	0	11.57	0	2.42	2
	10.33	3	6.01	3	11.31	0	12.06	0	3.62	3
	11.48	5	7.30	6	12.05	0	12.55	0	4.82	5
	12.63	8	8.59	9	12.79	0	13.04	0	6.02	8
	13.78	13	9.87	15	13.53	1	13.53	1	7.22	13
	14.93	20	11.16	24	14.27	1	14.02	1	8.42	20
	16.08	32	12.45	37	15.01	2	14.51	2	9.62	32
	16.73	73	12.98	81	15.52	3	15.32	3	9.82	75
	17.38	88	13.52	94	16.03	3	16.13	5	10.02	91
	18.03	94	14.06	98	16.54	4	16.94	6	10.22	97
	18.68	97	14.60	99	17.05	4	17.75	7	10.42	99
	19.33	98	15.13	100	17.56	5	18.56	8	10.62	100
	19.98	99	15.67	100	18.07	5	19.37	9	10.82	100
	20.63	100	16.21	100	18.58	6	20.18	11	11.02	100
	21.28	100	16.75	100	19.09	6	20.99	12	11.22	100
	21.93	100	17.28	100	19.60	7	21.80	13	11.42	100
	22.58	100	17.82	100	20.11	100	22.61	100	11.62	100
	-	-	-	-	-	-	-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC54		SAC55		SAC56		SAC57		SAC58	
Name		Andrus Island		Ryer Island		Prospect Island		Twitchell Island		Sherman Island	
Toe Elevation[3]		-2.4		-1.4		0.00		-1.4		-12.4	
AWSE		11.6		11.8		0.00		9.1		8.6	
Crest Elevation[3]		13.6		20.8		0.00		13.6		10.6	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	-2.39	0	-1.42	0			-1.40	0	-12.43	0
		-0.99	0	-0.10	0			-0.35	0	-10.33	0
		0.41	0	1.22	0			0.70	0	-8.23	0
		1.81	0	2.55	1			1.75	0	-6.13	1
		3.21	0	3.87	2			2.80	0	-4.03	2
		4.61	1	5.20	3			3.85	1	-1.93	3
		6.01	1	6.52	5			4.90	1	0.17	5
		7.41	2	7.84	8			5.95	2	2.27	8
		8.81	3	9.17	13			7.00	3	4.37	13
		10.21	4	10.49	20			8.05	5	6.47	20
		11.61	7	11.82	32			9.10	8	8.57	32
		11.81	7	12.72	75			9.55	9	8.77	75
		12.01	8	13.62	91			10.00	10	8.97	91
		12.21	8	14.52	97			10.45	12	9.17	97
		12.41	9	15.42	99			10.90	13	9.37	99
		12.61	9	16.33	100			11.35	14	9.57	100
		12.81	9	17.23	100			11.80	15	9.77	100
		13.01	10	18.13	100			12.25	16	9.97	100
		13.21	10	19.03	100			12.70	18	10.17	100
		13.41	10	19.94	100			13.15	19	10.37	100
		13.61	100	20.84	100		100	13.60	100	10.57	100
		-	-	-	-			-	-	-	-

Table 4-1. Sacramento River Basin Levee Performance Curves (contd.)

ID		SAC59		SAC60		SAC61		SAC62		SAC63	
Name		Moore		Cache Slough		Hastings		Lindsey Slough		Sacramento South	
Toe Elevation[3]		2.0		2.5		1.5		3.5		27.5	
AWSE		15.5		15.5		14.3		14.3		33.3	
Crest Elevation[3]		19.5		18.0		16.7		18.5		39.1	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		ULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	2.04	0	2.52	0	1.53	0	3.53	0	27.46	0
		3.39	0	3.82	0	2.81	0	4.60	0	28.04	0
		4.74	0	5.12	0	4.09	0	5.68	1	28.62	0
		6.09	1	6.42	0	5.36	1	6.75	1	29.20	0
		7.44	1	7.72	0	6.64	1	7.83	2	29.78	1
		8.79	2	9.02	0	7.92	2	8.90	4	30.36	1
		10.14	4	10.32	0	9.19	3	9.98	6	30.94	1
		11.49	6	11.62	1	10.47	5	11.06	11	31.52	1
		12.84	10	12.92	1	11.75	8	12.13	17	32.10	2
		14.19	16	14.22	2	13.02	13	13.21	27	32.68	2
		15.54	25	15.52	3	14.30	21	14.28	42	33.26	3
		15.94	63	15.77	3	14.54	52	14.71	86	33.84	4
		16.34	81	16.02	3	14.79	71	15.13	96	34.42	5
		16.74	90	16.27	3	15.03	83	15.55	99	35.00	6
		17.14	94	16.52	4	15.27	90	15.97	100	35.58	7
		17.54	97	16.77	4	15.52	94	16.40	100	36.16	8
		17.94	98	17.02	4	15.76	96	16.82	100	36.74	8
		18.34	99	17.27	4	16.00	98	17.24	100	37.32	9
		18.74	99	17.52	4	16.25	99	17.66	100	37.90	10
		19.14	100	17.77	5	16.49	100	18.09	100	38.48	12
		19.54	100	18.02	100	16.73	100	18.51	100	39.06	13
		-	-	-	-	-	-	-	-	39.07	100

