Proposed Interim Levee Design Criteria for Urban and Urbanizing Area State-Federal Project Levees

1. Definitions

- ***Accreditation*** means recognition by FEMA that a levee provides protection for the base flood (100-year or 1% annual chance) event, based on certification provided by a civil engineer or the Corps.

- ***Assurance*** means the probability of non-exceedance.

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

- ***Central Valley Flood Protection Plan*** means a strategic plan for improving integrated flood management in the Central Valley that is to be completed by DWR by January 1, 2012 and adopted by the Board by July 1, 2012 (Water Code § 9612(b)). This plan is to be updated every five years thereafter (Water Code § 9612(e)). The details of the plan are defined in recently passed State legislation (Senate Bill 5).

- ***Certification*** means documentation provided by a civil engineer or the Corps that a levee system has been analyzed, following specific criteria and accepted procedures, and found that it meets the requirements for a particular level of protection (e.g., 100-year base flood protection for FEMA certification, or 200-year protection for compliance with the requirements of Senate Bill 5).

- ***Comprehensive Study*** means the 2002 Sacramento-San Joaquin River Basins Comprehensive Study. This study, lead by the Corps, provided estimates of 100-year, 200-year, and 500-year expected 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 failure. This scenario is believed to be the one advocated/required by FEMA in its Base Flood certifications and to also be recommended by the Corps for levee design and analysis of hydraulic impacts.

- ***Corps*** means the United States Army Corps of Engineers.

- ***Corps' R&U approach*** means the analysis of flood hazard and consequence 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 the

Corps' EM 1110-2-1619 and included in the Corps' HEC-FDA software application.

- ***Design Water Surface Elevation*** (DWSE) means the stage or water level used in deterministic analyses such as geotechnical seepage and stability analyses.

- ***Developed Area*** means the same as set forth in Section 59.1 of Title 44 of the Code of Federal Regulations.

- ***DWR*** means the California Department of Water Resources.

- ***Early Implementation Program*** means the DWR program that funds critical flood risk reduction projects that will be initiated in advance of the Central Valley Flood Protection Plan. These projects represent *"no regrets"* types of projects that are likely to be consistent with the Central Valley Flood Protection Plan that will be developed over the next several years.

- ***Expected Water Surface Elevation*** means the most likely, or 50% assurance level, stage or stream water level for the selected design flood event (e.g., 100-year, 200-year, or 500-year flood event), assuming that all other levees in the region act like weirs when overtopped and do not breach.

- ***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 Water Code (Public Resources Code § 5096.805(e)).

- ***FEMA*** means the Federal Emergency Management Agency.

- ***Freeboard*** means the height of the physical top of levee above the expected water surface elevation.

- ***Hydraulic Top of Levee*** means the lower of either: (1) the expected 200-year water surface elevation plus 3 feet, (2) the physical top of levee (or the water surface profile that matches the physical top of levee at its lowest point) if it meets the interim criteria, or (3) the expected 500-year water surface elevation.

- ***Levee System*** means one or more discrete reaches of levee along one or more streams that together provide flood damage reduction to a common, defined area.

- ***Non-urban Area*** means an area that does not qualify as being an urban area.

- ***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 § 65007(g)).

- ***State*** means the State of California.

- ***State-Federal Project Levees*** means the levees in the Central Valley that are part of the facilities of the State Plan of Flood Control.

- ***Urban Area*** means a developed area in the Sacramento-San Joaquin Valley in which there are 10,000 residents or more (Government Code § 65007(i)).

- ***Urbanizing Area*** means a developed area or an area outside a developed area in the Sacramento-San Joaquin Valley that is planned or anticipated to have 10,000 residents or more within the next 10 years (Government Code § 65007(j)).

2. 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 1960's on the San Joaquin River, the State has only built or improved State-Federal project levees in the Central Valley by partnering with the Corps. In these partnerships the Corps set the design standard and constructed the levees accordingly. For the first time since the 1960's, 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 the Corps' design standards to provide consistency in system improvements, comply with existing standards, and to facilitate federal crediting. However, the Corps' levee design standards 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 strong evidence of geotechnical and maintenance adequacy of levees for the base flood in order to maintain their current accreditation by FEMA. State-Federal project levees in the Central 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. Central 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 requires urban and urbanizing areas to have 200-year protection by 2025 in order to continue development in the floodplain. Consequently, an early goal of most Central Valley communities is to provide FEMA-level protection as an important milestone on the way toward achieving 200-year protection.

