FloodSAFE
CALIFORNIA

May 2012

Urban Levee Design Criteria

PUBLIC SAFETY ENVIRONMENTAL STEWARDSHIP ECONOMIC STABILITY

Cover Photo: Pocket Area of Sacramento, courtesy of U.S. Army Corps of Engineers

Urban Levee Design Criteria

May 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

Levees have been constructed incrementally within California over the past 150 years by various parties. Construction methods have varied from hand labor, suction dredges, clamshell dredges, and mule-drawn excavators to the most modern excavation, earthmoving, and compaction equipment. For many communities, flood protection is provided by levee systems commonly referred to as "legacy" levees because they were completed before the use of modern engineering and construction methods. Some levees have lost integrity over time due to settlement, erosion, flood-related distress, or burrowing animals. In many cases, the levees contain deteriorating infrastructure or old penetrations, and may also have woody vegetation that represents the last remnants of once-thriving riparian habitats along river channels. These age-related issues have challenged our ability to verify that appropriate levels of flood protection are being provided to our communities. Further complicating this situation is the fact that when we consider the annual probability of occurrence of future rare events (such as a 200-year-return-period event), there are actually relatively few years of rainfall and river flow records available to base our flood frequency estimates upon. All of these factors must be included in the assessment of the public safety of the flood protection systems for urban and urbanizing areas in California.

The *Urban Levee Design Criteria* (ULDC) provides engineering criteria and guidance for the design, evaluation, operation, and maintenance of levees and floodwalls that provide an urban level of flood protection (i.e., 200-year level of flood protection) in California, as well as for determining design water surface elevations (DWSE) along leveed and unleveed streams. Other topics beyond design and evaluation are presented to provide reasonable assurance that once a levee or floodwall is found to provide an urban level of flood protection, it will continue to do so.

Criteria are presented with terms such as "must," "shall," "is required," and "needs to." These and similar terms are considered to be mandatory; if not followed, an exception is needed (following the procedure for exceptions). Guidance is presented with the word "should." Guidance is a recommendation and is not mandatory; if not followed, an exception is not needed.

The ULDC is incorporated by reference in a closely related document, entitled *Draft Urban Level of Flood Protection Criteria* (2012). The *Draft Urban Level of Flood Protection Criteria* or its successor contains procedural criteria for determining whether a specific area has an urban level of flood protection. Those procedural criteria are needed for a complete understanding of the engineering criteria for levees and floodwalls that are contained within the ULDC. The procedural criteria include a procedure for exceptions from the engineering criteria because it is recognized that there will be special situations in which it would be appropriate to deviate from the engineering criteria.

While it is now State of California (State) law that urban and urbanizing areas within the Sacramento-San Joaquin Valley will need to make a Finding related to an urban level of flood protection before approving new development 36 months after the Central Valley Flood Protection Board (Board) adopts the Central Valley Flood Protection Plan (CVFPP) in 2012, this document is also intended to be available as a guideline for evaluating flood protection in other urban or urbanizing areas located in California. In those other areas outside of the boundaries of the Sacramento-San Joaquin Valley, there may be local practices/criteria in place that may differ from those described herein. If these local practices/criteria are less restrictive than those contained within this document, the responsible engineer should evaluate whether the local practices/criteria or the criteria contained in this document are more appropriate for that particular area.

The ULDC is limited to engineering criteria; mitigation and conservation requirements are not discussed. Implementation of these criteria may affect existing agreements and requirements set by regulatory and resources agencies. It is the responsibility of levee project implementers to work with the appropriate agencies in obtaining, updating, and complying with existing contracts, biological opinions, memoranda of understanding, and other agreements. The California Department of Water Resources (DWR) supports and encourages integration of ecosystem restoration and enhancement measures into levee repair and improvement projects. Moreover, DWR recognizes that projects that integrate other benefits, including water supply and recreation, may be more prudent investments and provide more sustainable and resilient flood risk management solutions than single-purpose projects that simply address public safety; thus to the greatest extent possible, multi-benefit levee repair and improvement projects are encouraged.

The ULDC provides criteria and guidance for levees and floodwalls without specifically addressing unique situations that occur when levees or floodwalls tie into levee-like structures, such as roadway or railway embankments. Such levee-like structures must be evaluated carefully, considering that they are generally not designed, constructed, operated, or maintained for retention of flood waters. If such structures do not comply with these criteria and are relied upon for a Finding that an area has an urban level of flood protection, the procedure for exceptions contained in the *Draft Urban Level of Flood Protection Criteria* or its successor, is to be followed.

The Board and the U.S. Army Corps of Engineers (USACE) have developed regulations and guidance documents for levee design, construction, evaluation, operation, and maintenance that should be reviewed and considered in addition to this document. For levees regulated by the Board and/or USACE, it is recognized that many of the design features and activities addressed in this document (e.g., installing or abandoning a pipe through a levee) may require their approval and may need to meet their requirements. In some respects, their requirements may be more or less stringent than the requirements in this document.

Several of the criteria contained in this document will create a need for the levee maintaining agency and the city or county to work together to achieve and maintain an urban level of flood protection. Examples of this include major levee rehabilitation and improvements, right-of-way, post-earthquake remediation plans, and flood safety plans. In some cases, the Board may also need to be involved. Examples of this include right-of-way, encroachments, and penetrations. The criteria provide flexibility to allow more than one of these entities to accomplish the work.

Users of this document should understand that the principles and criteria described herein are subject to change. As new information becomes available concerning the performance of levees and floodwalls, the criteria will be updated in response. Depending on the type or magnitude of any particular change in criteria, the impact on levee projects could be significant; therefore, every reasonable effort to incorporate the most current criteria should be made when designing and constructing levee repair or improvement projects. However, it should be recognized that improving the level of flood protection provided by a levee system is beneficial and substantially delaying the implementation of badly needed levee improvements, for a small increment of improvement, may not be in the public's best interest.

The initial urban level of flood protection Finding by a city or county that involves a levee or floodwall can either be based on the current engineering criteria in place at the time the Finding is made or the engineering criteria that were in place when the final plans and specifications for levee or floodwall construction were completed so long as the Finding is made within 5 years of this milestone. In cases where the current criteria are not used, the procedure for exceptions is to be followed. All subsequent Findings for the same levee or floodwall must be based on the engineering criteria that are in place when the process of making the Finding begins.

Depending on the topography of the area protected by a levee system, it may be possible to find that a particular area of land in that overall leveed area relies on only a portion of the entire levee system to comply with the ULDC. Therefore, a city or county that makes a Finding for only a portion of the levee system, and all or some of the land that portion protects, would also need to support that Finding with a floodplain mapping study demonstrating that the particular area of land is not subject to flooding from a 200-year flood should other noncompliant portions of the levee system breach. See Figure 1-1 as an example.

Finally, it must be remembered that there is a 14 percent chance over the typical 30-year-life of a home mortgage that a flood equal to or greater than a 200-year flood will occur. While improving our levees to a 200-year level of flood protection provides significant reduction in flood risk, there is always the chance that a larger flood will occur and overwhelm the flood protection system. This suggests that over time we should continually seek higher and higher levels of flood protection to keep the risk from increasing as more people and infrastructure are located in the floodplain, and add resilience to these levee systems to minimize flood damage that could occur during events that exceed design levels. Furthermore, levee improvement alternatives that have minimal expansion potential (e.g., partially penetrating cutoff walls) are less desirable and should be designed with factors of safety greater than the current design minimums. Conversely, levee improvement alternatives that can be more easily expanded should be favored.

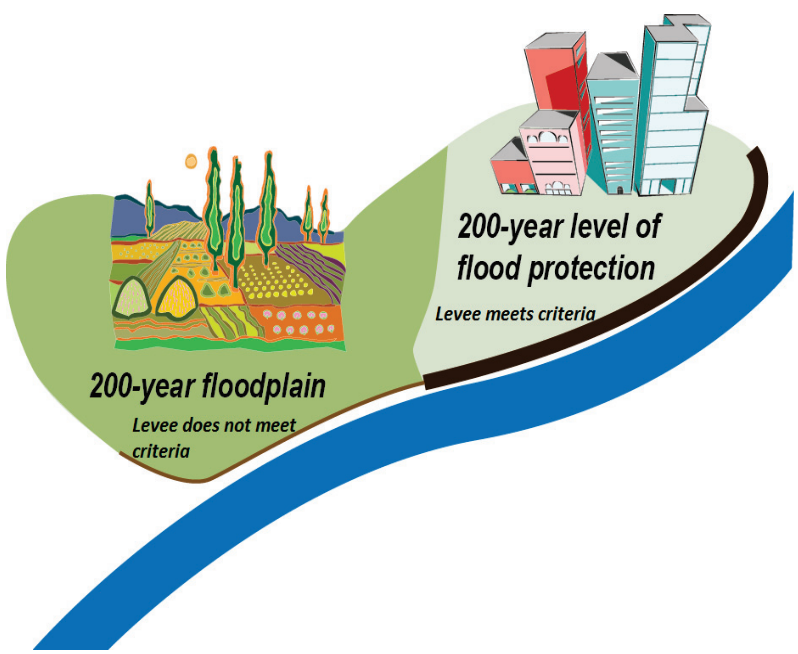

Figure 1-1. Example of Part of a Levee System Providing a 200-Year Level of Flood Protection

2.0 Purpose

The purpose of the ULDC is to provide engineering criteria and guidance for civil engineers to follow in meeting the requirements of California's Government Code Sections 65865.5, 65962, and 66474.5 with respect to Findings that levees and floodwalls in the Sacramento-San Joaquin Valley provide protection against a flood that has a 1-in-200 chance of occurring in any given year, and to offer this same guidance to civil engineers working on levees and floodwalls anywhere in California. The ULDC also provides engineering criteria and guidance for DWR's urban levee evaluations and participation in urban levee projects.

The ULDC may be updated from time to time, either in its current form or as regulations in the California Code of Regulations (CCR).

The ULDC was developed through a collaborative stakeholder involvement process with representatives from cities, counties, flood agencies, and State and federal agencies.

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3.0 Definitions

200-Year floodplain means an area that has a 1-in-200 chance of flooding in any given year, based on hydrological modeling and other engineering criteria accepted by the Department of Water Resources (Government Code Section 65300.2(a)).

Accreditation means recognition by the Federal Emergency Management Agency (FEMA) that a levee provides protection for the base flood (100-year or 1 percent annual chance) event, based on certification provided by a registered professional engineer or a federal agency with responsibility for levee design.

Adequate progress means all of the following:

a) The total project scope, schedule, and cost of the completed flood protection system have been developed to meet the appropriate standard of protection.

b) Revenues that are sufficient to fund each year of the project schedule developed in paragraph (a) have been identified and, in any given year and consistent with that schedule, at least 90 percent of the revenues scheduled to be received by that year have been appropriated and are currently being expended.

c) Notwithstanding paragraph (b), for any year in which state funding is not appropriated consistent with an agreement between a state agency and a local flood management agency, the Central Valley Flood Protection Board may find that the local flood management agency is making adequate progress in working toward the completion of the flood protection system.

d) Critical features of the flood protection system are under construction, and each critical feature is progressing as indicated by the actual expenditure of the construction budget funds.

e) The city or county has not been responsible for a significant delay in the completion of the system.

f) The local flood management agency shall provide the Department of Water Resources and the Central Valley Flood Protection Board with the information specified in this subdivision sufficient to determine substantial completion of the required flood protection.

> The local flood management agency shall annually report to the Central Valley Flood Protection Board on the efforts in working toward completion of the flood protection system (Government Code Section 65007(a)).

Appurtenant structures means features associated with a levee or floodwall that are necessary to reasonably reduce the potential of floodwater entering a defined area, and to manage ponding of internal drainage against the levee or floodwall through use of closure gates, flashboards, berms, revetments, pumping stations, culverts, and detention basins.

Assurance is a measure of confidence that the estimated 200-year water surface elevation used as the basis for design is equal to or higher than the true 200-year water surface elevation. This accounts for uncertainty about the true value that arises from fitting frequency curves with small samples of streamflow data, using imperfect knowledge and imperfect models of the hydrologic and hydraulic system.

Blanket layer means a top stratum of clayey and/or silty soil extending landward of the landside levee toe that has low vertical permeability in comparison to the horizontal permeability of deeper soils.

Board means the Central Valley Flood Protection Board (formerly The Reclamation Board).

Central Valley Flood Protection Plan (CVFPP) means a State plan that describes the challenges, opportunities, and a vision for improving integrated flood management in the Central Valley. The CVFPP documents the current and future risks associated with flooding and recommends improvements to the State-federal flood protection system to reduce the occurrence of major flooding and the consequence of flood damage that could result. The 2012 CVFPP was submitted by DWR to the Board on December 30, 2011, is required to be adopted by the Board by July 1, 2012, and is to be updated every 5 years thereafter. CVFPP development occurs under DWR's Central Valley Flood Management Planning Program.

Certification means a statement provided by a registered professional engineer that data submitted to FEMA supporting that a levee system complies with criteria specified in 44 Code of Federal Regulations (CFR) 65.10 for protection against the base flood (100-year or 1 percent annual chance) is accurate to the best of the engineer's knowledge. Alternatively, certification may mean that a federal agency with responsibility for levee design provides a statement that the levee has been adequately designed and constructed to provide protection against the base flood (44 CFR 65.10).

Civil engineer means a licensed civil engineer in the State of California.

Comprehensive Study means the 2002 Sacramento-San Joaquin River Basins Comprehensive Study. This study, led by USACE, provided estimates of median 100-year, 200-year, and 500-year flows and water surface elevations using various scenarios or sets of assumptions regarding whether and when upstream levees are breached. One set of assumptions, which is the set assumed in these criteria, had levees act as weirs and allow overtopping flows without levee breaching. This assumption is required by the USACE for National Flood Insurance Program (NFIP) levee system evaluations and is supported by FEMA in its levee system accreditations.

Creep ratio means the length of the seepage path along the line of creep divided by the maximum hydraulic head that could occur.

Critical gradient means the average head loss per foot of seepage traveling upward through a blanket layer at which seepage-induced movement of the soil particles will occur.

Critical infrastructure means the systems and assets, whether physical or virtual, that are so vital that their incapacitation or destruction may have a debilitating impact on the security, economy, public health or safety, environment, or any combination of these matters, across any federal, State, regional, territorial, or local jurisdiction.

Design Water Surface Elevation (DWSE) means the 200-year stage or water level used to design a levee or floodwall.

Developed area means an area of a community that is:

a) A primarily urbanized, built-up area that is a minimum of 20 contiguous acres, has basic urban infrastructure, including roads, utilities, communications, and public facilities, to sustain industrial, residential, and commercial activities, and

    1) within which 75 percent or more of the parcels, tracts, or lots contain commercial, industrial, or residential structures or uses; or

    2) is a single parcel, tract, or lot in which 75 percent of the area contains existing commercial or industrial structures or uses; or

3) is a subdivision developed at a density of at least two residential structures per acre within which 75 percent or more of the lots contain existing residential structures at the time the designation is adopted.

b) Undeveloped parcels, tracts, or lots, the combination of which is less than 20 acres and contiguous on at least three sides to areas meeting the criteria of paragraph (a) at the time the designation is adopted.

c) A subdivision that is a minimum of 20 contiguous acres that has obtained all necessary government approvals, provided that the actual "start of construction" of structures has occurred on at least 10 percent of the lots or remaining lots of a subdivision or 10 percent of the maximum building coverage or remaining building coverage allowed for a single lot subdivision at the time the designation is adopted and construction of structures is underway. Residential subdivisions must meet the density criteria in paragraph (a)(3) (Title 44 CFR Section 59.1 and Government Code Section 65007(c)).

DWR means the California Department of Water Resources.

Early Implementation Program means the DWR program that funds critical flood risk reduction projects that are initiated before adoption of the CVFPP. These projects are incorporated into the 2012 CVFPP. After adoption of the 2012 CVFPP, DWR will offer funding under a program that is the successor of the Early Implementation Program.

Encroachment means any obstruction or physical intrusion by construction of works or devices, planting or removal of vegetation, or by whatever means for any purpose, into any of the following:

- any flood control project works;
- the waterway area of the project;
- the area covered by an adopted plan of flood control; or
- any area outside the above limits, if the encroachment could affect any of the above (Title 23 CCR, Division 1, Chapter 1, Article 2, Section 4).

Exit gradient means the average head loss per foot for seepage traveling upward through a blanket layer.

Extended Finding means a Finding that applies to a specific geographic area, and can persist over time subject to specific requirements.

Facilities of the State Plan of Flood Control means the levees, weirs, channels, and other features of the federal and State authorized flood control facilities located in the Sacramento and San Joaquin River drainage basin for which the Board or DWR has given the assurances of nonfederal cooperation to the United States required for the project, and those facilities identified in Section 8361 of the California Water Code (Public Resources Code Section 5096.805(e)).

FEMA means the Department of Homeland Security's Federal Emergency Management Agency.

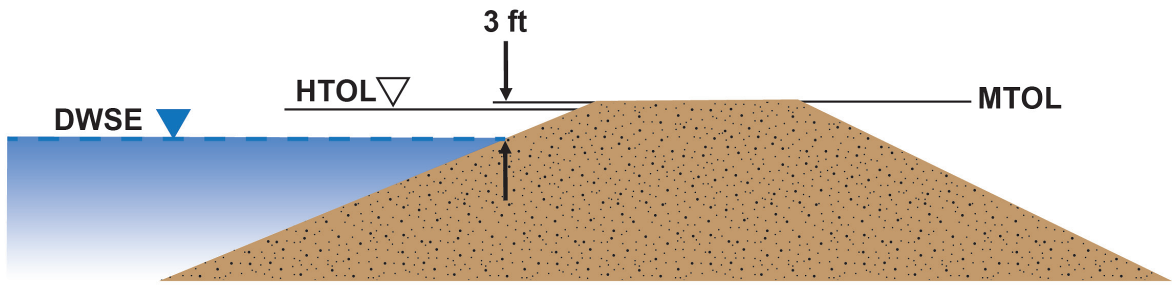
Finding means a written document describing an official declaration made by a city or county related to an urban level of flood protection (Government Code Sections 65865.5, 65962, and 66474.5). As used in this document, a Finding may also be an Extended Finding.