Notes:
[1] No State-federal project levees found within the impact area
[2] Assume overbank flow
[3] Elevations in feet, NGVD29

Key:
- = not applicable
AWSE = Assessment Water Surface Elevation
NGVD29 = National Geodetic vertical Datum of 1929
NULE = Non-Urban Levee Evaluations
RD = Reclamation District
ULE = Urban Levee Evaluations

Table 4-2. San Joaquin River Basin Levee Performance Curves

ID		SJ1	SJ2		SJ3		SJ4		SJ5	
Name		Fresno	Fresno Slough East		Fresno Slough West		Mendota		Chowchilla Bypass	
Toe Elevation[3]		1	159.6		150.9		151.6		157.8	
AWSE			163.8		155.9		153.6		166.8	
Crest Elevation[3]			166.8		158.9		156.6		170.8	
Type of Project (ULE or NULE)			NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	2	159.59	0	150.90	0	151.61	0	157.82	0
			160.01	0	151.40	0	151.81	0	158.72	0
			160.43	0	151.90	0	152.01	0	159.62	0
			160.85	1	152.40	0	152.21	0	160.52	1
			161.27	2	152.90	1	152.41	0	161.42	2
			161.69	3	153.40	1	152.61	0	162.32	3
			162.11	5	153.90	3	152.81	0	163.22	4
			162.53	7	154.40	4	153.01	0	164.12	7
			162.95	12	154.90	7	153.21	1	165.02	12
			163.37	20	155.40	11	153.41	1	165.92	19
			163.79	31	155.90	18	153.61	2	166.82	30
			164.09	75	156.20	46	153.91	3	167.22	74
			164.39	91	156.50	60	154.21	4	167.62	91
			164.69	97	156.80	67	154.51	5	168.02	97
			164.99	99	157.10	72	154.81	7	168.42	99
			165.29	100	157.40	74	155.11	8	168.82	100
			165.59	100	157.70	76	155.41	9	169.22	100
			165.89	100	158.00	77	155.71	10	169.62	100
			166.19	100	158.30	78	156.01	11	170.02	100
			166.49	100	158.60	79	156.31	12	170.42	100
			166.79	100	158.90	100	156.61	100	170.82	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ6		SJ7	SJ8		SJ9		SJ10	
Name		Lone Willow Slough		Mendota North	Firebaugh		Salt Slough		Dos Palos	
Toe Elevation[3]		152.2		1	141.2		114.8		114.8	
AWSE		157.4			143.1		117.5		117.5	
Crest Elevation[3]		160.4			146.1		120.5		120.5	
Type of Project (ULE or NULE)		NULE			NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	152.22	0	2	141.17	0	114.83	0	114.83	0
		152.74	0		141.37	0	115.10	0	115.10	0
		153.26	0		141.56	0	115.37	0	115.37	0
		153.78	0		141.76	0	115.64	0	115.64	0
		154.30	1		141.95	0	115.91	0	115.91	0
		154.82	1		142.14	0	116.18	0	116.18	0
		155.34	2		142.34	0	116.45	0	116.45	0
		155.86	3		142.53	1	116.72	1	116.72	1
		156.38	4		142.73	1	116.99	1	116.99	1
		156.90	7		142.92	2	117.26	2	117.26	2
		157.42	12		143.11	3	117.53	3	117.53	3
		157.72	28		143.41	4	117.83	4	117.83	4
		158.02	39		143.71	6	118.13	5	118.13	5
		158.32	45		144.01	8	118.43	6	118.43	6
		158.62	49		144.31	9	118.73	7	118.73	7
		158.92	52		144.61	11	119.03	9	119.03	9
		159.22	54		144.91	12	119.33	10	119.33	10
		159.52	55		145.21	14	119.63	11	119.63	11
		159.82	56		145.51	15	119.93	12	119.93	12
		160.12	57		145.81	17	120.23	13	120.23	13
		160.42	100		146.11	100	120.53	100	120.53	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ11		SJ12		SJ13		SJ14		SJ15	
Name		Fresno River		Berenda Slough		Ash Slough		Sandy Mush		Turner Island	
Toe Elevation[3]		184.1		148.2		139.1		98.6		96.5	
AWSE		189.2		150.9		142.6		105.8		105.7	
Crest Elevation[3]		192.2		153.9		145.6		109.8		109.7	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	184.14	0	148.17	0	139.06	0	98.61	0	96.49	0
		184.65	0	148.44	0	139.41	0	99.33	0	97.41	0
		185.16	0	148.71	0	139.76	0	100.05	0	98.33	0
		185.67	0	148.98	0	140.11	0	100.77	1	99.25	1
		186.18	1	149.25	0	140.46	0	101.49	2	100.17	2
		186.69	1	149.52	0	140.81	0	102.21	3	101.09	3
		187.20	3	149.79	0	141.16	1	102.93	4	102.01	4
		187.71	4	150.06	0	141.51	1	103.65	7	102.93	7
		188.22	7	150.33	1	141.86	2	104.37	12	103.85	12
		188.73	11	150.60	1	142.21	3	105.09	19	104.77	19
		189.24	19	150.87	2	142.56	5	105.81	30	105.69	30
		189.54	51	151.17	3	142.86	7	106.21	74	106.09	74
		189.84	71	151.47	4	143.16	8	106.61	91	106.49	91
		190.14	82	151.77	5	143.46	10	107.01	97	106.89	97
		190.44	89	152.07	5	143.76	11	107.41	99	107.29	99
		190.74	94	152.37	6	144.06	13	107.81	100	107.69	100
		191.04	96	152.67	7	144.36	14	108.21	100	108.09	100
		191.34	98	152.97	8	144.66	16	108.61	100	108.49	100
		191.64	99	153.27	9	144.96	17	109.01	100	108.89	100
		191.94	100	153.57	10	145.26	19	109.41	100	109.29	100
		192.24	100	153.87	100	145.56	100	109.81	100	109.69	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ16		SJ17		SJ18		SJ19		SJ20
Name		Bear Creek		Deep Slough		West Bear Creek		Fremont Ford		Merced River
Toe Elevation[3]		84.4		84.2		81.3		64.0		1
AWSE		89.1		89.9		85.8		70.9		
Crest Elevation[3]		92.1		92.9		88.8		73.5		
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	84.39	0	84.20	0	81.27	0	63.97	0	2
		84.86	0	84.77	0	81.72	0	64.66	0	
		85.33	0	85.34	0	82.17	0	65.35	0	
		85.80	0	85.91	0	82.62	0	66.04	0	
		86.27	0	86.48	1	83.07	1	66.73	0	
		86.74	0	87.05	1	83.52	1	67.42	0	
		87.21	0	87.62	3	83.97	3	68.11	1	
		87.68	1	88.19	4	84.42	4	68.80	1	
		88.15	1	88.76	7	84.87	7	69.49	2	
		88.62	2	89.33	11	85.32	11	70.18	3	
		89.09	3	89.90	19	85.77	19	70.87	4	
		89.39	4	90.20	51	86.07	51	71.13	5	
		89.69	5	90.50	71	86.37	71	71.39	5	
		89.99	6	90.80	82	86.67	82	71.65	6	
		90.29	7	91.10	89	86.97	90	71.91	7	
		90.59	8	91.40	94	87.27	94	72.17	7	
		90.89	9	91.70	96	87.57	96	72.43	8	
		91.19	9	92.00	98	87.87	98	72.69	8	
		91.49	10	92.30	99	88.17	99	72.95	9	
		91.79	11	92.60	100	88.47	100	73.21	10	
		92.09	100	92.90	100	88.77	100	73.47	100	