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

> **The FEMA approach** -- used by most civil engineers to certify levees for accreditation by FEMA, is a deterministic design approach based on the expected water surface elevation for a given flood frequency event. The levee must then 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 – 15 years, the Corps typically used this deterministic approach. In recent years the Corps has been developing and using a semi-probabilistic approach. FEMA has been working with the Corps on the concept of transitioning from its deterministic approach to the Corps' new approach.
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> **The Corps' approach** – used by the Corps and a limited number of other civil engineers, is a combined probabilistic and deterministic approach that utilizes conditional risk and uncertainty-based water surface elevations for performing a deterministic geotechnical levee design. The Corps' procedure for design and certification, as applied for the Natomas AR Zone determination in early 2008, is clear on many points, requiring that the seepage and slope stability analyses be performed using either the 90% assurance water surface elevation if 3 feet of freeboard exists relative to the expected (50% assurance) water surface elevation, or the 95% assurance water surface elevation if less than 3 feet of freeboard is available (but in no case is less than 2 feet of freeboard allowed). However, additional specificity is needed because the Corps has not yet presented: (1) guidance on whether and when upstream levees breach in calculating the risk and uncertainty-based water surface elevations, (2) guidance on levee design with different requirements for levee slope stability and seepage between urban/urbanizing and non-urban levees, (3) guidance on whether and how a check is performed to ensure that failure will occur from overtopping rather than from seepage or slope instability when design is exceeded, or (4) the rationale for using the 95% assurance water surface for slope stability and seepage analyses when less than 3 feet of freeboard is provided. Furthermore, the Corps has been trying to develop a new risk-based geotechnical analysis method to replace the deterministic geotechnical analysis method contained in Corps guidance

documents, including EM 1110-2-1913, ETL 1110-2-569, and draft ETL 1110-2-570. But the state of practice appears to be years away from developing an acceptable risk-based geotechnical approach for levee design.

Because a completely probabilistic approach would consider and quantify all of the important uncertainties influencing the Design Water Surface Elevation (DWSE), the Corps' approach to date in the Central Valley is more properly characterized as a semi-probabilistic or conditional probabilistic approach. Some of the factors that can be assigned uncertainty functions in a probabilistic analysis include rainfall, storm centerings, climate change, routing factors, reservoir storage, reservoir operations, hydraulics, topography, flood fighting capability, and levee fragility (which includes many uncertainties such as permeability, soil strength, erosion resistance, layer thickness, density, and homogeneity of soil properties). To make the analyses manageable, many simplifying assumptions may be made (and were made in developing the hydrology and hydraulics for the Comprehensive Study). In some cases, the simplifying assumptions may introduce conservatism rather than lead to a mean value (e.g., using the most severe storm centerings for any given levee being evaluated, or assuming upstream levees do not breach). The Corps' approach is very flexible and can utilize as few or as many simplifying assumptions as the user desires. However, the current tendency is for the Corps to make some of the simplifying assumptions lean toward being very conservative. The result is that the Corps' approach is a mixture of probabilistic and conservative deterministic approaches that, for infrequent flood events, results in water surface elevations with less likelihood of being exceeded than stated (i.e., a 90% assurance water surface elevation for a 200-year event actually has much less than a 10% chance of being exceeded). This is also true for the FEMA approach, since some conservative assumptions are employed in developing the expected water surface elevation.

Historically, most of the levee failures in the Central Valley have been caused by slope instability or seepage (including underseepage). Such failures tend to occur rapidly and with little or no warning – leaving little opportunity for evacuation prior to flooding. On the other hand, failures caused by levee overtopping are foreseeable and the levee failures tend to progress more slowly, and in some cases can be prevented through aggressive flood fighting. Failures from overtopping provide much better opportunity to successfully evacuate the threatened area and to take steps to minimize damage to personal property. Consequently, the Corps has begun considering new levee design criteria that require factors of safety for seepage and slope stability in excess of 1.0 for water at the top of the levee. The Corps 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 that protect urban and urbanizing areas as a reasonable requirement for protecting life and personal property.

3. Assumptions and Considerations

- Many communities in the Central Valley protected by State-Federal project levees will need to demonstrate within the next two years that the levees provide at least 100-year (1% annual chance) flood protection, using the 100-year expected water surface elevation to check for freeboard and geotechnical adequacy. Without documentation of this, FEMA is expected to map these communities into the 100-year floodplain and require mandatory flood insurance and building restrictions within the next three years.