Flood risk is the likelihood and consequence of inundation. The consequence may be direct or indirect economic cost, loss of life, environmental impact, or other specified measure of flood effect. Flood risk is a function of (1) loading, which is the frequency and magnitude of flood discharge or stage; (2) limits to exposure to the loading due to flood defense measures; and (3) consequence. Therefore, flood management actions may reduce risk by changing loading, exposure, or consequence. For clarity, flood risk is commonly quantified within an identified area for a specified climate condition, land-use condition, and with a flood management system (existing or planned) in place.

Floodwall means a man-made barrier constructed of material other than soil along a water course for the primary purpose of providing flood protection.

Freeboard means the height of the physical top of levee or floodwall above the median 200-year water surface elevation, and serves as a factor of safety for containing water in the stream without overtopping the levee or floodwall.

Frequently loaded levee means a levee that experiences a water surface elevation of 1 foot or higher above the elevation of the landside levee toe at least once a day for more than 36 days per year on average (10 percent of the number of days in a year).



NOTE: DWSE ≤ HTOL ≤ MTOL

Figure 3-1. Example of the Hydraulic Top of Levee for a Typical Levee

Hydraulic top of levee (HTOL) is a water surface elevation at or between the DWSE and the Minimum Top of Levee (MTOL) that is used to provide reasonable assurance that the levee will be stable for extreme loading conditions (see Figure 3-1). The HTOL is the higher of either A or B, where A is the lower of (1) the median 200-year water surface elevation plus 3 feet, (2) the median 500-year water surface elevation, or (3) the MTOL; and B is the DWSE. Each water surface elevation used in calculating the HTOL is to be adjusted as discussed in Section 7.1.3.

Intermittently loaded levee means a levee that does not experience a water surface elevation of one foot or higher above the elevation of the levee toe at least once a day for more than 36 days per year on average.

Levee means a man-made barrier constructed of soil along a water course for the primary purpose of providing flood protection.

Levee system means one or more discrete reaches of levee and/or floodwall and other flood management structures along one or more streams that together provide flood protection to a common, defined area (i.e., the protected area).

Levee toe means the most landward point of the levee where the landside levee slope meets natural ground (see Figure 3-2).

Level of (flood) protection means the return period of the highest water surface elevation for which a property, project, or subdivision will withstand flooding, or a levee or floodwall will protect against flooding, using criteria and safety margins consistent with, or developed by, the California Department of Water Resources for achieving an urban level of flood protection (Government Code Section 65007(k) and California Water Code Section 9602(i)).

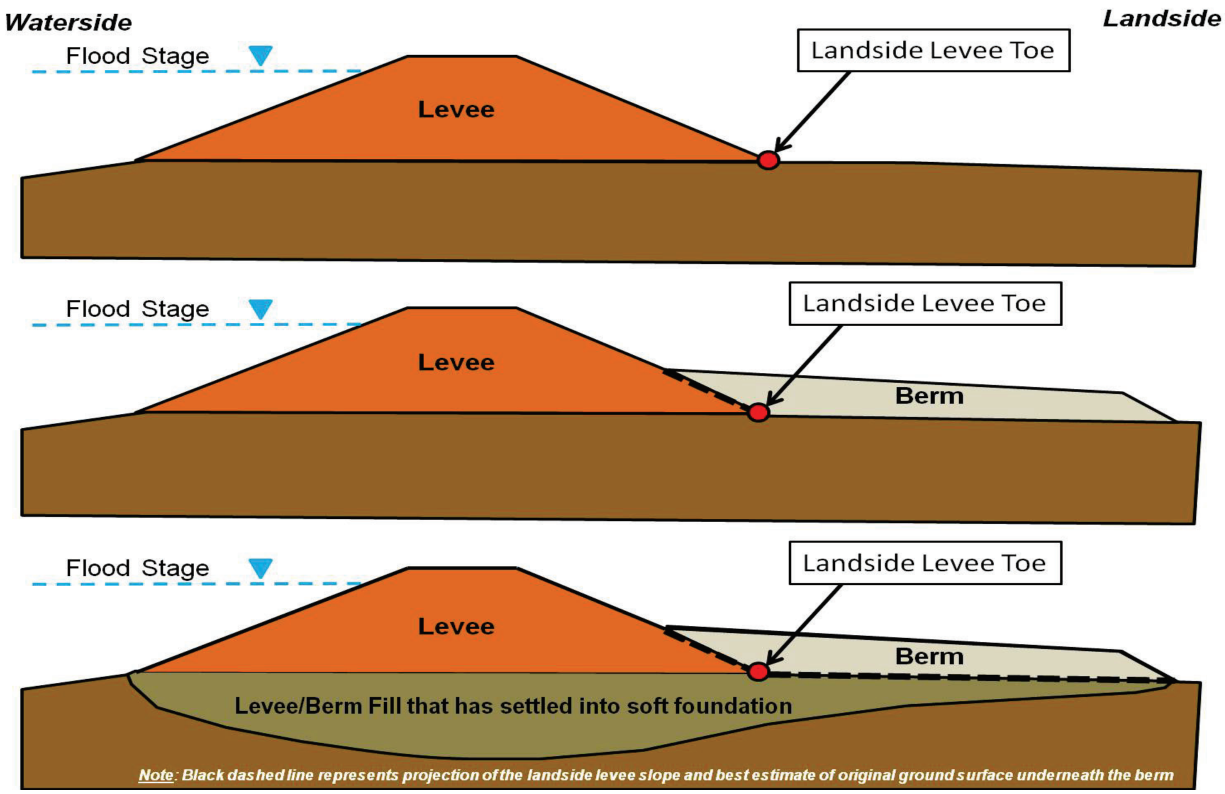


Figure 3-2. Levee Toe Schematic for Three Cases: (1) Levee Without Berm, (2) Levee with Berm, and (3) Levee with Berm on Soft Foundation

Median water surface elevation means the best estimate for the stage associated with the median flow for a given frequency. Median flow is as defined in the *Guidelines for Determining Flood Flow Frequency, Bulletin 17B of the Hydrology Subcommittee* (1982). The median flow for a given frequency may be estimated with standard procedures, including fitting a statistical model with unregulated streamflow observations; configuring, calibrating, and applying a watershed runoff model with design precipitation; or applying regional regression equations acceptable to FEMA, California Department of Transportation (Caltrans), USACE, or DWR. In determining the median water surface elevation, all levees in the region and upstream from the region are assumed to act like weirs and not breach when overtopped.

Minimum top of levee (MTOL) means the required minimum elevation of the physical top of the levee for providing reasonable assurance of containing the DWSE, including adjustments discussed in Section 7.1.3 and waves, assuming the levee is stable.

Non-project levee means a levee or floodwall that is not a project levee.

Nonurbanized area means a developed area or an area outside a developed area in which there are fewer than 10,000 residents (Government Code Section 65007(e)).

Penetration means a manmade object that crosses through or under a levee or floodwall and has the potential to provide a preferential seepage path or hydraulic connection with the waterside. Typically, a penetration is a pipe or transportation structure, such as a roadway or rail line.

Periodic review means a reoccurring review performed by a civil engineer at least every 5 years during the effective period of an urban level of flood protection Extended Finding. Or, it is to verify that a previous Accepted 200-Year Floodplain Map that includes levees or floodwalls providing an urban level of flood protection to more than 5 acres is still valid. The periodic review evaluates the operations and maintenance of the levee(s) or floodwall(s) and their appurtenant structures providing an urban level of flood protection to more than 5 acres, and determines that no damage, maintenance inadequacies, or significant physical change has occurred that impairs the ability of the levee(s) or floodwall(s) and their appurtenant structures to provide an urban level of flood protection. Previous land-use decisions based on an urban level of flood protection Extended Finding are not affected by periodic reviews.

Project levee means a levee or floodwall that is a facility of the State Plan of Flood Control, as defined in Public Resources Code Section 5096.805.

Relief cut means a man-made breach in a levee that is made by excavation or blasting that provides for evacuation of flood waters from within the protected area back to a stream or bypass.

Sacramento-San Joaquin Valley means any lands in the bed or along or near the banks of the Sacramento River or San Joaquin River, or any of their tributaries or connected therewith, or upon any land adjacent thereto, or within any of the overflow basins thereof, or upon any land susceptible to overflow therefrom. The Sacramento-San Joaquin Valley does not include lands lying within the Tulare Lake Basin, including the Kings River (Government Code Section 65007(g)).

State means the State of California.

State-Federal Flood Protection System means the collective works or facilities of the State Plan of Flood Control (California Water Code Section 9602(c)).

Urban area means a developed area in which there are 10,000 residents or more (Government Code Section 65007(j)).

Urbanizing area means a developed area or an area outside a developed area that is planned or anticipated to have 10,000 residents or more within the next 10 years (Government Code Section 65007(k)).

Urban levee design criteria (ULDC) means the levee and floodwall design criteria developed by DWR for providing the urban level of flood protection (Government Code Section 65007(k) and California Water Code Section 9602(i)).

Urban level of flood protection means the level of protection that is necessary to withstand flooding that has a 1-in-200 chance of occurring in any given year using criteria consistent with, or developed by, the Department of Water Resources (Government Code Section 65007(l) and California Water Code Section 9602(i)).

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

USACE's risk and uncertainty (R&U) approach means the analysis of flood hazard in which the uncertainty of contributing factors is accounted for explicitly – especially uncertainty in hydrologic and hydraulic inputs and in levee performance. The R&U procedures considered herein are those described in EM 1110-2-1619 and included in the HEC-FDA software application.

Vegetation management zone means the area on and near a levee in which vegetation is managed for visibility and accessibility using a life-cycle management approach discussed in Section 7.16.7. The vegetation management zone includes the entire landside levee slope (and berm) plus 15 feet beyond the landside toe (or less if the existing easement is less than 15 feet), the levee crown, and the top 20 feet (slope length) of the waterside levee slope (see Figure 7-5). For levees that have a waterside slope length of less than 20 feet, the vegetation management zone includes the entire waterside slope plus the extent of waterside berm within 20 feet of the crown as measured along the ground surface (see Figure 7-6). For levees that have a short waterside slope length above the water surface elevation that submerges the lower waterside slope frequently enough to prevent long-term tree establishment, the lower 5 feet (slope distance) of the waterside slope immediately above that water surface elevation is not included in the vegetation management zone (see Figure 7-7). For levees with a landside berm at least 3 feet thicker than required for structural integrity, the portion of the berm that is more than 15 feet from both the landside levee slope and the landward edge of the top of the berm is not included in the vegetation management zone (see Figure 7-8).

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4.0 Need

State law enacted in 2007 (Senate Bill [SB] 5) calls for 200-year flood protection to be the minimum level of flood protection for urban and urbanizing areas in the Sacramento-San Joaquin Valley (i.e., the urban level of flood protection). Beyond 36 months after adoption of the CVFPP (expected in 2012), the new law limits the conditions for approval of development if adequate progress toward achieving this standard is not met (Government Code Sections 65865.5, 65962, 66474.5). Urban and urbanizing areas protected by project levees (i.e., levees or floodwalls that are a facility of the State Plan of Flood Control) cannot use adequate progress as a condition to approve development after 2025. SB 5 requires that the urban level of flood protection be consistent with criteria used or developed by DWR (Government Code Section 65007(l)). To avoid delaying urgently needed flood protection, levee and floodwall design criteria are needed. The ULDC fulfills this need.

DWR reviewed current guidance and levee and floodwall criteria by the USACE and FEMA. This guidance is primarily contained in the USACE's EM 1110-2-1913, ETL 1110-2-569, EC 1110-2-6067, Section 65.10 of CFR Title 44, and FEMA's MT-2 form and instructions. With the exception of hydrologic, hydraulic, and levee freeboard requirements, FEMA's levee and floodwall design guidance contains no specific criteria and suggests use of various USACE documents. USACE has developed most of the guidance needed for engineers to design levee systems, and most engineers in the nation who are involved in levee and floodwall design and construction use that guidance. However, some important aspects of USACE guidance lack specificity, need to be modified, or are still under development (this is explained further in Section 5.0). For example, the USACE definition for a frequently loaded levee lacks specificity and there are no seismic design requirements for intermittently loaded levees. Due to the changing state of practice and the absence of specific guidance from the federal government on some levee design considerations, DWR has needed to provide guidance and criteria for DWSEs and levee and floodwall design for:

- Evaluations of project levees in urban and urbanizing areas
- Evaluations of non-project levees in urban and urbanizing areas
- Designs for urban and urbanizing area levees and floodwalls to be initiated/completed in the near future

- Eligibility criteria for urban Early Implementation Program funding[1]
- Assisting engineers, cities, counties, and local flood agencies in achieving FEMA 100-year flood protection
- Assisting engineers, cities, counties, and local flood agencies in achieving the urban level of flood protection
- Planning studies, such as the CVFPP

[1] The citizens of California passed two bond measures on November 6, 2006, that provide $4.9 billion of bond funds for reducing flood risk in California. Several urban areas in the Sacramento-San Joaquin Valley have received bond funding under DWR's Early Implementation Program. After adoption of the CVFPP, DWR will offer funding under a program that is the successor of the Early Implementation Program.

5.0 Background

Except for some Sacramento Valley levee construction early in the 20th century by the Board and the bypass levees constructed by DWR in the 1960s on the San Joaquin River, the State has only built or improved project levees in the Sacramento-San Joaquin Valley by partnering with USACE. In these partnerships, USACE set the design standard and constructed the levees accordingly. For the first time since the 1960s, the State is now in the lead in performing (or providing funding for local agencies to perform) new levee construction and improvements to existing levees. It is highly desirable to follow USACE design criteria to provide consistency in system improvements, comply with existing standards, and to facilitate federal crediting. However, the USACE levee and floodwall design criteria are evolving and some important aspects are not established in writing at this time.

Floodplain maps throughout the nation are being updated by FEMA under its Map Modernization Program pursuant to the procedures contained in Procedure Memoranda 34 and 43, issued in August 2005 and September 2006, respectively. These procedures require certification of the data supporting the adequacy of levees for protection against the base flood (i.e., 100-year flood) to maintain their current accreditation by FEMA (44 CFR Part 65.10). Levee owners and communities relying on these accredited and previously accredited levees are seeking to maintain or restore accreditation by performing engineering evaluations of their levees using available FEMA and USACE guidance.

Project levees and appurtenant non-project levees in the Sacramento-San Joaquin Valley are being evaluated for geotechnical adequacy by DWR. The evaluations will be used to support planning studies and decisions, the design of repairs and improvements, and floodplain mapping studies. Sacramento-San Joaquin Valley communities desire to maintain, or regain at the earliest opportunity, accreditation of the levees affecting their communities – thereby allowing urban growth to continue and flood insurance to be optional instead of mandatory.

In addition to FEMA’s requirements, SB 5 (i.e., Government Code Sections 65865.5, 65962, 66474.5) requires urban and urbanizing areas in the Sacramento-San Joaquin Valley to achieve, or have adequate progress toward, the urban level of flood protection within 36 months after adoption of the CVFPP to continue development in the 200-year floodplain. Urban and urbanizing areas protected by project levees in the Sacramento-San

Joaquin Valley will need to achieve the urban level of flood protection by 2025 to continue development in the 200-year floodplain. Consequently, an early goal of most Sacramento-San Joaquin Valley communities is to provide 100-year FEMA-level protection as an important milestone on the way toward achieving an urban level of flood protection. By having criteria for an urban level of flood protection while the levee construction is performed for achieving FEMA-level protection, the constructed features can be made compatible or expandable for achieving an urban level of flood protection.

In designing and certifying levees there are two commonly used approaches:

- **The FEMA Approach** – used by most civil engineers to certify and/or design levees for accreditation by FEMA, is a deterministic design approach based on the median 100-year water surface elevation. The levee must be analyzed for erosion, stability, seepage, and settlement based on this water surface and a minimum amount of freeboard (typically 3 feet) provided above this water surface elevation. As little as 2 feet of freeboard may be allowed if the uncertainty in flow and stage is characterized and justifies less than 3 feet of freeboard. Except for the last 10 to 15 years, USACE typically used this deterministic approach also. In recent years, USACE has been developing and using a combined probabilistic and deterministic approach. FEMA has been working with USACE on the concept of transitioning from its current deterministic approach to USACE's new approach.

- **The USACE Approach** – developed and used by USACE, is a combined probabilistic and deterministic approach that considers uncertainty in DWSE, combined with a deterministic geotechnical levee evaluation. The DWSE is calculated using probabilistic methods (discussed in more detail below) so that uncertainty is quantified. The DWSE is then used to perform a deterministic geotechnical evaluation of the levee. The USACE procedure for certification, called an NFIP levee system evaluation, uses deterministic seepage and slope stability analyses and conventional factors of safety for the 90 percent assurance 100-year water surface elevation. The USACE procedure for NFIP evaluations also requires at least 3 feet of freeboard, unless the top of levee is at or above the 95 percent assurance 100-year water surface elevation and provides at least 2 feet of freeboard. It also requires that the hydraulic modeling assume that other levees and floodwalls in the region not breach, even when overtopped.