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ21		SJ22		SJ23		SJ24		SJ25
Name		Merced River North		Orestimba		Tuolumne South		Tuolumne River		Modesto
Toe Elevation[3]		42.0		48.6		33.0		40.1		1
AWSE		52.6		57.0		38.6		47.0		
Crest Elevation[3]		54.9		57.0		38.6		50.4		
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	41.98	0	48.59	0	33.01	0	40.09	0	2
		43.04	0	49.43	0	33.57	0	40.79	0	
		44.10	0	50.27	0	34.13	0	41.48	1	
		45.16	1	51.11	1	34.69	1	42.17	1	
		46.22	2	51.95	2	35.25	2	42.86	2	
		47.28	3	52.79	3	35.81	3	43.56	4	
		48.34	4	53.63	4	36.37	4	44.25	6	
		49.40	7	54.47	7	36.93	7	44.94	10	
		50.46	12	55.31	12	37.49	12	45.64	17	
		51.52	19	56.15	19	38.05	19	46.33	27	
		52.58	30	56.99	30	38.61	31	47.02	41	
		52.81	74	57.29	74	38.61	75	47.36	87	
		53.04	91	57.59	91	38.61	91	47.70	97	
		53.27	97	57.89	97	38.61	97	48.05	99	
		53.50	99	58.19	99	38.61	99	48.39	100	
		53.73	100	58.49	100	38.61	100	48.73	100	
		53.96	100	58.79	100	38.61	100	49.07	100	
		54.19	100	59.09	100	38.61	100	49.41	100	
		54.42	100	59.39	100	38.61	100	49.75	100	
		54.65	100	59.69	100	38.61	100	50.09	100	
		54.88	100	59.99	100	38.61	100	50.43	100	