- Both State policy and recently enacted State legislation (Senate Bill 5) call for 200-year (0.5% annual chance) flood protection to be the minimum level of protection for urban and urbanizing areas in the Central Valley. Senate Bill 5 requires that the 200-year protection be consistent with criteria used or developed by DWR. Senate Bill 5 requires all urban and urbanizing areas in the Sacramento and San Joaquin Valleys to achieve 200-year flood protection in order to approve development. The new law restricts approval of development after 2015 if adequate progress towards achieving this standard is not met. Urban and urbanizing areas protected by State-Federal project levees cannot use adequate progress as a condition to approve development after 2025.

- The citizens of California passed two bond measures on November 6, 2006 that provide $4.9 billion of bond funds for reducing the flood risk in California. Over the next 10 years, approximately $2 billion of State bond funds is expected to be spent for improving urban flood protection in the Central Valley. Currently, several urban areas in the Central Valley are seeking to qualify for funding under the Early Implementation Program.

- Both the Corps and FEMA are currently in the process of revising their flood protection criteria. At this point in time, neither agency is able to provide definitive criteria for the design of levee systems that meet the needs of the State. Accordingly, to avoid delays in providing urgently needed flood protection, the State needs to step forward to provide interim levee design criteria.

- Local agencies seeking only to maintain or achieve FEMA 100-year protection are under no obligation to use the criteria set forth below, since they can submit their certification packages directly to FEMA. However, DWR is required by SB 5 to develop criteria for 200-year protection and the principles and considerations discussed below provide local agencies notice of the intent of DWR to develop criteria for 200-year protection that are not presently provided by FEMA.

- Due to the changing state of practice and the absence of specific guidance from the federal government on some levee design considerations, the State needs to provide interim guidance and criteria for design water surface elevations and levee design that will be used for:
  - Evaluations of State-Federal project levees in urban and urbanizing areas
  - Evaluations of urban and urbanizing area levees that are not part of the State-Federal system
  - Guidance for urban and urbanizing area levee designs to be initiated/completed in the near future
  - Eligibility criteria for urban Early Implementation Program grant funding
  - Assisting local agencies in achieving FEMA 100-year protection
  - Assisting local agencies in achieving 200-year protection
  - Planning studies, such as the Central Valley Flood Protection Plan

- 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 Delta. More current thinking is that levees which infrequently experience loading from high water should be evaluated for seismic performance using typical water surface elevations and addressing flood risk with emergency response, interim and long-term repairs following the earthquake, and/or seismic remediation prior to the earthquake.

- 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 = exit gradient
γ_s = saturated unit weight of soil
γ_w = unit weight of water (62.4 pcf)

- Except for criteria specifically provided in this interim document, the guidance for levee design provided in the Corps' EM 1110-2-1913, ETL 1110-2-569, draft ETL 1110-2-570, the Geotechnical Levee Practice SOP for the Sacramento District, and other Corps guidance documents for the selected design flood event is considered to be applicable.

4. Design Principles

- To the extent applicable, the FEMA approach is considered acceptable. However, the FEMA approach is not explicit in some of its requirements and does not consider the consequences of failure in an urban area or the failure mode of the levee for events that exceed design.

- To the extent applicable, the Corps' approach is considered acceptable. However, the conditional risk and uncertainty-based design procedure utilized by the Corps is evolving and some aspects of it are unclear at this time. Most aspects of the approach can be utilized by the State and local agencies as a basis of design, with some modifications and clarifications.

- Whichever approach is used, it needs to be acceptable to FEMA for accreditation based on a certification from a civil engineer. Since the Corps' approach would allow some levees to be designed with less than 3 feet of freeboard (if the assurance is at least 95%) and FEMA may accredit levees with less than 3 feet of freeboard if a civil engineer provides sufficient justification, with analysis of flow and stage uncertainty, either approach should be acceptable for accreditation by FEMA. In other words, an analysis that follows a modified Corps approach with less than 3 feet, but at least 2 feet, of freeboard should be acceptable to FEMA.

- Urban and urbanizing area levees are to be designed for a landside slope factor of safety greater than 1.0 (stable) for stages up to the hydraulic top of levee so that erosion from overtopping would be the expected mode of failure for extreme flood events. Levees that are already built higher than the hydraulic top of levee should not be degraded or reinforced to ensure that failure from overtopping occurs prior to failure from slope instability or seepage.

- Urban and urbanizing area levee designs should assume that (1) other levees in the regional system and upstream of the area do not breach, (2) other levees in the region and upstream of the area will be restored to their authorized design elevations, and (3) other urban levees in the region and upstream of the area will have at least 3 feet of freeboard for the 200-year event.