Because a completely probabilistic approach for developing the DWSE would consider and describe with a probability distribution all of the important uncertainties influencing the DWSE, the USACE Approach to date in the Sacramento-San Joaquin Valley can be properly characterized as a conditional probabilistic approach: simplifying assumptions are made to fix values of some uncertain inputs in the risk and uncertainty analysis. In most cases, the simplifying assumptions introduce conservatism. The result is that the USACE Approach described herein tends to result in water surface elevations with less likelihood of being exceeded than stated (i.e., a 90 percent assurance water surface elevation for a 200-year event actually has less than a 10 percent chance of being exceeded). This is also true for the FEMA Approach, since some conservative assumptions are employed in developing the median water surface elevation.

Historically, most of the levee breaches in the Sacramento-San Joaquin Valley have been caused by slope instability or seepage (including underseepage). Such breaches tend to occur rapidly and with little or no warning–leaving little opportunity for evacuation before flooding. On the other hand, breaches caused by levee overtopping are foreseeable and such levee breaches tend to progress more slowly, and in some cases can be prevented through aggressive flood-fighting. Levee breaches from overtopping provide much better opportunity to successfully evacuate the threatened area and to take steps to minimize damage to personal property. Consequently, although this is not a consideration in FEMA's 44 CFR 65.10, USACE considers capacity exceedance in its NFIP levee system evaluations. Furthermore, for designing levees, USACE has begun considering new criteria that require factors of safety for seepage and slope stability in excess of 1.0 for flood water at the top of the levee. USACE has not yet established the minimum factors of safety or a definition for the top of levee, or evaluated the cost-effectiveness of this requirement to justify it in an economic analysis. Because it is primarily a life-saving and injury-reducing criterion, it may not be possible to justify it economically. Nevertheless, DWR supports this approach for levees and floodwalls that protect urban and urbanizing areas as a reasonable requirement for protecting life and personal property and provides detailed criteria for this approach later in this document. DWR also recognizes that this requirement will tend to control the design of short levees far more often than for tall levees, simply because a few feet of additional hydrostatic loading on a short levee can constitute a large percentage increase in the driving head for seepage. But ignoring or relaxing the criteria for short levees may create an unsafe situation where the levee system would not have resiliency to handle these higher loads without distress.

Evaluation and mitigation for seismic performance of levee systems has generally had low priority in the past, except for levees with a high likelihood of having coincident high water and earthquake loading, such as many levees in the Sacramento-San Joaquin Delta (Delta). More current thinking is that intermittently loaded levees should be evaluated for seismic performance using typical water surface levels and addressing the post-seismic flood risk through emergency response, interim and long-term repairs following the earthquake, and/or seismic remediation before the earthquake.

6.0 Guiding Principles

Guiding principles serve as the foundation for specific levee and floodwall design criteria that follow in subsequent sections of this document. The ULDC is built upon USACE guidance and, to a lesser extent, FEMA guidance. Except for criteria specifically provided in this document, the guidance for levee and floodwall design provided in USACE's EM 1110-2-1913, EM 1110-2-2502, ETL 1110-2-569, EC 1110-2-6067, the *Geotechnical Levee Practice Standard Operating Procedures* (2008) for the Sacramento District, and other USACE guidance documents for the selected design flood event is considered to be applicable. The ULDC addresses three distinct cases:

1) Existing guidance lacks some specific details.

2) Existing guidance is under development.

3) Existing guidance needs modification.

6.1 General Principles

To the extent applicable, the FEMA Approach is considered acceptable because it provides for a reasonably conservative levee height and is commonly used by engineers. However, the FEMA Approach is not explicit in some of its requirements and does not consider the consequences of a levee breach or floodwall failure in an urban area or the failure mode of the levee for events that exceed design.

To the extent applicable, the USACE Approach is considered acceptable because it provides for a reasonably conservative levee height and may already be in use by USACE on a federal levee study or project for which the ULDC is being applied. Most aspects of the USACE Approach can be used by the State and local agencies as a basis of design, with some modifications and clarifications.

To the extent practical, sufficient right-of-way should be acquired to provide vehicular access along the landside levee toe, provide control of activities that could impact levee performance, and to provide for future levee expansion should it be needed.

Encroachments and vegetation should be evaluated and managed so as to not impact levee and floodwall safety, while recognizing their benefits.

With few exceptions, urban levee systems should be designed to perform without relying upon emergency actions, such as flood-fighting, and should have associated flood safety plans for emergency response that reduce the chance of levee breaches, floodwall failures, and loss of life.

Levee systems protecting urban areas need levee security plans with appropriate measures in place to protect against acts of terrorism and other malicious and negligent acts.

Criteria for operation, maintenance, inspection, monitoring, and remediation of poor performance are needed to provide reasonable assurance that levee systems are being properly maintained and performing as intended.

Future changes to the ULDC will need to be carefully evaluated for potential impacts on levee repair and improvement projects that are underway or have been completed recently.

6.2 Geotechnical Design Principles

Urban and urbanizing area levees should be designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) for flood stages at the top of the levee so that erosion from overtopping would be the expected cause of levee breaching for extreme flood events. However, there will be exceptions to this general rule where the physical top of levee provides more than the minimum required freeboard. By establishing design criteria based on the HTOL, these exceptions are considered to be acceptable and levee crown degradation (as a way of increasing the likelihood of overtopping before levee breaching) is not encouraged.

Performance of urban and urbanizing area levees and floodwalls during a seismic event with 200-year-return-period ground motions should be considered for existing levees as well as in the selection of all levee repair and improvement alternatives. Repairs or improvements primarily for seismic strengthening generally would not be justifiable for intermittently loaded levees. But there can be situations where such repairs or improvements are warranted. Otherwise, seismic remediation could occur as needed after the earthquake, pursuant to an appropriate post-earthquake remediation plan.

Frequently loaded levees and floodwalls should have additional reliability, approaching that expected of dams, and should continue to function during and after ground motions from a 200-year-return-period earthquake.

6.3 Hydrologic and Hydraulic Design Principles

Urban and urbanizing area levee and floodwall designs should assume that (1) other levees and floodwalls in the regional system upstream and downstream from the area do not breach, even when overtopped, (2) other levees and floodwalls in the regional system upstream and downstream from the area are no lower than their authorized design elevations, and (3) other urban levees in the regional system upstream and downstream from the area will have at least 3 feet of freeboard with respect to the 200-year water surface, which should be computed through appropriate analytical methods.

Urban and urbanizing area levee and floodwall designs should consider the potential for sea level rise and climate change to increase runoff and peak stages over those calculated using previous hydrology and hydraulics studies, considering the physical limitations of the regional system. A sensitivity analysis of increased stream flows can be useful in evaluating how high the DWSE should be raised.

Levees and floodwalls protecting urban and urbanizing areas should be designed as a system.

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7.0 Urban Levee Design Criteria

The following criteria and guidance are presented according to specific topics. Most of the criteria and guidance pertain to levee and floodwall design. However, some criteria and guidance pertain to other topics, such as emergency response, security, and operation and maintenance. Criteria and guidance for determining the DWSE apply for both leveed and unleveed streams.

The Board and USACE have developed regulations and guidance documents for levee design, construction, evaluation, operation, and maintenance that should be reviewed and considered in addition to this document. Except for criteria specifically provided in this document, the guidance for levee and floodwall design provided in USACE's EM 1110-2-1913, EM 1110-2-2502, ETL 1110-2-569, EC 1110-2-6067, the *Geotechnical Levee Practice Standard Operating Procedures* for the Sacramento District, and other USACE guidance documents for the selected design flood event needs to be followed. The most current version of these documents should be used.

As mentioned earlier, criteria are presented with terms such as "must," "shall," "is required," and "needs to." These and similar terms are considered to be mandatory; if not followed, an exception is needed (following the procedure for exceptions). Guidance is presented with the word "should." Guidance is a recommendation and is not mandatory; if not followed, an exception is not needed.

7.1 Design Water Surface Elevation

Two options are offered for determining the DWSE for urban and urbanizing area levee system design:

- FEMA Approach
- USACE Approach

For an urban area or urbanizing area, the entire levee system needs to be designed to provide a Finding of the urban level of flood protection using only one of the two options.

7.1.1 FEMA Approach

The DWSE is computed using the median 200-year discharge rate for the design storm event at the site. Appropriately configured channel models are to be used for computation of the elevation that corresponds to that discharge, as described below. The median discharge rate is to be determined from the best available results of recent flood-frequency studies and the channel models are to be configured using, or adjusted for, channel roughness values consistent with vegetation that is anticipated or likely to grow over the next 20 years. If results of a recent frequency study completed by USACE or DWR are available, the median 200-year discharge rate from that study is to be used. In the absence of an appropriate discharge rate from such a recent study, the 200-year discharge rate at the site from the 2002 Comprehensive Study may be used, if that is available. Finally, if an appropriate design discharge rate is not available for either a recent USACE or DWR study or the Comprehensive Study, the median 200-year discharge may be computed by the engineer with appropriate methods. Those methods include fitting a statistical model with unregulated streamflow observations; configuring, calibrating, and applying a watershed runoff model with design precipitation; or applying regional regression equations acceptable to FEMA, Caltrans, USACE, or DWR.

The hydraulic models are to use the following assumptions:

- Upstream, downstream, and nearby levees and floodwalls protecting urban areas are assumed to be raised to the median 200-year water surface elevation plus 3 feet and not allowed to breach, even if overtopped. Overtopping flows are assumed to leave the channel and remain in the 200-year floodplain.

- All project levees and floodwalls are to be modeled to incorporate a minimum crown elevation equal to the authorized (usually the 1955/1957) USACE design profiles – this affects nonurbanized areas for the most part – all such levees and floodwalls are to be allowed to overtop, act as weirs, and not breach for floods up to and including the median 500-year flood. Overtopping flows are assumed to leave the channel and remain in the 200-year floodplain.

- Non-project levees and floodwalls in nonurbanized areas in the region, to the extent they may affect the DWSE, are to be modeled at their existing or authorized height, whichever is higher, and to act as weirs without breaching if overtopped.

- Debris loading on bridges must be considered. Bridges with less than 3 feet of clearance above the DWSE may experience extraordinary debris loading that must be evaluated in addition to typical pier/bent debris loading. The evaluation should include historic and potential debris transport in the stream, an analysis of loading on the bridge, and analysis of backwater impacts on the DWSE in the vicinity of the bridge.

The median 200-year water surface elevation becomes the unadjusted DWSE, and the civil engineer considers adjustments described in Section 7.1.3.

7.1.2 USACE Approach

This approach requires specification of the median 200-year water surface elevation and a description of uncertainty about that elevation. The median water surface elevation from which the DWSE will be established should be computed with a channel model configured as described below, using the median 200-year discharge rate for the design storm event at the site, along with a description of uncertainty about that discharge and the corresponding stage that considers anticipated or likely vegetation growth over the next 20 years (procedures for developing the description of the uncertainty are presented in EM 1110-2-1619 and are included in the HEC-FDA computer program). The discharge-frequency function from which the required design discharge is to be taken should be the best available function from recent flood-frequency studies. If results of a recent frequency study completed by USACE or DWR are available, the 200-year discharge rate from that study and the description of uncertainty about that should be used. In the absence of an appropriate discharge rate from such a recent study, the 200-year discharge rate at the site from the 2002 Comprehensive Study may be used, if that is available. Finally, if an appropriate design discharge rate is not available for either a recent USACE or DWR study or the Comprehensive Study, the median 200-year discharge rate and uncertainty about that may be computed by the engineer with appropriate methods. Those methods include fitting a statistical model with unregulated stream flow observations; configuring, calibrating, and applying a watershed runoff model with design precipitation; or applying regional regression equations acceptable to FEMA, Caltrans, USACE, or DWR. Ratings or hydraulic models used to predict stage, given the design discharge, must represent channel conditions anticipated over the next 20 years, including growth or removal of vegetation and other features that influence elevation.

The hydraulic models are to use the following assumptions:

- Upstream, downstream, and nearby levees and floodwalls protecting urban areas are assumed to be raised to the median 200-year water surface elevation plus 3 feet and not allowed to breach, even if overtopped. Overtopping flows are assumed to leave the channel and remain in the 200-year floodplain.

- All project levees and floodwalls are to be modeled to incorporate a minimum crown elevation equal to the authorized (usually the 1955/57) USACE design profiles – this affects nonurbanized areas for the most part – all such levees and floodwalls are to be allowed to overtop, act as weirs, and not breach for floods up to and including the median 500-year flood. Overtopping flows are assumed to leave the channel and remain in the 200-year floodplain.

- Non-project levees and floodwalls in nonurbanized areas in the region, to the extent they may affect the DWSE, are to be modeled at their existing or authorized height, whichever is higher, and to act as weirs without breaching if overtopped.

- Debris loading on bridges must be considered. Bridges with less than 3 feet of clearance above the median water surface elevation may experience extraordinary debris loading that must be evaluated in addition to typical pier/bent debris loading. The evaluation should include historic and potential debris transport in the stream, an analysis of loading on the bridge, and analysis of backwater impacts on the DWSE in the vicinity of the bridge.

The civil engineer must determine the median 200-year water surface elevation and the corresponding 90 percent and 95 percent assurance 200-year water surface elevations with the procedures described above. The 90 percent assurance 200-year water surface elevation becomes the unadjusted DWSE, and the civil engineer considers adjustments described in Section 7.1.3.

7.1.3 DWSE Adjustments and Other Considerations

The civil engineer needs to consider making adjustments to the DWSE and whether there are other scenarios that could increase the DWSE as a result of nearby or upstream levee or floodwall breaches, as discussed below.

The civil engineer needs to evaluate whether there is a bend in the channel that could cause superelevation along the outside of the bend to become a concern. Superelevation is a tilting of the water surface; this may occur as water flows through a bend in the channel. In other than straight sections of a channel, superelevation is to be checked with velocity consistent with the 200-year discharge. EM 1110-2-1601 describes computational methods for superelevation. On the outside of a bend, the superelevation needs to be added to the DWSE (and HTOL). The DWSE (and HTOL) may not be reduced on the inside of a bend to account for negative superelevation as this stage reduction cannot be relied upon to occur at all times.

Based on the potential for underestimating the DWSE, the civil engineer should consider increasing the DWSE to account for the potential increases in water surface associated with climate change, updated hydrology, updated hydraulic models, and sea level rise. To the extent that the hydrology being used does not explicitly take into consideration climate change, the decision to increase the DWSE, and the actual amount to increase it by, should be based on a sensitivity analysis of the reach-specific variables. Civil engineers can consider the potential for increases in the DWSE and address it in a range of ways from not incorporating any change to adding 1 foot or more. The benefits of increasing the DWSE include providing a higher level of flood protection and minimizing the need to modify flood management structures in the future should the DWSE increase.

The above procedures should generally result in a conservative DWSE. However, the civil engineer also needs to address two other situations: (1) whether upstream levee or floodwall breaches could produce overland flows that would reach the area protected by the levee system or increase the water surface elevation along the levee system, and (2) whether flooding in a nearby leveed area could fill that area and breach a nearby levee or floodwall, returning flow to the stream and increasing the DWSE for a portion of the levee system.

7.2 Minimum Top of Levee

The MTOL, which may be measured either along the levee centerline or shoulder (and may include the roadway surface), is a required minimum elevation for the physical top of the levee to provide an adequate factor of safety that the levee will contain the 200-year flood without being overtopped. Under the FEMA Approach, freeboard is used to provide this factor of safety. Under the USACE Approach, this factor of safety is provided by a combination of freeboard and use of a DWSE with a high degree of assurance (either 90 percent or 95 percent assurance). Levees that meet the MTOL requirement are considered to be high enough to keep water out of the leveed area for the 200-year flood. Conversely, levees that are lower than the MTOL lack an adequate factor of safety for containment and are less likely to keep water out of the leveed area for the 200-year flood; unless such levees are designed for overtopping, they cannot be assumed to sustain overtopping during the 200-year flood without substantial damage or breaching. Levees that fail to meet elevation requirements are not generally accredited under FEMA or USACE guidelines for FEMA flood insurance studies (so the floodplain mapping study would assume the levee is absent or breached). But there may be rare situations where it is prohibitively expensive to meet the MTOL requirement and an alternative engineering solution can be employed (for example, where clearance requirements for overhead power lines are a constraint). Such cases must be approved as an exception and must address the prospect that the 200-year flood could overtop the levee, flooding property in the leveed area as well as breaching the levee.

Using the FEMA Approach, the MTOL is the higher of the DWSE plus 3 feet or the DWSE plus the computed wind setup and wave runup. Specific wind-wave analyses need to be completed using the DWSE. For the special case of the DWSE being fully contained within the channel, such that the reach of levee is only providing freeboard, it is recognized that floodplain mapping procedures generally would not require such a levee. This is because floodplain mapping procedures would identify the 200-year floodplain as being fully contained within the channel, with no overbank flow. So a city or county that chooses not to find that the freeboard levee complies with the ULDC can still find that the area that would have been protected by the freeboard levee has an urban level of flood protection (if it is not subject to flooding from other sources). The civil engineer should carefully consider providing a freeboard levee in this case, weighing the consequences of flooding caused by waves or by water surface elevations that exceed the DWSE in the event it is underestimated or exceeded by a larger flood.

Using the USACE Approach, the MTOL is the higher of either: (1) the DWSE, (2) the median 200-year water surface elevation plus adjustments and 3 feet, or (3) the median 200-year water surface elevation plus adjustments and computed wind setup and wave runup. Specific wind-wave analyses need to be completed using the median 200-year water surface elevation after adjustment. A lower MTOL is allowed if it is both: (1) at or above the 95 percent assurance 200-year water surface elevation, and (2) at least 2 feet above the median 200-year water surface elevation, plus any additional height needed to account for wind setup and wave runup. Under this approach, a freeboard levee is required if the median 200-year water surface elevation is less than 2 feet below the top of bank; and it may be required for a lower median 200-year water surface elevation.