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ26		SJ27		SJ28		SJ29		SJ30	
Name		3 Amigos		Stanislaus South		Stanislaus North		Banta Carbona		Paradise Cut	
Toe Elevation[3]		28.4		23.5		27.9		19.5		0.6	
AWSE		38.7		36.6		35.5		28.4		14.7	
Crest Elevation[3]		41.7		40.0		38.5		32.1		22.4	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	28.41	0	23.52	0	27.93	0	19.49	0	0.58	0
		29.44	0	24.83	0	28.69	0	20.39	0	1.99	0
		30.47	0	26.14	1	29.45	1	21.28	0	3.40	1
		31.50	1	27.45	1	30.21	1	22.17	1	4.81	1
		32.53	2	28.76	2	30.97	2	23.07	2	6.22	2
		33.56	3	30.07	4	31.73	4	23.96	3	7.63	4
		34.59	5	31.38	6	32.49	6	24.86	5	9.04	6
		35.62	7	32.69	10	33.25	10	25.75	7	10.45	10
		36.65	12	34.00	17	34.01	17	26.64	12	11.86	17
		37.68	20	35.31	27	34.77	27	27.54	20	13.27	27
		38.71	31	36.62	41	35.53	41	28.43	31	14.68	41
		39.01	75	36.96	87	35.83	87	28.79	75	15.45	87
		39.31	91	37.30	97	36.13	97	29.16	91	16.22	97
		39.61	97	37.64	99	36.43	99	29.52	97	16.99	99
		39.91	99	37.98	100	36.73	100	29.88	99	17.76	100
		40.21	100	38.32	100	37.03	100	30.25	100	18.53	100
		40.51	100	38.66	100	37.33	100	30.61	100	19.30	100
		40.81	100	39.00	100	37.63	100	30.97	100	20.07	100
		41.11	100	39.34	100	37.93	100	31.34	100	20.84	100
		41.41	100	39.68	100	38.23	100	31.70	100	21.61	100
		41.71	100	40.02	100	38.53	100	32.06	100	22.38	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ31		SJ32		SJ33		SJ34		SJ35	
Name		Stewart Tract		East Lathrop		Lathrop/ Sharpe		French Camp		Moss Tract	
Toe Elevation[3]		13.7		16.6		12.7		10.7		4.4	
AWSE		23.4		22.8		18.2		17.0		11.7	
Crest Elevation[3]		28.8		30.9		29.0		26.0		19.4	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	13.75	0	16.65	0	12.67	0	10.69	0	4.41	0
		14.72	0	17.27	0	13.22	0	11.32	0	5.14	0
		15.69	0	17.89	0	13.77	0	11.95	0	5.87	0
		16.66	1	18.51	0	14.32	0	12.58	0	6.60	0
		17.63	2	19.13	0	14.87	0	13.21	0	7.33	1
		18.60	3	19.75	0	15.42	0	13.84	0	8.06	1
		19.57	5	20.37	1	15.97	1	14.47	1	8.79	3
		20.54	7	20.99	1	16.52	1	15.10	1	9.52	4
		21.51	12	21.61	2	17.07	2	15.73	2	10.25	7
		22.48	20	22.23	3	17.62	3	16.36	3	10.98	11
		23.45	31	22.85	5	18.17	5	16.99	5	11.71	19
		23.99	75	23.66	7	19.25	9	17.89	8	12.48	51
		24.53	91	24.47	10	20.33	12	18.79	10	13.25	71
		25.07	97	25.28	12	21.41	16	19.69	13	14.02	83
		25.61	99	26.09	15	22.49	19	20.59	15	14.79	90
		26.15	100	26.90	17	23.57	22	21.49	18	15.56	94
		26.69	100	27.71	19	24.65	26	22.39	20	16.33	97
		27.23	100	28.52	21	25.73	29	23.29	23	17.10	98
		27.77	100	29.33	24	26.81	32	24.19	25	17.87	99
		28.31	100	30.14	26	27.89	35	25.09	27	18.64	100
		28.85	100	30.95	100	28.97	100	25.99	100	19.41	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ36		SJ37		SJ38		SJ39		SJ40	
Name		Roberts Island		Rough and Ready Island		Drexler Tract		Union Island		SE Union Island	
Toe Elevation[3]		4.6		2.7		-2.8		8.6		5.3	
AWSE		17.0		8.6		7.7		13.5		13.4	