- Levee design criteria for slope stability and seepage should not be more stringent for levees that have less than 3 feet of freeboard than for levees that have at least 3 feet of freeboard.

- Urban and urbanizing area levee 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 flood protection system. A sensitivity analysis of increased streamflows can be useful in evaluating how high the DWSE should be raised.

- Urban and urbanizing area levee designs should consider system concepts for the area protected by the levee.

- Seismic performance of urban and urbanizing area levees during 200-year 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 the purpose of seismic strengthening generally would not be justifiable for levees subject to only seasonal high water loading. 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 emergency response and remediation plan.

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

5. Proposed Interim Urban and Urbanizing Area Levee Design Criteria

A two-option approach is recommended for defining Design Water Surface Elevations and urban/urbanizing levee design criteria over the next two years. Local agencies would be able to choose either one of two approaches for design and 200-year certification of their levee systems, summarized as follows:

(1) A modified version of the FEMA approach: specifically, to perform geotechnical and structural analysis with conventional safety factors using the expected water surface elevation as the DWSE, calculated through a conventional deterministic hydraulic analysis that assumes non-urban area levees will overtop and not breach and urban area levees will not overtop. To ensure the primary risk of levee failure is from overtopping (rather than slope instability or seepage) when the design stage is exceeded, the Modified FEMA Approach requires a geotechnical analysis using less stringent design criteria for a water surface set at the hydraulic top of levee. The physical top of levee would need to be at least 3 feet higher than the DWSE, or higher if required for wave runup; or

(2) A modified version of the Corps' approach: specifically, to perform geotechnical and structural analyses with conventional safety factors using the 90% assurance water surface as the DWSE, calculated through a conditional R&U analysis that assumes non-urban area levees will overtop and not breach and urban area levees will not overtop. To ensure that the levee fails from overtopping (rather than slope instability or seepage) when design stage is exceeded, the Modified Corps Approach requires a geotechnical analysis using less stringent design criteria for a water surface set at the hydraulic top of levee. The physical top of levee would need to be at least 3 feet higher than the expected water surface elevation if the 90%

assurance water surface elevation is used to set the physical top of levee, or higher if required for wave runup. The physical top of levee would need to be at least 2 feet higher than the expected water surface elevation if the 95% assurance water surface elevation is used to set the physical top of levee, or higher if required for wave runup.

In addition, under either approach local agencies would be allowed and encouraged to adjust the DWSE upward to account for previous hydrologic studies having a small number of storm centerings and not addressing climate change -- until new hydrology is developed for the Central Valley that can be expected to yield higher flows than the current hydrology. DWR will also provide guidance with respect to considering sea level rise in hydraulic models. The adjustment should be based on judgment and consideration of the physical limits of the upstream and nearby regional flood protection system.

The two approaches would be available for use until rescinded by DWR (expected to be no sooner than January 1, 2011).

For an urban area or urbanizing area, the entire levee system needs to be designed or certified using a single approach. The approach can follow either of the following two options:

<u>Option 1: Modified FEMA Approach</u>

1. Where available, use the updated 2002 Comprehensive Study information to determine the expected water surface elevation (2002 Comprehensive Study data may be used if it has not been updated for the study area):

   a. The hydraulic models are to use the following assumptions:

      i. Upstream and downstream levees protecting an existing urban area are not allowed to overtop, nor are they allowed to breach.

      ii. All upstream and downstream levees are to be modeled to incorporate a minimum crown elevation equal to the 1955/57 original Corps design profiles – this affects non-urban areas for the most part – all such levees are to be allowed to overtop, act as weirs, and not breach for floods up to and including the 500-year flood.

   b. Based on judged potential for underestimating the design water surface elevation, add up to one foot to the results to account for the potential for the new, updated hydrology to yield higher flows. Once it is available, the updated hydrology and hydraulic modeling for the Central Valley, incorporating sea level rise and climate change considerations, should eliminate the need to consider adding height to the DWSE.

This modified Comprehensive Study expected water surface elevation, plus up to an additional foot, becomes the Design Water Surface Elevation (DWSE). This approach would be used for both the 100-year and the 200-year flood events.

In some cases, where hydrologic or hydraulic information is non-existent or out of date, it may be necessary to develop new hydrologic and/or hydraulic data.

2. The physical top of levee (levee crown elevation) must be no lower than the DWSE plus a minimum of 3 feet, or higher, to account for wave runup – specific wind-wave analyses need to be completed using the DWSE.