7.3 Soil Sampling, Testing, and Logging

Soil sampling, testing, and logging should follow standard procedures described in current guidance documents from USACE; U.S. Department of the Interior, Bureau of Reclamation; DWR; and others – such as the USACE Sacramento District's *Geotechnical Levee Practice Standard Operating Procedures* and DWR's *Division of Flood Management Soil and Rock Logging, Classification, Description and Presentation Manual* (2009), exercising proper care to:

- Sample soils, especially soft soils, used for strength and deformation analysis in a way that minimizes disturbance.
- Evaluate hydraulic conductivity using appropriate grain size analyses (including hydrometer) along with confirmatory laboratory permeability testing. Where appropriate, perform field pumping/infiltration testing to measure *in situ* properties.
- Perform consolidation tests that ensure the strain level exceeds virgin compression.
- Conduct strength tests with appropriately low strain rates and reflective of the low confining pressures near the landside levee toe.
- Use an appropriate field logging manual, such as appropriate American Society for Testing and Materials (ASTM) guidance and DWR's *Division of Flood Management Soil and Rock Logging, Classification, Description and Presentation Manual*.

7.4 Slope Stability for Intermittently Loaded Levees

7.4.1 Landside Slope Stability

Landside slope stability analyses are to use appropriate phreatic surfaces based on the DWSE and HTOL (if the HTOL is more than 0.5 foot above the DWSE – otherwise a separate slope stability analysis with the HTOL is not required). A minimum factor of safety of 1.4 is required for failure surfaces based on the DWSE that intersect the levee crown and are greater than a few feet deep in the levee slope. A minimum factor of safety of 1.2 is required for failure surfaces based on the HTOL that intersect the levee crown and are greater than a few feet deep in the levee slope, as discussed later.

The steady-state phreatic surface is generally considered to be appropriate, but a lower phreatic surface may be justified for slope stability analysis depending on the duration of the design hydrograph, the composition and dimensions of the levee, and the levee's performance history. Except for levees with a positive cutoff or internal drainage features, a phreatic surface lower than the steady-state phreatic surface is only justified for levee/foundation materials and construction methods that are well-understood and documented. The lowest phreatic surface that normally could be justified for a homogeneous levee would be along a straight line extending from the landside levee toe to the point where the DWSE (or HTOL) intersects the waterside levee slope. Deviations from use of a steady-state phreatic surface for levees subjected to river stage loading for short durations must be substantiated through appropriate presentation of information such as hydraulic data, field piezometric data and engineering evaluations. In certain circumstances, this can be achieved through transient seepage analyses. However, steady-state pore pressures within confined aquifers should generally be assumed for the purposes of underseepage analyses.

If the phreatic surface corresponding to the DWSE or HTOL emerges on a landside levee slope consisting of erodible soils, then remediation will be required to prevent unraveling and progressive slope failure that may lead to a levee breach (see discussion of extremely wide levees in Section 7.8, if applicable).

Shallow slip surfaces often develop on the slopes of levees during periods of heavy rain and/or elevated river stage. Shallow slides typically cut only a small portion of the levee slope and do not penetrate more than a few feet into the levee section. In cases where the shallow slide is above the phreatic surface and within a non-erosive cohesive material, the slide might be considered as not a serious threat to the integrity of the levee. These shallow surfaces are not a concern since they may be considered maintenance issues and will not lead to a levee breach. This is in contrast to the generally much more serious deeper sliding surfaces that might pass through the levee crown and remove much of the levee section (see deeper circular and noncircular sliding surfaces in Figure 7-1) or local toe slip surfaces which may remove a piece of the slope at the base of the slope and provide conditions for a progressive failure. On the other hand, a shallow slide in the lower portion of a levee constructed with noncohesive materials where seepage is exiting relatively high on the landward slope can be extremely dangerous (see lower black shallow sliding surface in Figure 7-1). This is because a small slide at this location can lead to a progressive through-levee seepage/stability failure.

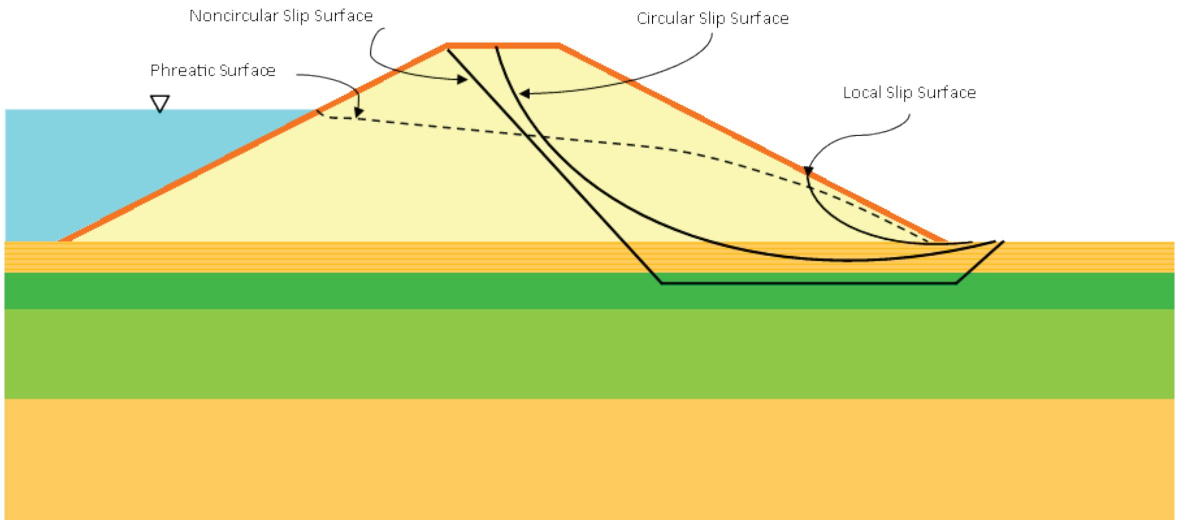

Figure 7-1. Potential Slip Surfaces for Steady-State Condition Stability Analysis

The potential threat to levee integrity from small sliding surfaces will vary greatly for different levees. Engineers should use sound engineering judgment and guidance from EM 1110-2-1902 to decide what constitutes a minor, insignificant slip surface versus a sliding surface that threatens the integrity of the levee. These determinations should be based on performance history, levee geometry, type of levee fill material, stratigraphy of the levee embankment and foundation soils, seepage conditions (including pore water pressures calculated for the seepage analysis), soil strength characteristics, and potential for erosion. Those surfaces which significantly threaten the integrity of the levee must meet minimum slope stability criteria.

7.4.2 Waterside Slope Stability

A rapid lowering of water level from a sustained high water condition causes rapid drawdown loading of a levee's waterside slope. This condition may occur due to either a decrease in upstream reservoir releases, decreases in surface drainage inflow, or as a result of a levee or floodwall breach in an adjacent/upstream levee reach. The rapid drawdown shall be considered from the DWSE. The amount of drawdown should be established based on site-specific data and/or hydrologic and hydraulics studies, using sound engineering judgment. As per USACE guidance, a factor of safety for stability of 1.0 to 1.2 is required, depending on the extent to which the DWSE may have saturated the waterside levee slope.

As with the condition for the steady-state seepage stability analyses, shallow failures represented by small localized slips should be examined for their potential threat to levee safety. This would include the potential for narrowing the crown width as well as possibly exposing permeable layers within the embankment. Past performance of the levee under similar drawdown conditions should be examined. Slopes steeper than 3h: 1v should be closely reviewed for stability. Sound engineering judgment and guidance from USACE design manuals should be used.

7.5 Underseepage for Intermittently Loaded Levees

Levee underseepage criteria for intermittently loaded levees are as follows:

- The underseepage exit gradient for levees is required to be 0.5 or less at the landside levee toe using a steady-state seepage analysis for a water surface set at the DWSE. For levees with a landside blanket layer with a saturated unit weight less than 112 pounds per cubic foot (pcf), a minimum factor of safety for underseepage of 1.6 is required at the landside levee toe.

- The underseepage exit gradient is required to be 0.8 or less at the toe of a seepage berm less than 300 feet wide using steady-state seepage analysis for a water surface set at the DWSE. If the saturated unit weight of the blanket layer is less than 112 pcf, a minimum factor of safety for underseepage of 1.0 is required at the toe of the seepage berm.

- Sound engineering judgment should be applied where the DWSE results in an elevated seepage gradient beyond the toe of a 300-foot-wide seepage berm (i.e., greater than 0.8 or a factor of safety of less than 1.0 for blanket layer soils with saturated unit weight of less than 112 pcf). Factors that should be included in the engineering judgment include:

    - Performance history of the levee reach based on a review of whether heavy seepage/boils have previously been reported in the vicinity

    - Site-specific geomorphic conditions or surficial geologic conditions that could exacerbate or concentrate seepage by construction of an undrained seepage berm

    - Geophysical data, if available, that indicates anomalous subsurface conditions may be present

  - Variability of subsurface conditions along the levee reach based on site-specific explorations that confirm blanket layer conditions along the toe of the proposed seepage berm

- Before a computed seepage gradient above 0.8 for the DWSE should be allowed beyond the toe of a 300-foot-wide seepage berm, a sensitivity analysis of the seepage model should be performed. This sensitivity analysis should include:

  - Consideration of model boundary conditions

  - Variations in assumed layer permeability/anisotropy

  - Presence of highly permeable underlying layers that may affect the ability to flood fight the condition

  - Empirical relationships such as the creep ratio

- Where a seepage berm is needed, the required minimum berm width is four times the levee height.

- The allowable underseepage exit gradient through the combined seepage berm/blanket layer between the levee toe and the seepage berm toe for a water surface set at the DWSE is determined by interpolation, using 0.5 at the levee toe and 0.8 at the seepage berm toe. The evaluation is to be done throughout the seepage berm, paying close attention to areas where the blanket layer is thinnest. If the saturated unit weight of either the blanket layer or seepage berm material is less than 112 pcf, the minimum factor of safety for underseepage through the combined seepage berm/blanket layer is 1.6 at the levee toe and 1.0 at the seepage berm toe, with linear interpolation applying between.

- In order for the levees to be more resilient for higher water levels up to the HTOL, the following criteria apply (if the HTOL is more than 0.5 foot above the DWSE – otherwise a separate seepage analysis with the HTOL is not required):

  - The underseepage exit gradient at the landside levee toe is required to be 0.6 or less through the combined seepage berm/blanket layer using a steady-state seepage analysis for a water surface set at the HTOL. If the saturated unit weight of either the blanket layer or seepage berm material is less than 112 pcf, the minimum factor of safety for underseepage through the combined seepage berm/blanket layer is required to be 1.3 at the levee toe.

- For seepage berms less than 300 feet wide designed to have a maximum 0.8 underseepage exit gradient at the berm toe for the DWSE, steady-state analyses using water surfaces set at the HTOL will be expected to yield higher gradients and lower factors of safety. In some cases seepage calculations may indicate a factor of safety of less than 1.0. This by itself does not necessarily indicate a lack of resiliency of the levee system as the berm toe is generally a distance of at least four times the levee height from the levee itself. Seepage berms should be able to experience some repairable foundation damage from boils for a limited period during an extreme event without seriously compromising the integrity of the levee. This would be expected to be particularly true for berms wider than 100 feet or so. To meet criteria regarding HTOL resiliency while using seepage berms, sound engineering judgment should be used to evaluate if the safety of the levee would be compromised with elevated seepage exit gradients beyond the berm toe. Factors to consider in this assessment should include:

    - Width and thickness of berm and distance from landside levee toe

    - Thickness and composition of the blanket layer

    - Thickness and characteristics of pervious stratum beneath blanket layer and berm. Extreme caution should be used if thick deposits of relatively clean sands, gravels, or cobbles are present immediately beneath the blanket layer.

    - Duration of the hydrograph corresponding to the HTOL

    - Conservatism of the analysis

    - Exit gradient and factor of safety calculated at both the landside levee toe and at the berm toe for the DWSE

    - Magnitude of increase in average exit gradient, or decrease in factor of safety, at berm toe for the HTOL water surface compared to values obtained using the DWSE. In general, if the berm is less than 100 feet wide, for steady-state seepage at the HTOL the allowable exit gradient may increase by up to 20 percent (as compared to the DWSE). For blanket layer soils with a saturated unit weight of less than 112 pcf, if the berm is less than 100 feet wide, for steady-state seepage at the HTOL the allowable factor of safety for underseepage may not decrease by more than 10 percent (as compared to the DWSE).

- Underseepage exit gradient and factor of safety criteria also apply within a ditch, canal, or depression near either the levee toe or seepage berm toe. The following requirements relate to the evaluation of underseepage in ditches, canals, and depressions:

  - Gradient calculations must be performed assuming that the water level in the ditch, canal, or depression is at the bottom of the ditch, canal, or depression, unless it can be assured that the ditch, canal, or depression would be filled or partially filled.

  - For cases where the ditch, canal, or depression is expected to contain water, sound engineering judgment must be exercised regarding the margin of safety being provided, the ability to observe seepage distress through the water, and the ability to flood-fight should a boil develop. Where either of these abilities is in doubt, lower allowable gradients and higher minimum factors of safety should be provided to mitigate for these limitations. Actual field performance during high water should be used to verify that a boil, should it develop, would likely be observable.

  - Following USACE procedures, for steady-state seepage at the DWSE, the maximum allowable exit gradients in a ditch, canal, or depression are 0.5 at the levee toe and 0.8 at 150 feet from the levee toe and beyond (up to 300 feet), with linear interpolation applying between the levee toe and 150 feet. For blanket layer soils with saturated unit weights of 112 pcf or less, the required minimum underseepage factors of safety are 1.6 at the levee toe and 1.0 at a distance of 150 feet and beyond, with linear interpolation applying between the levee toe and 150 feet. If the underseepage exit gradient in a ditch, canal, or depression at least 300 feet from the levee toe exceeds 0.8, or if the factor of safety calculated is less than 1.0 for low saturated unit weights of the blanket layer, sound engineering judgment should be applied in deciding whether the design is acceptable.

  - For steady-state seepage at the HTOL (if the HTOL is more than 0.5 foot above the DWSE – otherwise a separate seepage analysis with the HTOL is not required), the maximum allowable exit gradient in the ditch, canal, or depression is 0.6 at the levee toe. Gradients beyond the toe are allowed up to 20 percent higher than the maximum allowable exit gradients specified above for the DWSE for the same distance from the levee toe. For blanket layer soils with saturated unit weights of 112 pcf or less, the minimum factors of safety are allowed to be 10 percent lower than the minimum underseepage factors of safety specified above for the DWSE for the same distance beyond the levee toe.

Instrumentation should also be included at the toe of the seepage berm as part of the remedial construction to measure actual piezometric conditions during elevated river stage conditions and compare to seepage model results. Further, the berm design should be expandable with sufficient space to either extend the berm footprint or install relief wells at the berm toe if it is deemed necessary in the future.

Notes:

- In calculating the factor of safety for underseepage, the following equations apply:

  $FS = i_c/i_e$
  $i_c = (\gamma_s - \gamma_w)/\gamma_w$

  where:

  FS = Factor of Safety

  i_c = critical gradient

  i_e = calculated exit gradient

  γ_s = saturated unit weight of soil (blanket layer)

  γ_w = unit weight of water (62.4 pcf)

- If relief wells are constructed for seepage control, exit gradient criteria and factors of safety for underseepage must be achieved midway between relief wells.

7.6 Frequently Loaded Levees

USACE's EM 1110-2-1913 states the following:

> *Embankments that are subject to water loading for prolonged periods (longer than normal flood protection requirements) or permanently should be designed in accordance with earth dam criteria rather than the levee criteria given herein.*

To make USACE guidance more specific, a frequently loaded levee is defined as a levee that experiences a water surface elevation of 1 foot or higher above the elevation of the landside levee toe at least once a day for more than 36 days per year on average.

Frequently loaded levees should include seepage control and crack-stopping features, like those commonly included in earthen dams of similar height, whenever such levees protect urban or urbanizing areas. In general, seepage exiting the landside slope of the levee without being controlled by filter drains is not acceptable.

In addition to levee design criteria for intermittently loaded levees as provided in other sections of this document, the criteria for frequently loaded levees include the following more stringent requirements:

- A phreatic water surface lower than that calculated using steady-state seepage analysis is not allowed for landside slope stability analyses.

- The minimum allowable landside slope stability factor of safety for steady-state seepage at the DWSE is 1.5; and 1.3 for a water surface at the HTOL.

- The minimum allowable rapid drawdown slope stability factor of safety is 1.2 for a pre-drawdown water surface at the DWSE; for analyses of frequent, large tidal fluctuations, the minimum allowable factor of safety is 1.4 for pre-drawdown and post-drawdown water surfaces corresponding to the mean high-high tide and the mean low-low tide from published data, if available (see Figure 7-2).

- The requirements for seismic stability are more extensive (see Section 7.7).

Extra caution is advised for frequently loaded levees that have a ditch, canal, or depression near the levee toe.

Frequently loaded levees also require a higher standard of maintenance to prevent damage from vegetation and burrowing animal activity. Design features such as the incorporation of burrowing animal barriers into slope protection, that aid in lower cost and more reliable maintenance are encouraged.