Crest Elevation[3]		26.1		13.9		8.4		23.4		19.3	
Type of Project (ULE or NULE)		NULE		NULE		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	4.58	0	2.75	0	-2.85	0	8.61	0	5.28	0
		5.82	0	3.34	0	-1.80	0	9.10	0	6.09	0
		7.06	0	3.93	0	-0.74	0	9.59	0	6.90	1
		8.30	1	4.52	0	0.31	0	10.08	1	7.71	1
		9.54	1	5.11	0	1.37	1	10.57	2	8.52	2
		10.78	2	5.70	0	2.43	1	11.06	3	9.33	4
		12.02	3	6.29	0	3.48	2	11.55	5	10.14	6
		13.26	4	6.88	0	4.54	3	12.04	7	10.95	10
		14.50	7	7.47	1	5.59	5	12.53	12	11.76	17
		15.74	12	8.06	1	6.65	8	13.02	20	12.57	27
		16.98	20	8.65	2	7.71	13	13.51	31	13.38	41
		17.89	52	9.18	3	7.78	29	14.50	75	13.97	87
		18.80	71	9.71	3	7.85	39	15.49	91	14.56	97
		19.71	83	10.24	4	7.92	45	16.48	97	15.15	99
		20.62	90	10.77	5	7.99	48	17.47	99	15.74	100
		21.53	94	11.30	5	8.06	50	18.46	100	16.33	100
		22.44	97	11.83	6	8.13	52	19.45	100	16.92	100
		23.35	98	12.36	7	8.20	53	20.44	100	17.51	100
		24.26	99	12.89	7	8.27	53	21.43	100	18.10	100
		25.17	100	13.42	8	8.34	54	22.42	100	18.69	100
		26.08	100	13.95	100	8.41	100	23.41	100	19.28	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		SJ41		SJ42		SJ43	
Name		Fabian Tract		RD 1007		Grayson	
Toe Elevation[3]		5.5		6.3		31.6	
AWSE		10.4		10.4		42.4	
Crest Elevation[3]		21.3		19.3		46.2	
Type of Project (ULE or NULE)		NULE		NULE		NULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	5.49	0	6.27	0	31.60	0
		5.98	0	6.68	0	32.68	0
		6.47	0	7.09	0	33.76	0
		6.95	0	7.50	0	34.84	0
		7.44	0	7.91	0	35.92	0
		7.93	0	8.32	0	37.00	1
		8.42	1	8.73	0	38.08	1
		8.91	1	9.14	1	39.16	1
		9.40	2	9.55	1	40.24	2
		9.89	3	9.96	2	41.32	4
		10.38	4	10.37	3	42.40	6
		11.47	8	11.26	6	42.78	7
		12.57	11	12.15	9	43.16	8
		13.67	15	13.04	12	43.54	9
		14.76	18	13.93	15	43.92	10
		15.86	21	14.82	17	44.30	11
		16.95	24	15.71	20	44.68	11
		18.05	28	16.60	22	45.06	12
		19.15	31	17.49	25	45.44	13
		20.24	33	18.38	27	45.82	14
		21.34	100	19.27	100	46.20	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		STK6		STK7		STK8	
Name		Stockton Diverting Canal		Calaveras River North		Bear Creek South	
Toe Elevation[3]		31.2		8.6		19.8	
AWSE		33.8		9.9		25.7	
Crest Elevation[3]		36.8		17.6		30.0	
Type of Project (ULE or NULE)		NULE		ULE		ULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	31.16	0	8.58	0	19.85	0
		31.42	0	9.03	1	20.36	0
		31.68	0	9.48	1	20.87	0
		31.94	0	9.93	1	21.38	0
		32.20	0	10.38	1	21.89	1
		32.46	0	10.83	1	22.40	1
		32.72	0	11.28	2	22.91	1
		32.98	0	11.73	2	23.42	1
		33.24	1	12.18	2	23.93	1
		33.50	1	12.63	2	24.44	1
		33.76	2	13.08	14	24.95	4
		34.06	3	13.53	17	25.46	8
		34.36	4	13.98	21	25.97	13
		34.66	5	14.43	26	26.48	19
		34.96	6	14.88	32	26.99	26
		35.26	6	15.33	40	27.50	35
		35.56	7	15.78	49	28.01	46
		35.86	8	16.23	59	28.52	58
		36.16	9	16.68	68	29.03	67
		36.46	10	17.13	76	29.54	75
		36.76	100	17.58	81	30.05	81
				17.59	100	30.06	100