3. Landside slope stability analyses are to use appropriate phreatic surfaces based on the DWSE – with a minimum factor of safety of 1.4 for failure surfaces that intersect the levee crown. The steady-state phreatic surface is generally considered to be appropriate, but a lower phreatic surface may be justified depending on the duration of the design hydrograph and the composition and dimensions of the levee. A minimum factor of safety of 1.2 is also required for an appropriate phreatic surface corresponding to the water surface set at the hydraulic top of levee. If the phreatic line corresponding to the DWSE emerges on the landside levee slope of embankments consisting of erodible soils, then remediation will be required to prevent unraveling and progressive slope failure.

4. The underseepage exit gradient for existing levees is required to be 0.5 or less at the landside levee toe using steady-state seepage analysis at the DWSE (for new levees, 0.3 is required). For levees with a landside blanket top stratum with a saturated unit weight less than 112 pcf, a minimum factor of safety for underseepage of 1.6 is required at the landside levee toe (for new levees, 2.7 is required).

5. The underseepage exit gradient for existing levees is required to be 0.6 or less at the landside levee toe using steady-state seepage analysis for a water surface set at the hydraulic top of levee (for new levees, 0.4 is required). For existing levees with a landside blanket top stratum with a saturated unit weight less than 112 pcf, a minimum factor of safety for underseepage of 1.3 is required at the landside levee toe for seepage analysis using a water surface set at the hydraulic top of levee (for new levees, 2.0 is required).

6. The underseepage exit gradient is required to be 0.8 or less at the toe of a seepage berm less than 300-400 feet wide using steady-state seepage analysis at the DWSE. If the underseepage exit gradient at or beyond the toe of a seepage berm that is at least 300-400 feet wide exceeds 0.8, sound engineering judgment should be applied in deciding whether the design is acceptable. If the saturated unit weight of the blanket layer is less than 112 pcf, the minimum factor of safety for underseepage at the toe of the seepage berm is 1.0.

7. The underseepage exit gradient is required to be 0.9 or less at the toe of a seepage berm less than 300-400 feet wide using steady-state seepage analysis for a water surface set at the hydraulic top of levee. If the saturated unit weight of the blanket layer is less than 112 pcf, the minimum factor of safety for underseepage at the seepage berm toe is 0.9 using a water surface set at the hydraulic top of levee.

8. The underseepage exit gradient at the levee toe is required to be 0.5 or less through the combined seepage berm/blanket layer using steady-state seepage analysis at the DWSE (unless a drainage blanket is provided in the seepage berm with sufficient capacity to accommodate the seepage). The allowable underseepage exit gradient through the combined seepage berm/blanket layer beyond the levee toe is determined by linear interpolation, using 0.5 at the levee toe and 0.8 at the seepage berm toe. 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. For impermeable seepage berms, the required minimum uplift factor of safety for the combined seepage berm/blanket layer is 1.5 using the Corps' procedures.

9. An analysis of seismic vulnerability of the levee system from 200-year ground motions is required, using typical summer and winter water surface elevations. For levees subject to seasonal high water that are planned for repair or improvement and that are also found to be vulnerable to seismic damage, the repair or improvement alternative that is most resistant to seismic damage and/or easily and economically repaired following an earthquake should be selected over other cost-comparable alternatives (e.g., a berm is preferable to a cost-comparable slurry wall). If seismic damage is expected after all 200-year flood improvements are in place, a post-earthquake remediation plan will be required for quickly restoring the levee system's grade and dimensions sufficient for protection against the 10-year flood, with 3 feet of freeboard, or higher as needed for 10-year wave runup. 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 protection

within a few months, seismic strengthening may be required for 200-year certification. Levees subject to frequent high water, such as many levees in the Delta, would need seismic stability sufficient to maintain a 10-year level of flood protection during and immediately after the earthquake.

Notes:

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

2. Underseepage exit gradient and factor of safety criteria also apply within a ditch or depression near the levee toe or seepage berm toe. Gradient calculations within the ditch or depression must be performed assuming the ditch or depression is not filled with water, unless it can be assured otherwise. Following Corps procedures, for steady state seepage at the DWSE, the allowable exit gradients in the ditch or depression are 0.5 at the levee toe and 0.8 at 150 feet from the levee toe and beyond (300-400 feet), with linear interpolation applying between. If the underseepage exit gradient in a ditch or depression at least 300-400 feet from the levee toe exceeds 0.8, sound engineering judgment should be applied in deciding whether the design is acceptable. For steady state seepage at the hydraulic top of levee, allowable exit gradients in the ditch or depression are 0.6 at the levee toe and 0.9 at 150 feet from the levee toe and beyond (300-400 feet), with linear interpolation applying between. For soils in the ditch or depression with saturated unit weights of less than 112 pcf, the applicable factors of safety for underseepage should be used instead of exit gradients.