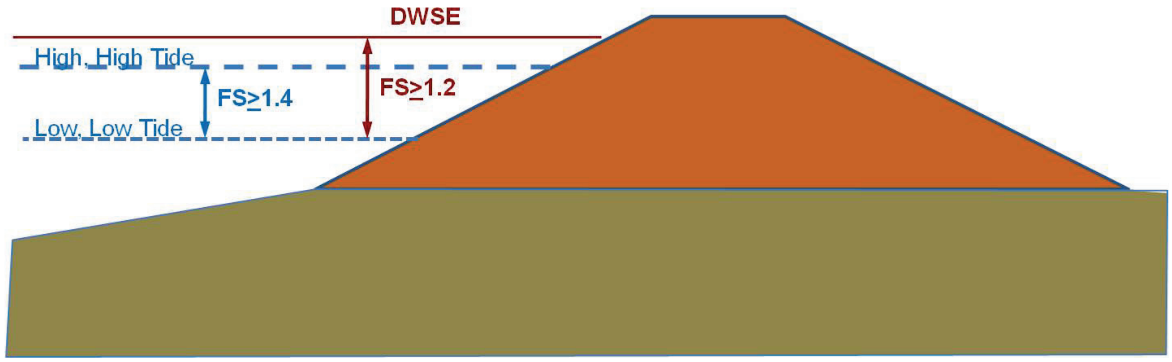

Figure 7-2. Rapid Drawdown Loading for Frequently Loaded Levee with Frequent, Large Tidal Fluctuations

7.7 Seismic Vulnerability

An analysis of seismic vulnerability of the levee system for 200-year return period ground motions is required to meet the urban level of flood protection. Peak ground accelerations can be estimated from the most current information developed by the U.S. Geological Survey and, in the Sacramento-San Joaquin Valley, from DWR's Urban Levee Evaluation Program's *Development of a 200-year Return Period Seismic Hazard Map for the Urban Levee Evaluation Program* (2012). Draft USACE Sacramento District guidance – *Guidelines for Seismic Stability Evaluation of USACE Levees* (2011) – also contains useful information on seismic analysis methods.

The seismic vulnerability analysis should employ typical summer and winter water surface elevations or mean annual high tide and mean annual low tide over the period of gage record. Additionally, potential damages due to either tsunami or seiche wave loading must be considered for levees potentially exposed to such loading.

The most common mode of earthquake-induced damage is expected to be lateral spreading and cracking associated with earthquake shaking together with potential strength losses in the levees and their foundations (e.g., liquefaction). The seismic vulnerability analyses must make use of the most current seismologic interpretations of potential faulting and earthquake sources, together with recent acceleration and velocity attenuation relationships for the soil profiles being analyzed. In some cases, simplified analyses (e.g., *Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 198 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils* (2001)) may be used, while other cases may require dynamic response analyses, pseudo-static slope stability analyses used in conjunction with Newmark-style displacement analyses, and other more detailed numerical displacement analyses. Detailed analysis using the finite element method may be justified by potential savings in seismic remediation work when simplified analyses are identifying the need for significant seismic remediation. All such analyses should employ recent correlations between field testing (e.g., Standard Penetration Test (SPT) and Cone Penetration Test (CPT) penetration results) and liquefaction triggering and residual shear strengths. The end product of these analyses should be estimates of the ranges of deformations along the levee system and an overall estimate of the amount of damage that could be sustained during a 200-year earthquake. In many cases, an estimate regarding potential longitudinal and transverse cracking should also be made, particularly for transverse cracking between liquefied levee reaches and unliquefied levee reaches and at locations where liquefied levee reaches contain or abut appurtenant structures with rigid or deep foundations.

Levees and floodwalls that are already going to be repaired or improved to provide an urban level of flood protection and that are vulnerable to seismic damage should be repaired or improved with alternatives that are more resistant to seismic damage and/or easily and economically repaired following an earthquake over other cost-comparable alternatives (e.g., a berm is usually preferable to a seepage cutoff wall).

7.7.1 Intermittently Loaded Levees

For intermittently loaded levees (and floodwalls), if seismic damage from 200-year-return-period ground motions is expected after the urban level of flood protection is achieved, a post-earthquake remediation plan is required as part of a flood safety plan that is developed in coordination with pertinent local, State, and federal agencies. Although the post-earthquake remediation plan must address 200-year-return-period ground motions at a minimum, civil engineers should consider a range of earthquakes significantly exceeding the 200-year return period. The purpose of the seismic vulnerability analysis is to develop a rough estimate of seismic damage to the levee or floodwall system, so as to anticipate the scale and location of damage to be addressed in the post-earthquake remediation plan. At a minimum, the post-earthquake remediation plan must contain provisions for emergency preparations, mobilization, data gathering, actions, interim repairs, long-term repairs, and public notifications. Included in this plan is an estimate of the amount and extent of damage that might be sustained following an earthquake, and the general magnitude of earth and other materials that would be required to restore a modest level of flood protection within 8 weeks. This plan must also include a general set of repair procedures for the interim remediation of cracked and slumped levee sections, including general procedures for excavating and filling cracks, removing disturbed or slumped ground, and keying in new fill. During each periodic review, the post-earthquake remediation plan needs to be reviewed and updated as appropriate. Similarly, if appropriate for amendments to the general plan and/or zoning ordinances, such amendments should address the availability and preservation of sources of post-earthquake construction materials. Specific considerations for the interim repairs for intermittently loaded levees include:

- An estimate is to be developed of the general magnitude and locations of damage expected throughout the levee system along with the amounts and locations of material needed to restore the levee system's grade and dimensions (e.g., appropriate crown width – such as 20 feet along a major stream – and 3h:1v levee slopes) sufficient for protection against the 10-year flood, with 3 feet of freeboard.

- The interim repairs would need to restore 10-year grade and dimensions within 8 weeks or less to avoid prolonged exposure of the community during flood season.

- Borrow areas and/or stockpiles that could easily provide the materials needed for interim repairs need to be identified. Such materials should meet the levee fill requirements of the USACE Sacramento District's *Geotechnical Levee Practice Standard Operating Procedures*.

- Haul routes for fill placement need to be identified.

- Slope protection for the newly placed fill needs to be included.

- To the extent that seismic damage to the levee system would be so significant and widespread that it would be infeasible to restore 10-year grade and dimensions within eight weeks, seismic strengthening is required to provide the urban level of flood protection.

- The public should be informed as quickly as possible after a damaging earthquake as to system damages and the resulting interim level of protection that will be provided.

7.7.2 Frequently Loaded Levees

Frequently loaded levees (and floodwalls), such as many levees in the Sacramento-San Joaquin Delta, are required to have seismic stability sufficient to maintain the integrity of the levee and its internal structures without significant deformation. In most cases, for frequently loaded levees with less than 5 feet of freeboard, earthquake-induced deformations should be limited to less than 3 feet of total deformation and about 1 foot of vertical displacement. Levees with rigid penetrations or appurtenances may require smaller allowable seismic deformations. Considerations of potential transverse and longitudinal cracking are even more important for frequently loaded levees and such assessments are required to provide an urban level of flood protection. However, frequently loaded levees with larger cross-sections and freeboard may be allowed larger seismic deformations subject to engineering analyses and sound engineering judgment.

For frequently loaded levees and floodwalls, design ground motions higher than the 200-year-return-period level should also be considered based on the potential consequences of a levee breach or floodwall failure.

7.8 Levee Geometry

Minimum levee geometry criteria have previously been specified by various USACE and State guidance documents. The guidance for various minimum levee geometry and their references are as follows in Table 7-1.

Table 7-1. Summary of Existing Levee Geometry Guidance

	USACE Engineering Manual EM 1110-2-1913 (April 30, 2000)	Title 23. Waters Division 1. Central Valley Flood Protection Board California Code of Regulations (January 22, 2010)	USACE Sacramento District Geotechnical Levee Practice SOP (April 11, 2008)
Minimum Crown Width (feet)	10	20 (major stream levees) 12 (minor stream levees)	20 (main line, major tributary, and bypass levees) 12 (minor tributary levees)
Minimum Waterside Levee Slope	2h:1v	3h:1v 4h:1v (bypass levees)	3h:1v
Minimum Landside Levee Slope	2h:1v	2h:1v 3h:1v (bypass levees)	3h:1v (new levees) 2h:1v (existing levees with good performance)

Key:
USACE = U.S. Army Corps of Engineers

For new levees, or levees with extensive reconstruction, situated along major waterways, a minimum 20-foot-wide crown width and 3h:1v waterside and landside slopes (4h:1v waterside slope for bypass levees) is required. Exceptions may be allowed for reconstruction of existing levees where the authorized geometry provides for a steeper slope or narrower crown, the levee has performed well, and it meets stability and seepage criteria. These geometry requirements represent minimum requirements, and wider levee crowns and/or flatter slopes may be necessary in some areas, depending upon geologic and geotechnical considerations. At the same time, however, minimum requirements should be associated with generally uniform, levee materials and homogeneous embankments. Steeper slopes may be allowed in certain circumstances where there is limited space available, and where levees are demonstrated to meet minimum seepage and stability criteria. Steeper waterside levee slopes may be acceptable where stability criteria are met and either slope protection is provided or it is determined that wavewash erosion for a water surface at or below the DWSE could not result in breaching of the levee. For example, levees with slopes steeper than new minimum requirements may be acceptable with elements such as central clay cores, seepage cutoff walls, landside filters or drains, or soil reinforcement that substantially decrease seepage hazards and increase slope stability.

The levee prism should be considered to continue underground based on projection of the above-ground levee slopes. The projected levee slopes are useful for evaluating erosion, excavations, and encroachments near the levee.

7.8.1 Wide Levees

Levees that are wider than the minimum requirement may have steeper slopes if the minimum required dimensions would fit entirely within the actual levee, and if seepage and slope stability criteria are met (for both deep and shallow failure surfaces). See Figure 7-3.

For extremely wide levees (e.g., more than 50-foot crown width), seepage and slope stability criteria do not need to be met for the outer levee slopes as long as the following criteria are met:

- An analysis must be performed which demonstrates that the anticipated slope failure soil mass would effectively buttress the remaining levee slope to meet stability criteria. The analysis must consider that seepage, sloughing, and erosion can lead to a progressive failure and breaching of the levee.

- The central remnant portion of the levee after sliding or slumping of the outer slopes must incorporate a minimum levee geometry cross section (i.e., the minimum required dimensions would fit entirely within the remnant levee mass).

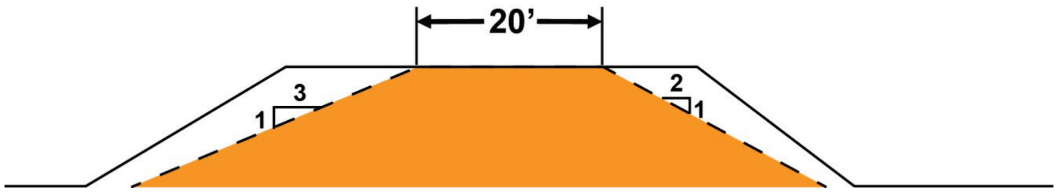

Figure 7-3. Example of a Wide Levee with Steep Slopes that Contains a Levee with Required Dimensions

- The combined remnant levee and slumped portions must meet seepage and slope stability criteria for both landside and waterside slopes and for both deep and shallow failure surfaces. Residual soil shear strength parameters must be used along sliding surfaces beneath slumped soil masses.
- For a rapid drawdown condition, the resulting slide mass on the waterside slope should be considered to be eroded away and cannot be relied upon to create a stabilizing or buttressing soil mass.

7.8.2 Patrol Roads, Access Ramps, and Turnouts

A patrol road is required along the crown of the levee for inspection, maintenance, and flood-fighting. The patrol road must be designed, constructed, and maintained to provide "all weather" support of maintenance and patrolling vehicles. A patrol road should also be provided near the toe of a seepage berm that is too wide for levee crown patrollers to see seepage conditions at the berm toe. Access ramps to the levee should be provided at reasonably close intervals. For levees with a narrow crown (less than about 15 feet wide) turnouts should be provided if the distance to an access ramp is more than about 2,500 feet.

7.9 Interfaces and Transitions

The civil engineer must consider, evaluate, and explicitly design for interfaces and transitions between different types of levee sections and features along a levee system. Appropriate overlaps, transitions, and connections between features must be evaluated and designed to ensure that the levee system functions holistically, such that no levee reach is more susceptible to problems than an adjacent reach due to gaps in features, loading/demand concentrations, or other three-dimensional effects. Such interfaces, transitions, and connections commonly occur at the ends of seepage berms, seepage cutoff walls, revetments, and floodwalls.

7.10 Erosion

The potential for erosion damage must be evaluated and addressed. Erosion damage to riverine levees is usually due to the following conditions: (1) high velocity flows coupled with erosive levee materials and/or poor hydraulic conditions; (2) large waves developed by wind over large, open bodies of water like a bypass; and (3) boat wakes. Erosion hazard is increased by a number of factors, which include:

- Compromised levee prism geometry
- Geomorphologic trends as indicated by channel migration and historical damage
- Loss or narrowing of the natural berm located between the levee and stream bank
- Streamflow velocity, depth, duration, and shear
- Wind-wave shear stress
- Levees constructed from erodible materials, particularly low cohesion sands/silts or dispersive soils
- Stream banks or berms composed of erodible materials such as mining debris
- Detrimental hydraulic anomalies, such as encroachments
- Absence of beneficial vegetation or other slope protection

Levees that pose an immediate erosional breaching hazard during either a flood or normal flow condition need to be repaired based on analysis of the above hazard factors. Similarly, levees that are likely to be significantly damaged during either a flood or normal flow condition should be protected with appropriate slope treatments. Field surveys of bank conditions and near-bank bathymetry may reveal new or worsened vulnerabilities after high-flow events. Operation and maintenance of flood protection features should be implemented in a forward-looking manner that identifies potential levee safety risks due to erosion. Performance-based analyses should be considered as well as predictive models. At a minimum, the civil engineer's analyses should consider the annual erosion surveys conducted under USACE's Sacramento River Bank Protection Project and the DWR erosion surveys conducted on the San Joaquin River flood protection system. The downward projection of the theoretical 3h:1v waterside levee slope that stays within the natural stream bank has traditionally been considered to represent a minimum element of slope stability for the overlying levee fill. Figure 7-4 shows how this projection is made for a typical levee section.

Velocity and shear stress computations for assessment of erosion potential should follow methods described in EM 1110-2-1913 and EM 1110-2-1601. River channel hydraulics and migration can be assessed using the methods described in EM 1110-2-1416 and EM 1110-2-1418. Hydraulic models developed for the Sacramento River Bank Protection Project are available from USACE Sacramento District or from DWR.

National Resource Conservation Service maps, geomorphologic study reports prepared for the DWR Levee Evaluations Program, or other local sources should be reviewed to evaluate whether dispersive soils are in the vicinity and thus may have been incorporated into the levee embankments (*Geomorphology Technical Memoranda and Maps, South NULE Geomorphic Assessments* (2011) and *Geomorphology Technical Memoranda and Maps, North NULE Geomorphic Assessments* (2011)). If further evaluation is warranted, the testing procedures summarized in ASTM STP 623 *Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects* (1977) should be considered.

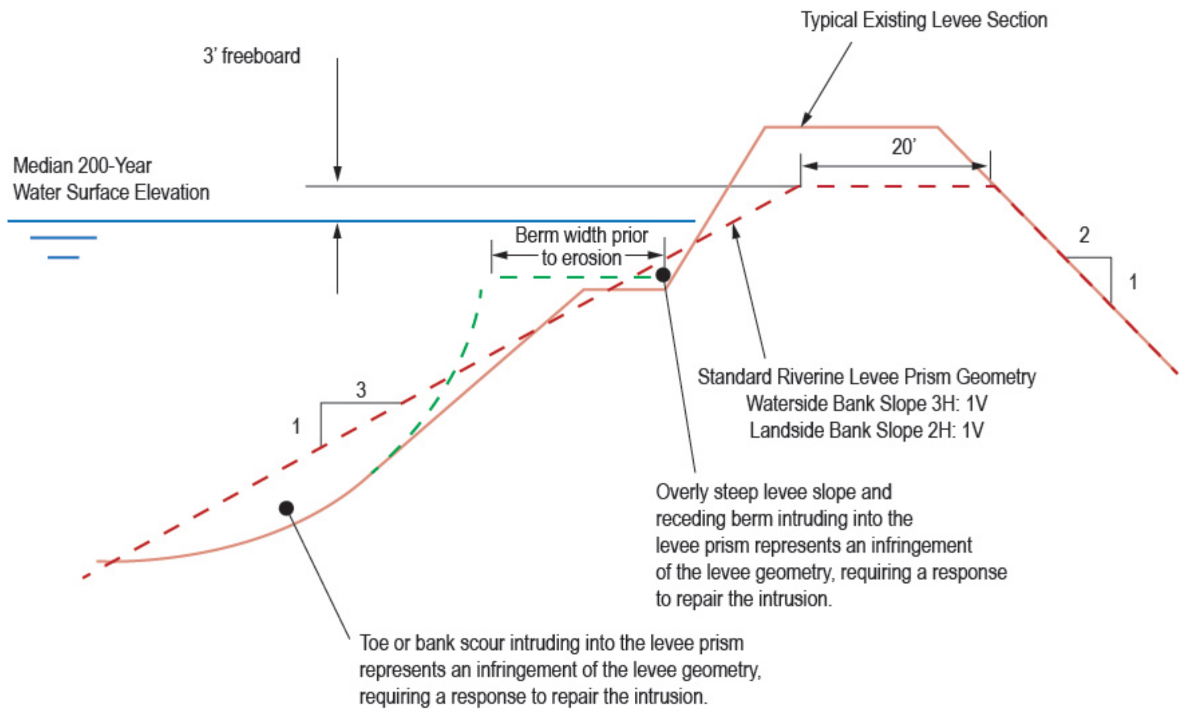

Figure 7-4. Example of How to Project the Waterside Levee Slope for Determining Acceptable Bank Erosion

Design of erosion repairs and erosion protection should conform to guidance in USACE documents cited above and in USACE's *Hydraulic Design Criteria* (1987), including flattening the slope, armoring the slope, and vegetation. Procedures for computation of wind setup and wave runup for the purpose of evaluating erosion potential need to conform to requirements identified elsewhere in these criteria. If the presence of dispersive soils is confirmed, in addition to rock protection, mitigation measures may include flattening the slopes or use of native grasses that can tolerate the soil chemistry. In severe cases, covering of dispersive soils or removal and replacement may be appropriate.