Table 4-2. San Joaquin River Basin Levee Performance Curves (contd.)

ID		STK9		STK10	
Name		Bear Creek North		Central Stockton	
Toe Elevation[3]		16.4		2.1	
AWSE		19.8		9.6	
Crest Elevation[3]		24.0		15.6	
Type of Project (ULE or NULE)		ULE		ULE	
Water Surface Elevation (NGVD29) (feet)	Associated Probability of Failure (breach) (percent)	16.39	0	2.08	0
		16.77	0	2.75	1
		17.15	0	3.43	1
		17.53	0	4.10	2
		17.91	0	4.78	2
		18.29	1	5.45	2
		18.67	1	6.13	3
		19.05	1	6.80	4
		19.43	1	7.48	5
		19.81	1	8.15	6
		20.19	1	8.83	8
		20.57	2	9.50	11
		20.95	2	10.18	15
		21.33	2	10.85	22
		21.71	2	11.53	30
		22.09	4	12.20	41
		22.47	6	12.88	55
		22.85	8	13.55	69
		23.23	11	14.23	78
		23.61	14	14.90	85
		23.99	18	15.58	90
		24.00	100	15.59	100

Notes:
[1] No State-federal project levees found within the impact area
[2] Assume overbank flow
[3] Elevations in feet, NGVD29
Key:
- = not applicable
AWSE = Assessment Water Surface Elevation
NGVD29 = National Geodetic vertical Datum of 1929
NULE = Non-Urban Levee Evaluations
RD = Reclamation District
ULE = Urban Levee Evaluations

4.2 Limitations

This assessment has been performed in accordance with the standard of care commonly used as the state-of-practice in the civil engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period. The levee performance curves are intended to be used in current hydraulic and economic damage modeling being performed by DWR for the CVFPP; these curves should not be taken out of this context in forecasting local levee performance issues.

The current version of the NULE levee performance curve Excel tool has produced curves for more than 200 NULE levee segments using cross-section-specific geometry, GAR categories, and a few curve-fitting parameters. Because geometries of levees vary widely, some curves may look distorted when compared to the expected curve shapes presented in Figure 3-1. This distortion is present to greater or lesser degrees for levees with only one or two high (C) or lacking sufficient data (LD) ratings and is further exacerbated for levees that are either very short (particularly if they have more than 3 feet of freeboard) or very tall (particularly if they have less than 3 feet of freeboard). The tool provides a set of curves with consistent properties relative to each other that are appropriate for the intended use in systemwide models and that are sufficient for initial hydraulic and damage modeling. The impact of these distortions (if any) can be addressed once results of initial damage model runs become available.