<u>Option 2: Modified Corps Approach</u>

1. Where available, use updated 2002 Comprehensive Study information to perform the conditional risk and uncertainty analysis for hydrology and hydraulics (2002 Comprehensive Study data may be used if it has not been updated for the study area):

   a. The hydraulic models are to use the following assumptions:

      i. Upstream and downstream levees protecting an existing urban area are not allowed to overtop, nor should they be allowed to breach.

      ii. All upstream and downstream levees are to be modeled to incorporate a minimum crown elevation equal to the 1955/57 original Corps design profiles – this affects non-urban areas for the most part – all such levees are to be allowed to overtop, act as weirs, and not breach for floods up to and including the 500-year flood.

b. Determine the expected water surface elevation and the corresponding 90% and 95% assurance water surface elevations for the design event. Any methodology that meets the Corps standards for determining the 90% and 95% assurance elevations may be used. An example of an approved method for determining the assurance levels would be the utilization of the computer program HEC-FDA.

c. Based on judged potential for underestimating the design water surface elevation, add up to one foot to the results to account for the potential for the new, updated hydrology to yield higher flows. Once it is available, the updated hydrology and hydraulic modeling for the Central Valley, incorporating sea level rise and climate change considerations, should eliminate the need to consider adding height to the DWSE.

The 90% assurance water surface elevation, plus up to an additional foot, becomes the DWSE. This approach would be used for both the 100-year and the 200-year flood events.

For locations where the Comprehensive Study information is unavailable or superseded, use the best available hydrologic and hydraulic data and follow the same procedure as above. In some cases, where information is non-existent or out of date, it may be necessary to develop new hydrologic and/or hydraulic data.

2. The physical top of levee (levee crown elevation) must be no lower than the DWSE or 3 feet above the expected water surface elevation, whichever is higher, or higher for wave runup – specific wind-wave analyses need to be completed using the expected water surface elevation. A lower physical top of levee is allowed if it is both (1) at or above the 95% assurance water surface elevation, or higher for wave runup and (2) at least 2 feet above the expected water surface elevation, or higher as needed for wave runup.

3. Landside slope stability analyses are to use appropriate phreatic surfaces based on the DWSE – with a minimum factor of safety of 1.4 for failure surfaces that intersect the levee crown. The steady-state phreatic surface is generally considered to be appropriate, but a lower phreatic surface may be justified depending on the duration of the design hydrograph and the composition and dimensions of the levee. A

minimum factor of safety of 1.2 is also required for an appropriate phreatic surface corresponding to the water surface set at the hydraulic top of levee. If the phreatic line corresponding to the DWSE emerges on the landside levee slope of embankments consisting of erodible soils, then remediation will be required to prevent unraveling and progressive slope failure.

4. The underseepage exit gradient for existing levees is required to be 0.5 or less at the landside levee toe using steady-state seepage analysis at the DWSE (for new levees, 0.3 is required). For existing levees with a landside blanket top stratum with a saturated unit weight less than 112 pcf, a minimum factor of safety for underseepage of 1.6 is required at the landside levee toe (for new levees, 2.7 is required).

5. The underseepage exit gradient for existing levees is required to be 0.6 or less at the landside levee toe using steady-state seepage analysis for a water surface set at the hydraulic top of levee (for new levees, 0.4 is required). For existing levees with soils in the foundation top stratum with saturated unit weights less than 112 pcf, a minimum factor of safety for underseepage of 1.3 is required at the landside levee toe for seepage analysis using a water surface set at the hydraulic top of levee (for new levees, 2.0 is required).

6. The underseepage exit gradient is required to be 0.8 or less at the toe of a seepage berm less than 300-400 feet wide using steady-state seepage analysis at the DWSE. If the underseepage exit gradient at or beyond the toe of a seepage berm that is at least 300-400 feet wide exceeds 0.8, sound engineering judgment should be applied in deciding whether the design is acceptable. If the saturated unit weight of the blanket layer is less than 112 pcf, the minimum factor of safety for underseepage at the toe of the seepage berm is 1.0.

7. The underseepage exit gradient is required to be 0.9 or less at the toe of a seepage berm less than 300-400 feet wide using steady-state seepage analysis for a water surface set at the hydraulic top of levee. If the saturated unit weight of the blanket layer is less than 112 pcf, the minimum factor of safety for underseepage at the seepage berm toe is 0.9 using a water surface set at the hydraulic top of levee.