7.11 Right-of-Way

Right-of-way criteria for levees and floodwalls in urban and urbanizing areas need to meet the following objectives:

- Allow adequate room for maintenance, inspection, patrolling during high water, and flood-fighting.
- To the extent practical, adequate right-of-way should be available to provide additional room to expand facilities in the future. Reasons to expand the facilities might include:
  - Desire by the community to provide higher levels of flood protection
  - Changes in design criteria, poor performance during high water, updated hydrology and/or hydraulics, or other data that would indicate that additional modifications are necessary to maintain the urban level of flood protection
- Prohibit excavations and land modifications that would endanger the integrity of the levee or floodwall.

7.11.1 Right-of-Way for Access and Inspection

To meet the first objective, fee title or an easement for the entire levee prism extending to a minimum of 20 feet beyond the landside toe of the flood protection system needs to be acquired, except as provided below. Where seepage/stability berms and/or relief wells are present, the minimum 20-foot-wide landside zone needs to extend beyond the limits of those features (and should include seepage collection ditches). The 20-foot-wide landside zone must be maintained adequately clear for visibility and access to enable inspection and flood-fighting. From an encroachment control perspective, an easement is less desirable than fee title – but fee title ownership entails additional responsibilities that may offset its advantages. These are minimum right-of-way requirements; the facts and circumstances for a specific levee system may require acquisition of additional property to meet the first objective.

Waterward of the levee prism, where there is sufficient area to do so without resulting in the loss of sensitive riparian habitat, consideration should be given to acquiring a 15-foot-wide zone where this zone would be beneficial for levee inspection and maintenance – such as for managing animal burrows and for maintaining a firebreak next to a levee slope that is routinely burned.

Fee title or an easement also may be needed throughout the channel to enable appropriate channel maintenance and management activities consistent with the channel characteristics used in determining the DWSE.

If the rights for the 20-foot-wide landside zone have not been acquired, and present a major challenge to acquire, then the following alternatives are acceptable for meeting right-of-way requirements:

- For levee systems that currently have development within 20 feet of the landside toe of the levee and where acquiring the rights for the 20-foot-wide landside zone presents a major challenge, an alternative would be for the city or county to adopt a long-term right-of-way plan to either obtain rights for a minimum 10-foot-wide landside clear zone, or to meet visibility requirements over a 20-foot-wide landside zone by obtaining rights or making arrangements with the landowner. Visibility requirements are met if fencing, walls, structures, vegetative screens, and other physical obstructions which could restrict the ability to conduct inspections of the landside toe and adjacent 20 feet have been modified or removed to allow for visual inspection of the ground surface. Complete removal, partial removal, thinning, and trimming of vegetative growth within 20 feet (such as thick groundcovers, shrubs, wild thickets, and low hanging trees) would also be performed to achieve visibility requirements. Since this approach may require easements, it is expected that this approach will take significant time and financial resources. If a city or county pursues this alternative approach, they must take the following minimum actions to meet right-of-way requirements:
    - The city or county is required to have a right-of-way plan in place for the entire reach of the levee system that the Finding is to cover. This plan would include, to the extent allowable by law, either that the property owner for a noncompliant parcel grant an easement or fee title for either the 10-foot-wide landside clear zone for access,

or meet the 20-foot-wide landside zone visibility requirements, at some reasonable time in the future. One approach for accomplishing this, as may be allowed by law, would be to acquire the rights at the time of property sale or transfer in ownership.

- The city or county must establish, document, and publicize a realistic target schedule for either acquiring the property rights or meeting visibility requirements for the levee reaches on noncompliant parcels. An example target schedule would be to obtain easements for 50 percent of the currently noncompliant parcels within the 20-year period for which the initial Finding is in effect, and to obtain the remaining easements within 20 years after the second Finding.

- Structural features, such as a berm that serves as a road 4 to 5 feet high at the landside levee toe that is appropriately designed with a retaining structure, can mitigate some of the access and visibility limitations, and may be considered as meeting access criteria in limited circumstances in lieu of obtaining additional right-of-way.

- In all situations where access and visibility are restricted, consideration should also be given to increasing the factor of safety for the geotechnical design of the levee to compensate for the limited access and visibility.

• For levee systems where the adjoining lands are currently undeveloped and are currently largely agricultural or open space, there must be a right-of-way plan to acquire rights for the 20-foot-wide zone at the landside toe. If a city or county currently does not have the financial ability to obtain this right-of-way in the short-term, the city or county must take the following minimum actions to meet right-of-way requirements:

  - The city or county must have general plan policies, building standards, or an ordinance that prevents, to the extent allowable by law, incompatible structures or excavations in the 20-foot-wide landside zone until it is acquired.

  - The city or county must establish, document, and publicize a realistic target schedule for acquiring the rights for the 20-foot-wide landside zone. An example target schedule would be to obtain fee title or easements for 100 percent of the parcels within the 20-year period for which the initial Finding is in effect.

7.11.2 Right-of-Way for Long-Term Flood Protection

In order to meet the second objective, the city, county, or levee maintaining agency should consider acquiring right-of-way for a future needs area that has a width equal to at least four times the levee height or 50 feet, whichever is greater, on the land side of the 20-foot clear zone. If acquired:

- Structures should not be constructed in this future needs area.
- It must also be understood that some seepage is normal and acceptable during high water, so uses incompatible with this seepage should not be allowed in this area. The future needs area may be used for open space, agriculture, bike and pedestrian trails, outdoor recreation, parking lots, or other similar uses not likely to have an adverse impact on the structural integrity of the levee or floodwall, but with the understanding that these facilities may be displaced by future levee construction.

For urbanizing areas adjacent to levees, cities and counties should consider developing even more aggressive setback criteria that keep permanent structures away from the levees. The criteria should also limit actions that could have adverse effects on the performance of the levee system or restrict future modifications to the levee system. Setback distances could range from 70 to 400 feet beyond the future needs area, depending on the height of the levees, future plans for the levee system, and other site-specific conditions.

7.11.3 Land-Use Restrictions to Prohibit Loss of Levee Integrity

To meet the third objective, the city or county should adopt restrictions on excavations within 400 feet of levees (or floodwalls) greater than 15 feet in height and within 200 feet for levees (or floodwalls) less than 15 feet in height. Restrictions should address any excavation or land modification that would endanger the integrity of the levee (or floodwall) by increasing seepage or uplift. Excavation or grading may be allowed as long as it does not adversely affect the functioning of the levee (or floodwall). As a general guide, the bottom of a permanent excavation should not extend below a plane that starts at the boundary of the future needs area and extends downward at a 10h:1v slope. Any permanent excavation or grading that extends below this plane requires a report from a civil engineer stating that the proposed or existing activities or features will not have an adverse impact on the integrity/operation of the flood control system.

7.12 Encroachments (Excluding Penetrations, Closure Structures, and Levee Vegetation)

7.12.1 Assessment of Existing Encroachments

The civil engineer needs to assess existing encroachments and render an opinion as to their impact on the reliable performance of the levee/floodwall for the full range of loading up to the HTOL. The opinion needs to consider all encroachments within the channel, on the levee, and within the landside right-of-way identified in Section 7.11, irrespective of whether the property rights have been acquired. Due to the limitations of analytical tools for assessing the impacts of encroachments, the civil engineer needs to exercise sound engineering judgment in rendering this opinion. The civil engineer shall consider the following when rendering this opinion: type, age, condition, performance history of the encroachment, and impacts on the levee/floodwall structural integrity, impacts on the hydraulic effect on the channel and floodway, and impacts on the operation and maintenance of the levee/floodwall.

A hazard assessment needs to be performed for each existing encroachment, whether permitted or not. Encroachments with a potential to be a high hazard need to have a full engineering evaluation, to demonstrate that the hazard is acceptable, or be removed or modified.

In cases where the existing encroachment is outside the levee minimum geometry and visibility right-of-way, sound engineering judgment may replace the detailed geotechnical and hydraulic analyses.

All existing encroachments are to be authorized by the agency responsible for permitting encroachments along the levee (or floodwall), or removed. Operation and maintenance of the encroachment shall comply with the conditions required by the approved permit application.

Recognizing that establishing permits for existing encroachments and/or removing unpermitted encroachments can be a lengthy process, often requiring administrative and/or legal actions by state or federal entities, the following is acceptable for meeting the urban level of flood protection:

- All existing encroachments considered a high hazard are to be removed or modified to restore the reliability of the levee/floodwall. Encroachment removal or modification shall be performed under the direction of a civil engineer and should address, at a minimum, seepage and slope stability issues and the structural integrity of the levee. In addition, the encroachment removal or modification must not significantly diminish hydraulic capacity of the channel or hinder operations and maintenance. A proposed removal or modification plan is to be approved by the levee maintaining agency and the Board (for levees regulated by the Board).

- For other existing encroachments which are not considered to be a high hazard, but either: (1) have not been permitted, or (2) interfere with operation, maintenance, or flood fight capability, the city or county is required to have an encroachment remediation plan in place, or reference such a plan, for the entire length of levee that the Finding is to cover. To the extent allowable by law, this plan needs to address eventual removal or permitting of all such encroachments. In some cases, permits may need to provide for access by qualified officials. The city or county must work with the levee maintaining agency and the entity responsible for issuing encroachment permits to establish, document, and publicize a realistic target schedule for implementation of this plan. An example target schedule would be to remove or permit 50 percent of the currently noncompliant encroachments within 5 years and to address the remaining 50 percent in the subsequent 5 years.

7.12.2 New Encroachments

All new (proposed) encroachments within the levee right-of-way, 20-foot-wide visibility zone, and the future needs area shall meet current USACE guidance for design and construction, unless otherwise authorized by the agency responsible for permitting encroachments along the levee (or floodwall). All new encroachments should be properly permitted.

7.13 Penetrations

7.13.1 Assessment of Existing Penetrations

Penetrations typically include pipe crossings through the levee embankment and its foundation as well as transportation structures over or through part of the levee/floodwall. Penetrations have the potential to produce rapid breaching as they can provide a preferential seepage path or an open conveyance for floodwaters. The civil engineer needs to assess existing penetrations and render an opinion as to their impact on the reliable performance of the levee/floodwall for the full range of loading up to the HTOL. Due to the limitations of analytical tools for assessing the impacts of penetrations, the civil engineer needs to exercise sound engineering judgment in rendering this opinion.

A hazard assessment needs to be performed for each penetration, whether permitted or not. Penetrations with a potential to be a high hazard need to have a full engineering evaluation, to demonstrate that the hazard is acceptable, or be removed or modified. All penetrations are to be authorized by the agency responsible for permitting penetrations along the levee (or floodwall), removed, or properly abandoned. Operation and maintenance of the penetration shall comply with the conditions required by the approved permit application.

Recognizing that establishing permits for existing penetrations and/or removal of unpermitted penetrations can be a lengthy process, often requiring administrative and/or legal actions by State or federal entities, the following is acceptable for meeting the urban level of flood protection:

- All existing penetrations considered high hazard are to be removed or modified to restore the reliability of the levee/floodwall. Penetration removal or modification shall be performed under the direction of a civil engineer and should address, at a minimum, seepage and slope stability issues and the structural integrity of the levee. In addition, the penetration removal or modification must not significantly diminish hydraulic capacity of the channel or hinder operations and maintenance. A proposed removal or modification plan is to be approved by the levee maintaining agency and the Board (for levees regulated by the Board).
- For other existing penetrations which are not considered to be a high hazard, but have not been permitted, the city or county is required to have a penetration remediation plan in place, or reference such a plan, for the entire length of levee that the Finding is to cover. To the extent allowable by law, this plan needs to address eventual removal or permitting of all such penetrations. The city or county must work with the levee maintaining agency and the entity responsible for issuing encroachment permits to establish, document, and publicize a realistic target schedule for implementation of this plan. An example target schedule would be to remove or permit 50 percent of the currently noncompliant penetrations within 5 years and to address the remaining 50 percent in the subsequent 5 years.

7.13.2 Pipes and Culverts

The civil engineer shall consider guidance in Chapter 8 of EM 1110-2-1913 and the following when assessing pipes and culverts and rendering an opinion: the type of utility, pipe diameter, pipe material, pipe joint type, number of joints, angles, thrust protection, pipe bedding and method, age, degree of corrosion, location and depth below the DWSE, performance history, pipe testing or inspection (including video inspection) results, and remaining life of the facility.

Chapter 8 of EM 1110-2-1913 provides guidance on factors to consider in evaluating penetrations through levees. These include the height of the levee, the duration and frequency of high water stages against the levee, the susceptibility to piping and settlement of levee and foundation soils, the type of pipeline (low-pressure or high-pressure line, or gravity drainage line), the pipe material, the structural adequacy of existing pipe and pipe joints, the adequacy of the backfill compaction, the feasibility of providing closure in event of ruptured pressure lines or failed flap valves in gravity lines during high water, the ease and frequency of required maintenance, the cost of acceptable alternative systems, possible consequences of piping or failure of the pipe, and previous experience with the owner in constructing and maintaining pipelines. Other factors to consider include, but are not limited to, corrosion/degradation rates, the elevation of the penetration relative to the design water surface, and the design life of the penetration.

7.13.3 Transportation Penetrations

Examples of transportation penetrations include, but are not limited to, roadway and railroad crossings of a levee below the elevation of the adjacent levee crown, and their associated closure structures such as gates and flashboards. The civil engineer shall consider the following when assessing transportation penetrations and rendering an opinion: the maintaining entity, results of the last inspection, type of corridor, width of corridor, structural section thickness and types, structural section conditions, configuration of abutments and/or piles, and associated closure structure type and location. The engineering assessment also needs to include an opinion regarding the effects on seepage and stability, any three-dimensional effects, operation and maintenance of the existing closure structure, and potential for overtopping of the transportation penetration during the design event and its consequences.

7.13.4 Investigation for Unknown Penetrations

The civil engineer must consider whether there could be unknown penetrations, taking into account such factors as the levee's construction history, maintenance and encroachment control history, and any previous investigations for unknown penetrations. The objective is to provide confidence that all penetrations have been identified and their effect on levee integrity considered. If there is uncertainty as to the presence of unknown pipe penetrations, the civil engineer needs to use or conduct a study that should use land-based continuous levee crown geophysical methods with a capability of assessing the levee material and the upper 20 feet of foundation materials. Pipe penetrations that are located from this survey need to be reported to the appropriate permitting agency for enforcement action and assessed for structural and functional integrity. A permit application for any unpermitted pipe needs to be provided to the permitting agency or the pipe is to be removed or properly abandoned.

7.13.5 Abandoned Penetrations

Penetration abandonment needs to be performed under the direction of a civil engineer and should address at a minimum seepage issues, migration of soils, and the structural integrity of the levee. Penetration abandonment needs to follow USACE requirements (for project levees) and any other levee/floodwall owner/regulator requirements. Any unpermitted abandoned pipes or culverts need to be removed or modified.

7.13.6 Pipe and Culvert Inspection

Exposed portions of pipe and culvert penetrations need to be visually inspected at least annually. At minimum 5-year intervals, the interiors of all pipes and culvert penetrations need to be visually inspected and/or pressure tested. Additionally, pipes and culverts that could be damaged by corrosion should be examined for signs of interior and external corrosion. Inspections of the exterior should be performed in representative areas where the pipe or culvert is in contact with the levee embankment and/or foundation soils. Corrosion assessment inspections performed from the interior can be completed using nondestructive means such as ultrasonic or electrical conductivity measurements. An inspection report needs to be made available upon request to qualified officials.

7.13.7 New Penetrations

All new (proposed) penetrations are to be authorized by the agency responsible for permitting penetrations along the levee (or floodwall). All new penetrations need to meet current USACE guidance for design and construction. For smaller diameter pipes installed in larger diameter pipes through the levee or its foundation, the annular space between the two pipes must be fully grouted along the entire portion crossing the levee or its foundation. No plastic pipes are permitted for new or replacement construction. New penetrations should be designed to allow for interior video access for inspection purposes. In addition, new pressurized pipelines must have their invert placed above the DWSE and not be located in the actual levee prism or its foundation unless the civil engineer provides a professional opinion that the pipe or culvert will not have an adverse impact on the integrity/operation of the flood control system. EM 1110-2-1913 indicates the conditions of a pressurized pipe to be accepted in the levee foundation. All new pressurized pipes need to be equipped with a positive closure at the waterside edge of the levee crest. Any gravity-flowing pipe needs to be provided with a flap gate at the waterside outlet and a sluice gate located in a gatewell at the waterside edge of the levee crest. The positive closures and the sluice gates need to be accessible during high water stages.

7.14 Floodwalls, Retaining Walls, and Closure Structures

Current USACE design guidance for special features such as floodwalls, retaining walls, and closure structures is to be followed. This information is included in EM 1110-2-1913, EM 1110-2-2502, EC 1110-2-6067, and ETL 1110-2-571. Because design considerations for floodwalls and closure structures are still evolving since the 2005 New Orleans flood, caution should be used when designing and assessing these structures. All global slope stability and embankment through-seepage and underseepage safety criteria requirements are applicable for floodwalls, retaining walls, and closure structures on levees. In addition, the civil engineer must evaluate and address the potential for the floodwall to induce settlement in the levee.

Floodwalls and retaining walls should only be used where it is impractical to use a conventional earth embankment, such as where there is insufficient space due to preexisting improvements. If floodwalls are proposed on a levee, they should only be used for supplemental freeboard along the levee crest and account for impacts on operation and maintenance.

For closure structures, the civil engineer needs to provide the following information: maintaining entity, levee mile, Global Positioning System coordinates, Board permit number (if applicable), structure details, length of time to close structure, location and type of materials for closure, structure dimensions, age, and performance history.