As mentioned above, levee performance curves presented in this attachment are intended for use with systemwide hydraulic and economic damage modeling performed for the CVFPP. Actual hydraulic and economic damage modeling results depend on a number of factors beyond the geotechnical levee performance curves (such as hydrologic and hydraulic uncertainty), and although the levee performance curves may seem reasonable, they may, when combined with other factors and used in the modeling, produce unexpected results; therefore, care must be taken in their use.

In the methodology described in Section 3, individual failure mode levee performance curves were combined to yield a cumulative or combined levee performance curve. This approach assumed that the failure modes are independent, and that the different failure processes operate independently. This assumption is likely not true in all cases and has been offset to some extent by reducing the probability of failure for individual failure modes.

In developing NULE levee performance curves, for simplicity, the geometry and location of the under-seepage cross section that was assessed in the GARs (URS, 2010a; Kleinfelder, 2010) was used for each curve. For some NULE segments, the GARs used different cross sections for different failure modes. In developing levee performance curves, geometry and location from the GAR under-seepage cross section was used as input for hydraulic and flood damage models.

As noted previously, levee crest elevations used in the Comprehensive Study (USACE, 2002) are sometimes different from those identified in the ULE and NULE projects. The ULE and NULE projects relied on recent LiDAR and CLD topographic data to estimate topographic parameters. The Comprehensive Study relied on older, since superseded, topographic information and, in most instances, the ULE and NULE levee crest elevations were used.

In developing NULE levee performance curves, results from the draft North and South GARs (URS, 2010b; Kleinfelder, 2010) were used without modification. There are ongoing efforts to finalize these GARs, and some of the data used in development of the levee performance curves may change. Similarly, ULE data that were current through the FCSSR, and some data used to develop the levee performance curves, may change as the ULE Project proceeds.

DWR makes no warranty that actual encountered site and subsurface conditions will exactly conform to the conditions described herein, nor that the interpretations and recommendations in this attachment will be sufficient for construction-planning aspects of any future work to reconstruct or remediate levees. The design engineer or contractor should perform a sufficient number of independent explorations and tests that the engineer or contractor believes are necessary to verify subsurface conditions rather than relying solely on the information presented in this attachment or other referenced documentation.

DWR does not attest to the accuracy, completeness, or reliability of maps, data sources, and geotechnical borings and other subsurface data produced by others that were presented in the GARs and used to develop levee performance curves described in this attachment. DWR has not performed independent validation or verification of data reported by others.

Data presented in this attachment are time-sensitive in that they apply only to locations and conditions that were identified at the time this attachment was prepared. Data should not be applied to any other projects in or near the area of this study nor should they be applied at a future time without appropriate verification, at which point the entity verifying the data takes on the responsibility for the data and any liability for its use.

The levee performance curve information and results contained in this attachment is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

Information in this attachment should not to be used as a basis for design, construction, remedial action, or major project-specific capital spending decisions.

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6.0 Acronyms and Abbreviations

AWSE ....Assessment Water Surface Elevation

Board ....Central Valley Flood Protection Board

CLD................................California Levee Database

Comprehensive Study .....Sacramento and San Joaquin River Basins Comprehensive Study

CVFPP ....Central Valley Flood Protection Plan

Delta...............................Sacramento-San Joaquin Delta

DWR ....California Department of Water Resources

ETL ....Engineer Technical Letter

FCSSR............................Flood Control System Status Report

FS ....factor of safety

GAR ....Geotechnical Assessment Reports

HEC-FDA ....Hydrologic Engineering Center Flood Damage Assessment model

i ....vertical exit gradient

LD ....lacking sufficient data

LiDAR.............................light detection and ranging

NULE ....Non-Urban Levee Evaluation

Pf ....probability of failure

PFP ....probable failure point

PNP................................probable non-failure point

SPFC ....State Plan of Flood Control

ULE ....Urban Levee Evaluation

USACE............................U.S. Army Corps of Engineers

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DEPARTMENT OF WATER RESOURCES