8. The underseepage exit gradient at the levee toe is required to be 0.5 or less through the combined seepage berm/blanket layer using steady-state seepage analysis at the DWSE (unless a drainage blanket is provided in the seepage berm with sufficient capacity to accommodate the seepage). The allowable underseepage exit gradient through the combined seepage berm/blanket layer beyond the levee toe is determined by linear interpolation, using 0.5 at the levee toe and 0.8 at

the seepage berm toe. 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. For impermeable seepage berms, the required minimum uplift factor of safety for the combined seepage berm/blanket layer is 1.5 using the Corps' procedures.

9. An analysis of seismic vulnerability of the levee system from 200-year ground motions is required, using typical summer and winter water surface elevations. For levees subject to seasonal high water that are planned for repair or improvement and that are also found to be vulnerable to seismic damage, the repair or improvement alternative that is most resistant to seismic damage and/or easily and economically repaired following an earthquake should be selected over other cost-comparable alternatives (e.g., a berm is preferable to a cost-comparable slurry wall). If seismic damage is expected after all 200-year flood improvements are in place, a post-earthquake remediation plan will be required for quickly restoring the levee system's grade and dimensions sufficient for protection against the 10-year flood, with 3 feet of freeboard, or higher as needed for 10-year wave runup. 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 protection within a few months, seismic strengthening may be required for 200-year certification. Levees subject to frequent high water, such as many levees in the Delta, would need seismic stability sufficient to maintain a 10-year level of flood protection during and immediately after the earthquake.

Notes:

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

2. Underseepage exit gradient and factor of safety criteria also apply within a ditch or depression near the levee toe or seepage berm toe. Gradient calculations within the ditch or depression must be performed assuming the ditch or depression is not filled with water, unless it can be assured otherwise. Following Corps procedures, for steady state seepage at the DWSE, the allowable exit gradients in the ditch or depression are 0.5 at the levee toe and 0.8 at 150 feet from the levee toe and beyond (300-400 feet), with linear interpolation applying between. If the underseepage exit gradient in a ditch or depression at least 300-400 feet from the levee toe exceeds 0.8, sound engineering judgment should be applied in deciding whether the design is acceptable. For steady state

seepage at the hydraulic top of levee, allowable exit gradients in the ditch or depression are 0.6 at the levee toe and 0.9 at 150 feet from the levee toe and beyond (300-400 feet), with linear interpolation applying between. For soils in the ditch or depression with saturated unit weights of less than 112 pcf, the applicable factors of safety for underseepage should be used instead of exit gradients.

6. Inspection, Monitoring, and Remediation of Poor Performance

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 flood stage monitoring programs for levees protecting urban and urbanizing areas, with all of the attendant appurtenances and features. Any levee that shows distress before it is overtopped should be remediated before the next flood season.

Although the draft interim criteria are aimed toward a goal of ensuring the primary risk of levee failure is from overtopping, rather than slope instability or seepage, this goal is balanced against cost concerns, so that only the most marginal of levee projects would have their feasibility jeopardized by the additional requirements of the draft interim criteria. Consequently, the draft interim criteria allow for some levees to be designed and certified for 200-year protection without necessarily providing strict design measures that eliminate the potential for failure before overtopping occurs (e.g., levees that are significantly higher than the hydraulic top of levee, and levees with exit gradients at the toe of a seepage berm slightly exceeding the critical exit gradient for water at the hydraulic top of levee). In these rare situations, if the engineering properties have been properly characterized and there is no additional conservatism in the computations, signs of distress such as boils, can be expected *before* overtopping occurs. In this case, a flood stage monitoring program is even more justified. Left unattended, sustained boils could cause enough piping to damage the seepage berm and even possibly cause a levee breach.

Engineers that design and certify levee systems must also incorporate features that provide for prompt identification of distress after or during an event. Such features include all-weather roadways that allow visual inspection of the levee slope and toe area, the seepage berm, and the seepage berm toe area. The roadways need to be designed and constructed to sustain heavy construction vehicles needed for effective flood fighting in wet conditions.

Levee designs also need to incorporate piezometers, and possibly other types of instrumentation, to verify design computations and adjust for actual field conditions. Remediation may be needed, based on either instrumentation readings or poor field performance during high water conditions.