Closure structures need to be tested at least once a year before the flood season so that crews responsible for implementing the structures are familiar with their operation and to provide assurance that all parts are present and in working order.

7.15 Animal Burrows

Burrowing animals can present a significant threat to levee integrity; therefore, proactive animal control and damage repair are two required levee maintenance practices where burrowing animals are present. The potential for burrowing animal damage and associated remediation should also be considered during design. USACE's *Levee Owner's Manual for Non-federal Flood Control Works* (2006) states that burrowing animal control techniques involving fumigation, bait stations, bait broadcasting, or trapping have proven effective in certain situations, but regulatory agencies over various jurisdictions may have different requirements for environmental compliance. The issues to consider during levee design and evaluation include:

- Individual or networked animal burrows may completely traverse a levee section.
- There is no effective method to completely exclude burrowing animals from occupying grass-covered levees.
- Rodenticide-treated baits are the most economical of all approaches to rodent population reduction.
- DWR and other flood control agencies have found that (1) excavating and backfilling, and (2) grouting are effective methods for repairing burrows. Grouting is more cost effective. A common and effective grout mix is made up of 9 parts cement, 1 part bentonite, and water added to achieve 8 to10 inches of slump. Grout is pumped at low pressures to avoid damaging the embankment, starting low and proceeding up the levee slope.
- Levee dragging should only occur after burrows are repaired.
- Burrows temporarily covered for fumigation should be marked for later excavation and repair.
- Extra vigilance in monitoring and repair of burrows is needed for frequently loaded levees.
- For certain situations, such as short levee reaches, permanent burrowing animal barriers should be considered in designs.

7.16 Levee Vegetation

DWR is committed to developing flood risk reduction solutions that also integrate environmental stewardship. Guidance for levee vegetation management is focused on improving public safety by providing for levee integrity, visibility, and accessibility for inspections, maintenance, and flood fight operations, while at the same time protecting important and critical environmental resources, including the remaining shaded riverine aquatic habitat along many levees.

Policies and criteria regarding removing trees and other woody vegetation that have grown and matured on levees are evolving and will be informed by ongoing and future research. Engineers and levee maintaining agencies are encouraged to consider the results of this research when deciding how to manage trees and other woody vegetation on levees.

The State's policy directives for managing vegetation on State Plan of Flood Control levees are incorporated into the 2012 CVFPP.

The following criteria are to be used for managing vegetation on levees protecting urban and urbanizing areas. The criteria provide significant flexibility for engineers and levee maintaining agencies to remove or retain existing trees and other woody vegetation. Because of the importance of these critical resources, it is anticipated that implementation of these criteria will result in near-term retention of the vast majority of existing trees and other woody vegetation that provide important and critical habitat. In the long-term, it is anticipated that the vast majority of trees and other woody vegetation on the lower waterside levee slope would continue to grow with little or no management.

7.16.1 Engineering Evaluation

An engineering inspection and evaluation shall be conducted to identify trees and other woody vegetation (alive or dead) on the levee and within 15 feet of the levee toe that pose an unacceptable threat (currently or before the next periodic review) to the integrity of the levee. Identified trees shall be removed and associated root balls and roots shall be appropriately remediated. At a minimum, all roots larger than 1.5 inches in diameter that are within 3 feet of the perimeter of the tree trunk will be removed. Immature trees less than 4 inches in diameter at breast height that are removed may be cut off at or below ground level, generally without root removal. More extensive root removal may be required, depending upon the location, size, and type of tree; the quantity, orientation, and size of the roots; the dimensions of the levee (or floodwall); the composition of the levee and foundation; and the levee features that address seepage and underseepage. Less extensive root removal may be justified where roots from adjacent trees would be unduly damaged. Any excavation resulting from the above actions shall be backfilled with engineered fill using appropriate placement, moisture conditioning, and compaction methods.

Based on the engineering inspection and evaluation, trees and other woody vegetation that do not pose an unacceptable threat need not be removed.

7.16.2 Routine Inspection

As part of the routine operation and maintenance responsibilities of the levee maintaining agency, trees and other woody vegetation that are not removed must be monitored to identify changed conditions that cause any of these remaining trees and other woody vegetation to pose an unacceptable threat to levee integrity.

7.16.3 Newly Constructed Levees

New levees are to be designed, constructed, and maintained according to ETL 1110-2-571. These standards limit vegetation to native grass species on levee crown, slopes, and within 15 feet of the levee toe, as measured from the centerline of the tree trunk. In certain circumstances, trees and other woody vegetation may be allowed on portions of the landside slope, waterside slope, and riverbank or berm for a newly constructed levee if a specially designed planting berm is added. This planting berm must represent an over-built section with respect to minimum geometries, and be of sufficient size and configuration to serve to mitigate potential negative impacts to levee safety with respect to seepage, stability, and erosion criteria should either windfall or root decay occur. Trees and other woody vegetation that are within the 20-foot-wide landside right-of-way described in Section 7.11, but outside of the vegetation management zone, need to be trimmed up 5 feet above the ground and thinned for visibility and access; plantings and natural revegetation may also be allowed.

7.16.4 Levee Repair or Improvement

In cases of levee repair or improvement, vegetation shall be removed as required to meet objectives of the specific project. Vegetation removed as part of direct construction activities may not be replaced in the vegetation management zone. However, vegetation on other sections of the levee, not affected by the construction activity may remain in place, natural revegetation may be allowed outside of the vegetation management zone, and replanting may be allowed as described in Section 7.16.8; for levees regulated by USACE and/or the Board, their approval is required for planting. Note that in many instances, waterside trees and other woody vegetation would be allowed to remain, particularly on the waterside slope and channel bank outside of the vegetation management zone, due to environmental and engineering benefits that include erosion protection, soil reinforcement, and sediment recruitment.

Engineers and levee maintaining agencies should also consider preserving trees and other woody vegetation within the vegetation management zone that provide important or critical habitat in consultation with the appropriate resources agencies, or erosion protection on the waterside levee slope and nearby bank by including the following root mitigation alternatives as part of any levee improvement program:

- Where feasible, the overall width of the levee is widened landward by at least 15 feet beyond the standard minimum levee dimensions, or

- An effective root or seepage barrier is installed within the upper 10 to 15 feet of the levee to mitigate potential impacts by tree roots.

7.16.5 Levees with Existing Vegetation

Levees with existing vegetation are to be maintained according to the levee vegetation management criteria included in the CVFPP, described below. DWR's levee inspection program first developed interim criteria for use in the fall 2007 levee inspections, which were later described as interim criteria for visibility and accessibility in *California's Central Valley Flood System Improvement Framework* (2009).

The vegetation management criteria establish a vegetation management zone in which trees are trimmed up to 5 feet above the ground (12-foot clearance above the crown road) and thinned for visibility and access (see Figures 7-5 through 7-8). Brush, trees and other woody vegetation less than four inches in diameter at breast height, weeds or other such vegetation over 12 inches high are to be removed in an authorized manner. Trees and other woody vegetation that are within the 20-foot-wide landside right-of-way described in Section 7.11, but outside of the vegetation management zone, need to be trimmed up 5 feet above the ground and thinned for visibility and access; plantings and natural revegetation may also be allowed.

7.16.6 Lower Waterside Vegetation

Waterside vegetation below the vegetation management zone may remain in place without trimming or thinning, unless it poses an unacceptable threat to levee integrity.

7.16.7 Life-Cycle Vegetation Management

Life-cycle management (LCM) achieves visibility and accessibility criteria while progressing gradually (over many decades) toward the current USACE vegetation policy goal of eventually eliminating woody vegetation from the vegetation management zone on the landside slope, crown, and upper waterside slope of levees.

LCM provides that:

- The required removal of immature trees and other woody vegetation less than four inches in diameter at breast height is conducted in consultation with the appropriate resources agencies.

- Trees and other woody vegetation beyond this size (that do not pose an unacceptable threat to levee integrity) may live out their normal lives on the levee.

- Throughout their lives and after their deaths, these trees and other woody vegetation are periodically evaluated, and if found to pose an unacceptable threat to levee integrity, would be removed.

7.16.8 Vegetation Planting

Trees and other woody vegetation may be: (1) planted, and (2) allowed to naturally revegetate on a landside planting berm. Only the portion of the landside planting berm that is both 15 feet or more from the landside levee slope and 15 feet or more from the landward top of the planting berm may be planted and allowed to naturally revegetate. All trees and other woody vegetation in this area of the planting berm must be trimmed up 5 feet above the ground and thinned for visibility. Any landside berm can be a planting berm if its top is more than 30 feet wide (as measured perpendicular to the levee centerline) and the berm is at least 3 feet thicker than required for levee integrity (to account for potential overturning of trees from windthrow) (see Figure 7-8).

Trees and other woody vegetation may be planted on a waterside planting berm below the vegetation management zone, and on natural ground more than 20 feet (slope distance) waterward of the waterside levee crown hinge point.

For levees regulated by USACE and/or the Board, their approval is required for any plantings on the levee, within the channel, and within the right-of-way. USACE and/or the Board may allow plantings of (and retention of existing) trees and other woody vegetation according to their policies or variances from policy. Before planting, consideration should be given to the possibility that some or all of the vegetation may need to be removed in the future.

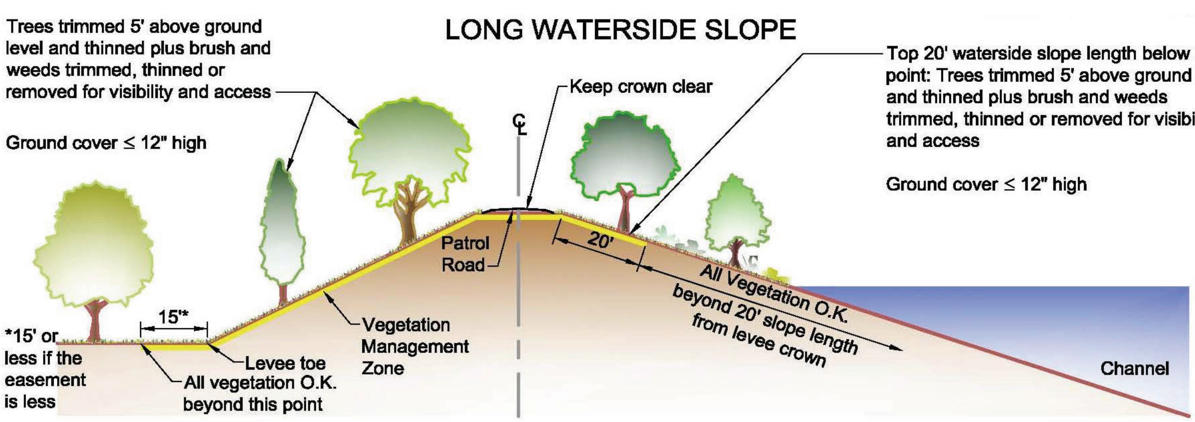

Figure 7-5. Vegetation Management for Existing Levees with a Long Waterside Slope

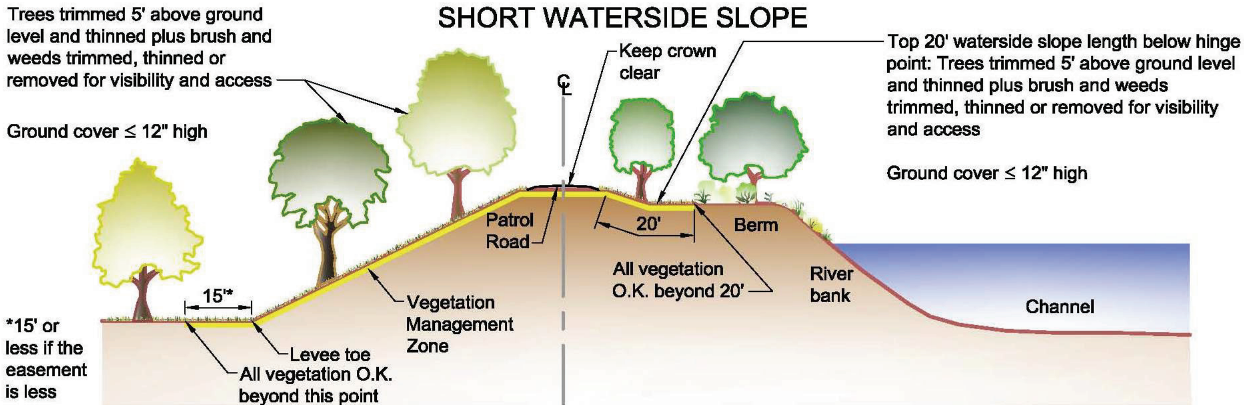

Figure 7-6. Vegetation Management for Existing Levees with a Short Waterside Slope

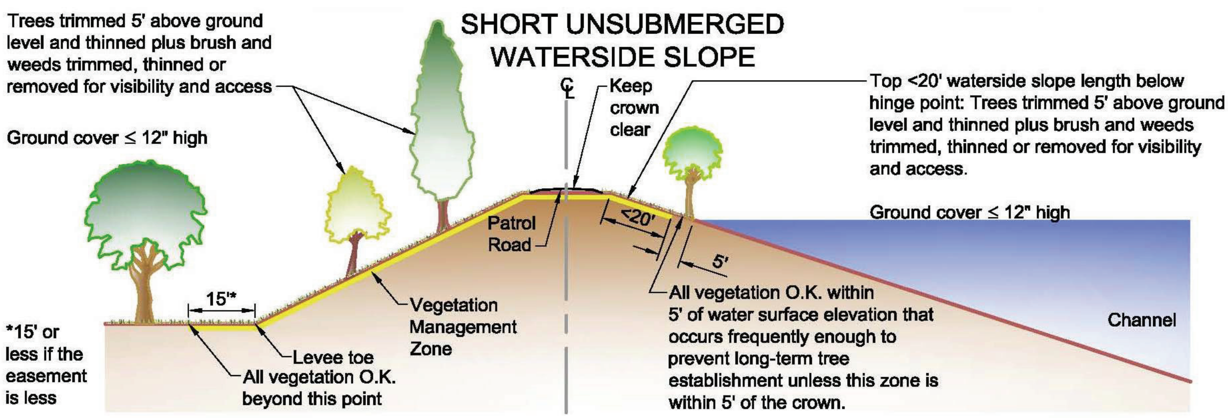

Figure 7-7. Vegetation Management for Existing Levees with a Short Waterside Slope above the Water Surface Elevation that Frequently Submerges the Lower Waterside Slope

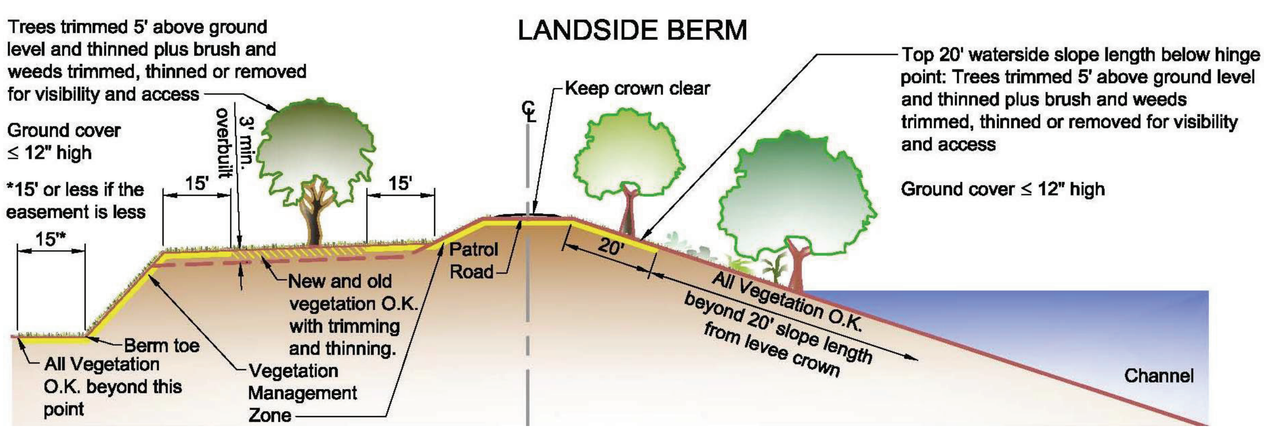

Figure 7-8. Vegetation Management for Existing Levees with a Landside Berm

7.17 Wind Setup and Wave Runup

Wind wave analysis is required, as noted elsewhere in these criteria. The wind setup and wave runup distances must be computed and added to the median 200-year still water surface elevation to determine the required elevation of the MTOL or floodwall. The setup and runup also must be computed and considered for analysis of erosion and overtopping impacts.

While the civil engineer has discretion in selection of the method to use, guidance for computing setup and runup distances is provided in USACE's *Shore Protection Manual* (1984), EM 1110-2-1100, and EC 1110-2-6067. Other guidance is provided in *Wave Overtopping of Sea Defenses and Related Structures: Assessment Manual* (2007), and in FEMA's *Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast for the United States* (2005), and *Mississippi Coastal Flood Hazard Project: Wave Runup Method* (2008).

The setup and runup computations require specification of potential wind speed and direction, fetch length, and water depth along the fetch. Standard practice should be followed to determine fetch length and water depths for the computations, consistent with the references cited above.

The wind speed to be used for setup and runup computations is based on design practice for bank protection on the Sacramento River. The wind speed to be used is that which has a 50 percent probability of not being exceeded in any 50-year design period. This criterion yields a design wind speed with a return period of 72.6 years, or annual probability of 0.0138. This design wind speed should be used for design of levees covered by the criteria in this document. Per USACE guidance, a limited amount of levee overtopping can be allowed without armoring, depending on levee geometry, soil conditions, and ground cover; typically ranging between 0.01 cubic feet per second per foot (cfs/ft) and 0.1 cfs/ft.