7. Achievements and Considerations

- The proposed criteria allow local agencies to choose between two well defined approaches that are similar to the two existing federal approaches, but modified to make them more specific and designed to avoid sudden, unexpected levee failures.

- The simpler approach, the Modified FEMA Approach, is similar to the approach currently employed by most civil engineers.

- The Modified Corps Approach, the more complex of the two approaches, uses a higher water surface elevation for geotechnical design, and may require more freeboard, and therefore will tend to result in a more robust levee design. In some cases (where the 95% assurance water surface elevation is used) it may result in less freeboard than would normally be required by FEMA. In some cases, the Modified Corps Approach uses a lower water surface for geotechnical design than the Corps would use (90% assurance as compared to 95% assurance, respectively).

- Because FEMA appears to be moving away from deterministic design and has proposed a 10-year transition toward the Corps' approach, local agencies that choose the Modified FEMA Approach may find that they will need to make additional improvements in the future in order to sustain the level of protection to which they are designing.

- Because the Corps' approach is evolving, local agencies that choose to follow the Modified Corps Approach may ultimately find that they will need to make additional improvements in the future in order to sustain the level of protection to which they are designing, as measured by the Corps' procedures. They are less likely to need to make additional improvements than if they followed the Modified FEMA Approach.

- Because new hydrology and hydraulic studies are being developed over the next few years, and they will consider additional storm centerings, sea level rise, and climate change, any design based on current hydrology and hydraulics may ultimately provide less protection than intended. Therefore, an increase in the design water surface elevation of up to one foot is allowed and encouraged, based on judgment.

- The proposed criteria allow use of the widely available 2002 Sacramento-San Joaquin River Basins Comprehensive Study model with conservative modifications.

- The proposed criteria establish guidance for slope stability and seepage for water levels set at the hydraulic top of the levee that, except for levees with excessive freeboard, should minimize the likelihood of the levee failing from any of these mechanisms – so that the primary risk of failure is from overtopping. This is desirable in order to minimize unpredicted levee failures and loss of life and is an additional consideration absent from FEMA's approach and not well defined in the Corps' approach.

- The proposed criteria use a lower factor of safety for water levels set at the hydraulic top of levee (e.g., underseepage exit gradient of 0.6 instead of 0.5, and seepage berm exit gradient of 0.9 instead of 0.8) than some engineers may advocate and more conservative than others may advocate. However, the criteria still control the reduction of the factor of safety for this extreme loading event and provide an additional safety check not required by FEMA and not yet fully established by the Corps.

- The proposed criteria provide guidance regarding seismic performance and design of levees, how to incorporate seismic considerations in selection of levee repair and improvement alternatives, and how to address unremediated seismic performance problems.

- The proposed criteria address expectations for inspection, monitoring, and remediation of poor performance to address uncertainties in levee designs and field performance.

- Other considerations not addressed by the proposed criteria will need to be addressed in subsequent versions. For example, criteria are needed for levee penetrations, waterside erosion, right of way, levee vegetation, encroachments, floodwalls, and certification/recertification procedures.

- This interim approach would last until rescinded by DWR (expected to be no sooner than January 1, 2011). After this date, DWR should have new, updated hydrology and hydraulics information and modeling that will better define appropriate design water levels. Hopefully by this date, both the Corps and FEMA will have agreed with the State on appropriate design criteria.

8. Proposed Circulation

It is proposed that this draft be circulated with Corps, FEMA, and local agencies to continue discussions on refinements and additions to these criteria, and to allow designs to proceed expeditiously using either option.

9. References

a. EM 1110-2-1913, Engineering and Design - Design and Construction of Levees, dated 30 April 2000.

b. ETL 1110-2-569, Engineering and Design: Design Guidance for Levee Underseepage, dated 01 May 2005.

c. Draft ETL 1110-2-570, Certification of Levee Systems for the National Flood Insurance Program, dated 12 September 2007.

d. EM 1110-2-1619, Engineering and Design - Risk-Based Analysis for Flood Damage Reduction Studies, dated 1 August 1996.

e. Code of Federal Regulations, Title 44, Part 65.10. 44 CFR 65.10 - Mapping of Areas Protected by Levee Systems.

f. Senate Bill 5 (Machado), 2007.

g. CESPK-ED-G Memorandum for Record dated 11 January 2008, Summary of the Natomas Basin 3% Event Screening Level Levee Certification Analysis.

h. EM 1110-2-556. Appendix B, Evaluating the Reliability of Existing Levees, dated 28 May 1999.

i. Geotechnical Levee Practice SOP Sacramento District, USACE, effective 11 April 2008.