To estimate the maximum wave runup for setting the elevation of the physical top of the levee or floodwall, a design wind speed duration of less than 1 hour should be used, consistent with historical bank protection design.

For setup and runup computations for erosion protection design, and particularly for estimating median stone weight for armoring a levee, the duration of the wind should be the shortest length of time that would yield significant levee erosion; 4- and 6-hour durations have been used previously by USACE along the Sacramento River.

In performing these computations, the civil engineer should consider the duration of the hydrograph and that this method is based on open water and can result in excessive wave heights for riverine environments. Civil engineers should use caution in specifying excessive freeboard for wave runup until further research is performed. Based on the long history of performance of the Sacramento River Flood Control Project, 6 feet of freeboard should be considered sufficient except in unusual circumstances.

7.18 Security

A security plan is required to protect urban and urbanizing area levee systems (including closure structures and other appurtenances) from acts of terrorism and other malicious or negligent acts. The security plan is to identify security personnel, responsibilities, resources, and measures. The security plan should be made available to qualified officials within and outside of the levee maintaining agency. Security measures should be increased for frequently loaded levees and floodwalls, elevated threat periods, and during high water on intermittently loaded levees and floodwalls. In developing the security plan, the agency/agencies responsible for levee maintenance must consider and prioritize vulnerabilities and employ an array of security measures from four basic categories to address vulnerabilities:

- Networked detection
- Deterrence
- Physical security
- Intrusion interdiction during high threat periods

Some security measures, such as signs and access controls, fall into several of these categories.

Each levee maintaining agency must appoint a security director who will manage the security planning efforts and establish a chain of command for emergency operations. The security director will be responsible for an annual review and update of the security plan.

Documentation and discussions regarding security measures may qualify for Freedom of Information Act exclusion under federal and State laws and programs, such as the Protected Critical Infrastructure Information Program (PCII). Any public discussion or documentation of the full range of security measures, or of specific security measures or vulnerabilities applicable for any given levee or floodwall system, will need to be managed in a manner that prevents unauthorized access to the information and maintains the integrity and effectiveness of the measures to the maximum extent possible.

7.18.1 Networked Detection

Networked detection provides for monitoring and reporting of security information between the levee maintaining agencies and the Intelligence Community, comprised of multiple federal, state, and local agencies. Detection measures should include, but not be limited to, improved personnel and public awareness, suspicious activity reporting, and integration with the existing Terrorism Liaison Officer (TLO) program.

Reporting from the networked detection system should be through the National Suspicious Activity Reporting System (SARs) and fed into the Intelligence Community through the local Fusion Center for analysis. This network establishes the baseline awareness level for periods of normal threat.

The levee maintaining agency should establish a coordinated network partnership consisting of the public and community entities or citizens who have access to the levee, to report suspicious activity/intrusions to the appropriate authorities. One way to achieve this is through a "Neighborhood Watch" or "See Something, Say Something" program through the TLO network to enhance community awareness and focus reporting of suspicious behaviors.

The levee maintaining agency should provide for security training and awareness of its personnel through participation in InfraGard and California Emergency Management Agency's (Cal-EMA) Homeland Security Information Network – Critical Sectors (HSIN-CS).

7.18.2 Deterrence

The deterrence program should consist of appropriate visible security measures such as gates, physical presence such as increased flood watch patrols during high water, and access control to the degree possible. Aspects of the following physical security program serve as deterrence aids as well.

The levee maintaining agency should create an atmosphere of vigilance and security that hinders surveillance efforts and inhibits/delays intrusion efforts and maximizes potential for security and law enforcement intervention.

Signs that prohibit motor vehicles should be placed at all gated accesses and at regular intervals on the levee to aid law enforcement efforts and clarify intent of vehicles found there. Regular intervals should be considered for the signs to be within eyesight of each other, or every 0.25 mile where vision is obscured. "Neighborhood Watch" type signs should also be considered at gated access points.

Gated access points should be lighted and protected by locks that are shielded from bolt cutters.

7.18.3 Physical Security

Physical security is divided between deterrence (discussed above), access control, intrusion detection, and levee performance alerting mechanisms.

Access Control
Access controls along the levee are generally to be limited to restricting motor vehicle access. Non-vehicular public access along levees is generally not considered to be a security problem, except typically at specific locations such as pumping plants. The levee maintaining agency should implement access control measures to stop, inhibit or delay access by unauthorized persons. One goal of physical security is to force intruders who enter restricted areas to do so by knowingly unauthorized means, thereby limiting the number of such intruders and establishing intent on the part of the intruders.

The levee maintaining agency should consider an upgrade for all gates at roadway access points to K4 impact rating and install shielded lock mechanisms that prevent cutting the lock with bolt cutters. Gates should completely block vehicle access or be supplemented by K-rails, cables, or bollards. Automated gates can deter unauthorized access and facilitate quick access by authorized patrols.

Security measures related to levee penetrations and closure structures should be considered. Pump houses, pipes, culverts, and flood gates should all have signage, grates, locks, and alarms if needed and applicable.

Sensor systems should be considered for detecting problems, remotely if practical. Such systems may include pressure sensors, motion sensors, disturbance detection cables, and water flow detectors such as water level gages and piezometers.

Intrusion Detection
To enhance the ability to detect unauthorized intrusion, the levee maintaining agency should consider using security systems such as

cameras, motion detectors, and alarms at critical nodes, especially during high water or periods of increased threat.

The levee maintaining agency should develop and implement high water levee patrolling protocols that provide for the safety of patrollers if an unauthorized intrusion is underway and that emphasize detection of vehicular trespass.

Levee Performance
In addition to the measures above, alerting mechanisms that indicate a potential performance problem should be considered. These include sensors that detect levee movement, water pressure, water elevation, and water flow.

Consideration should be given to remote monitoring at the levee maintaining agency's office of as many of these systems as possible.

7.18.4 Intrusion Interdiction

Interdiction capabilities are determined by the preparedness and willingness of the local first responders. The goal is to facilitate awareness of and investment in swift response to reported intrusions during high water or increased threat periods.

Planning efforts should be considered, such as participating in or hosting a security seminar, workshop, and tabletop exercise with local agencies to familiarize, update and validate the security and evacuation plans related to levee security and breaches. The Cal-EMA Exercise Division should be contacted for support in these efforts.

7.18.5 Resources

Resources include:

- For contacting the Fusion Center / TLO network: *https://www.sacrtac.org*

- For contacting InfraGard: *http://www.infragard.net*

- For training and exercise assistance (Cal-EMA): *http://www.calema.ca.gov*

- For reports on Critical Infrastructure Protection (Department of Homeland Security): *http://www.dhs.gov/files/publications/counterterrorism.shtm*

- For hundreds of free training courses on incident management (FEMA): *http://www.fema.gov/prepared/train.shtm*

- General terrorism awareness video “8 Signs of Terrorism”: *http://www.azactic.gov/Video*

7.19 Sea Level Rise

The effects of sea level rise are to be estimated and addressed for the duration during which a Finding that the urban level of flood protection exists may be valid. For example, if the effect of sea level rise on the levee or floodwall is estimated to be 1 inch on the DWSE during the duration in which a Finding may be valid, then the levee or floodwall design must be for the DWSE that includes the inch of sea level rise. It is advisable to consider a range of estimates and prepare for future expansion and structural raises to address long-term sea level rise. The Ocean Protection Council adopted guidance on March 11, 2011 for sea level rise along California’s coast. The guidance is available at:

http://www.opc.ca.gov/webmaster/ftp/pdf/docs/OPC_SeaLevelRise_Resolution_Adopted031111.pdf

USACE guidance is provided in EC 1165-2-212.

7.20 Emergency Actions

Although emergency actions, such as flood-fighting, are expected to be employed as needed to prevent levee breaches and floodwall failures wherever feasible, they may not be relied upon for a Finding that the urban level of flood protection exists for an area. There are two exceptions:

1) Closure structures that meet the requirements contained in the “Floodwalls, Retaining Walls, and Closure Structures” section may be assumed effective and relied upon for performing as designed.

2) Flood relief structures such as culverts, gates, weirs, pumping plants, and levee relief cuts may be assumed effective and relied upon for performing as designed provided they are identified in an approved flood relief plan in the operation and maintenance manual (and/or in the flood safety plan) for the project.

7.20.1 Flood Relief Structures

The following requirements apply for flood relief structures:

- The flood relief plan in the operation and maintenance manual (or flood safety plan) must have specified triggers, procedures, and responsible agencies.

- Such flood relief structures may only be used to reduce the extent and/or depth of flooding within the protected area in the event a levee breach or floodwall failure has occurred (e.g., an area may have some levees or floodwalls that provide the urban level of flood protection and other levees or floodwalls that do not – the levees or floodwalls that do not provide the urban level of flood protection must be assumed to breach, with an appropriately sized breach, during the 200-year flood and a flood relief structure may limit the extent and/or depth of flooding within the protected area).

- The flood relief plan must be found to be clearly feasible for all levee breaches and floodwall failure scenarios during which the plan would need to be executed.

- Pumping plants must be designed to operate up to the full depth of potential flooding and have a dependable backup power supply.

- In the case of levee relief cuts, the flood relief plan must also include location(s), dimensions, and equipment (with identification of reliable sources of the equipment in time of emergency) and may not rely on flood waters to aid in making the relief cut.

- The flood relief plan must identify the hydraulic impacts of using the flood relief structure and specifically be approved as part of the Finding that the urban level of flood protection exists.

- If such a flood relief plan is approved, it may be used to lower the ponded water surface in the flooded areas of the basin based on the hydraulic capacity of the flood relief structure(s) and the most severe levee breach or floodwall failure scenario that is reasonably expected. In the case of levee relief cuts, the ponded water surface may be no lower than the levee crown elevation (due to the higher uncertainty associated with this type of flood relief structure), except as additional capacity for relief is provided by other fixed flood relief structures, such as culverts. Without a flood relief structure in an approved plan, the assumed ponding depth must be the depth resulting from the most severe levee breach or floodwall failure scenario that is reasonably expected. If that depth would exceed the top of the levee or floodwall, weir flow over the top of the levee or floodwall is to be assumed.

7.20.2 Flood Safety Plan

It is important that local maintaining agencies and communities understand the responsibilities of flood risk management within their jurisdictions. Emergency preparedness is an important part of an integrated flood risk safety framework. As such, each public agency with the responsibility for public safety for residents protected by levees and floodwalls must have a plan for flood events and other natural or man-made flood-related incidents that could result in human casualties, property destruction, and economic losses. This flood safety plan is to be made available upon request to qualified officials.

A sample flood safety plan which can be tailored for a particular location is available from DWR at:

http://www.water.ca.gov/floodmgmt/hafoo/fob/rass/Sample_Flood_Safety_Plan/safetyplan.cfm

Important components within this plan include:

- Organization and assignment of responsibilities
- Direction, control, and coordination
- Communications
- Administration, finance, and logistics
- Plan development and maintenance
- Authorities and maintenance
- Flood fight plan element
- Floodwater removal element
- Evacuation plan
- Requirements for siting new essential services buildings
- Levee patrol element

7.21 Urban Levee Design Criteria Summary

Urban levee design criteria for the two DWSE options are summarized in Tables 7-2 and 7-3, for intermittently loaded and frequently loaded levees, respectively:

Table 7-2. Urban Levee Design Criteria Summary for Intermittently Loaded Levees

Parameter	Criteria			
DWSE (Option 1)	Median 200-year WSE			
DWSE (Option 2)	90% assurance 200-year WSE			
MTOL (Option 1)	Median 200-year WSE + higher of (1) 3 feet, or (2) height for wind setup and wave runup			
MTOL (Option 2)	Lower of A or B, where: • A is the higher of (1) 90% assurance 200-year WSE, (2) median 200-year WSE plus 3 feet, or (3) median 200-year WSE plus height for wind setup and wave runup • B is the higher of (1) 95% assurance 200-year WSE, (2) median 200-year WSE plus 2 feet, or (3) median 200-year WSE plus height for wind setup and wave runup			
HTOL (Option 1)	Lower of (1) median 200-year WSE plus 3 feet, or (2) median 500-year WSE			
HTOL (Option 2)	Higher of A or B, where: • A is the lower of (1) median 200-year WSE plus 3 feet, (2) median 500-year WSE, or (3) MTOL (Option 2) • B is the DWSE			
Seepage-Exit Gradient at Levee Toe	For DWSE		For HTOL	
	$\gamma \geq 112$ pcf	$\gamma < 112$ pcf	$\gamma \geq 112$ pcf	$\gamma < 112$ pcf
	$i \leq 0.5$	FS ≥ 1.6	$i \leq 0.6$	FS ≥ 1.3
Seepage-Exit Gradient at Seepage Berm Toe	$i \leq 0.8$	FS ≥ 1.0	<20% FS degradation for berms less than 100 feet	<10% FS degradation for berms less than 100 feet
Steady-State Slope Stability (Landside)	FS ≥ 1.4		FS ≥ 1.2	
Rapid Drawdown Slope Stability (Waterside)	FS ≥ 1.2 (prolonged high stage) FS ≥ 1.0 (short lasting high stage)			
Seismic Vulnerability	Restore grade and dimensions for at least 10-year WSE plus 3 feet of freeboard or higher for wind setup and wave runup within 8 weeks			
Levee Geometry	For new or extensive reconstruction on a major stream, minimum 20-foot-wide crown, 3h:1v waterside and landside slopes for all levees except bypass levees (4h:1v waterside slope)			

Notes:
- This table includes only criteria that are easily quantified.
- The median 200-year WSE, the 90 percent assurance 200-year WSE, and the 95 percent assurance 200-year WSE in this table are assumed to have been increased appropriately as discussed in Section 7.1.3.
- Whichever option is selected, that same option is to be used for the DWSE, MTOL, and HTOL.

Key:
Option 1 = FEMA Approach
Option 2 = USACE Approach
DWSE = design water surface elevation
FS = factor of safety
HTOL = hydraulic top of levee
i = exit gradient
pcf = pounds per cubic foot
MTOL = minimum top of levee
WSE = water surface elevation
γ = saturated unit weight of soil (blanket layer)

Table 7-3. Urban Levee Design Criteria Summary for Frequently Loaded Levees

Parameter	Criteria	
	For DWSE	For HTOL
Steady-State Slope Stability (Landside)	FS ≥ 1.5	FS ≥ 1.3
Minimum Allowable Rapid Drawdown Slope Stability (Waterside)	FS ≥ 1.2*	
Frequent, Large, Tidal Fluctuations Rapid Drawdown Slope Stability (Waterside)	FS ≥ 1.4**	
Seismic Vulnerability	No significant deformation, usually limited to 3 feet maximum with 1 foot of vertical settlement.	

Notes:
These criteria are additions or exceptions to the criteria presented for intermittently loaded levees.
*Applies for the DWSE.
**Additional criterion that applies for the range of tidal fluctuation, not the DWSE.
Key:
DWSE = design water surface elevation
FS = factor of safety
HTOL = hydraulic top of levee

8.0 Operation, Maintenance, Inspection, Monitoring, and Remediation of Poor Performance

At a minimum, the following operation and maintenance-related requirements apply:

- The levee system must have an operation and maintenance manual consistent with USACE requirements (except as may be appropriate to deviate from those requirements to comply with the ULDC). In developing or updating the operation and maintenance manual, the civil engineer and/or the levee maintaining agency should consider guidance contained in DWR's *Superintendent's Guide to Operation & Maintenance of California's Flood Control Projects* (undated).

- All facilities necessary for providing the urban level of flood protection must be operated and maintained by an identified public agency with the authority and resources to do so. Where the levee system has more than one agency with operation and maintenance responsibilities, they will need to coordinate the responsibilities.

- USACE standard inspection requirements for project levees are applicable for all levees and floodwalls considered to provide the urban level of flood protection, including that a public agency (or agencies) routinely operates and maintains the levee system and inspects the entire levee system at least every 90 days and after every high water event.

- Damage and maintenance inadequacies identified from inspections should be prioritized and addressed in a timely manner, not awaiting the periodic review process.

- It is almost never practical or possible to completely know all of the engineering properties of levees and their foundations. Consequently, there will almost always be some degree of uncertainty that justifies both robust regular inspections and high water monitoring programs for levees and floodwalls protecting urban and urbanizing areas, with all of the attendant appurtenances and features (such as all-weather access roads on levee crowns and near the toe of wide landside berms).

- Monitoring during high water needs to provide for a thorough visual inspection of both the waterside and landside levee slope (and landside berm toe area) at intervals of no more than 1 hour.
- The levee system must have a levee security plan that meets the requirements described in Section 7.18.
- The levee system must have a flood safety plan that meets the requirements described in Section 7.20.

Other requirements – such as for a post-earthquake remediation plan, right-of-way plan, encroachment remediation plan, penetration remediation plan, or flood relief plan – may also apply, depending on the situation.

9.0 References

Some of the references below are not cited in the ULDC, but may provide state-of-practice guidance and be useful for urban levee design, evaluation, operation, and maintenance.

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Geotechnical Levee Practice Standard Operating Procedures (SOP) USACE Sacramento District, April, 2008.

Guidance Document for Geotechnical Analyses, Revision 11, URS Corporation, December, 2011.

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10.0 Work Group Member List

Building upon DWR's *Third Draft Interim Levee Design Criteria for Urban and Urbanizing Area State-Federal Project Levees* (2009), a work group collaboratively developed the ULDC between December 2009 and April 2012. Work group meetings were facilitated by the Center for Collaborative Policy. Work group members consisted primarily of civil engineers from California's Central Valley experienced in levee design and construction. Each work group member represented a public agency.

DWR would like to express its appreciation for the participation of the work group members (and their sponsoring organizations), many of whom authored original drafts of sections of the document and provided numerous helpful edits to improve successive drafts.

Work group members and facilitators are identified below. Private sector members not identified with a public agency in the list below were working for DWR.

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