US Army Corps of Engineers

ENGINEERING AND CONSTRUCTION BULLETIN

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SUBJECT: Managed Overtopping of Levee Systems

CATEGORY: Guidance

APPLICABILITY: The U.S. Army Corps of Engineers (USACE) will use this directive and guidance for commands responsible for planning, design, construction, and operation and maintenance of civil works projects. The procedures are general in nature and can be applied to any phase of study, as directed by Engineer Regulation (ER) 1110-2-1150. The level of detail in the overtopping analysis will depend on the study phase. This document is applicable for all USACE riverine levee and floodwall systems. This Engineering and Construction Bulletin (ECB) provides an interim update to expired technical guidance Engineer Technical Letter (ETL) 1110-2-299 and provides a methodology for configuring the engineered capacity exceedance related to flood overtopping at a specific location or locations along the levee system. This guidance does not address overtopping of the entire system on those occasions when the overall system capacity is exceeded. Content of this ECB supersedes previous guidance on the subject of overtopping of levee systems and will be incorporated into an Engineer Manual (EM) in the future.

1. **References**:

    a. EC 1110-2-6066 ‘Engineering of Design: Design of I-Walls’

    b. EM 1110-2-1619 ‘Risk-Based Analysis for Flood Damage Reduction Studies’

    c. EM 1110-2-1913 ‘Design and Construction of Levees’

    d. ER 1100-2-8162 ‘Incorporating Sea Level Change in Civil Works Programs’

    e. ER 1105-2-100 ‘Planning Guidance Notebook’

    f. ER 1105-2-101 ‘Risk Assessment for Flood Risk Management Studies’

    g. ER 1110-2-1150 ‘Engineering and Design for Civil Works Projects’

    h. ETL 1110-2-299 ‘Overtopping of Flood Control Levees and Floodwalls’

2. **Introduction.**

a. A levee system (or sometimes referred to as just “levee” in this document), is comprised of one or more components which collectively provide flood risk reduction to a defined area, referred to as a leveed area. A levee system is inclusive of all components that are interconnected and necessary to exclude floods from the leveed area. Components include embankment and floodwall sections, closure structures, pumping stations, culverts, and interior drainage works.

The configuration of the levee system could also be influenced by reservoir operations and channelization features. The 1986 version of ETL 1110-2-299 conceptually introduced the overtopping reach in a system that is located adjacent to a low hazard, lower risk inundation area. The ETL also presented the notion of system superiority for reaches of higher economic and life safety risks. The ETL then provided a methodology for establishing the top of levee profile incorporating these overtopping and superiority concepts. However, the ETL did not include the risk analysis concepts that USACE requires today nor did the ETL delve into the composition of a levee cross-section (base levee and appropriate increments) and the evaluation of the economic and the engineered performance of overtopping features. The ETL only tangentially touched on resiliency of the overtopping reach and how resiliency might contribute to the design of the overtopping configuration. Resiliency, as used in this document, refers to the ability of an engineered structure to withstand overtopping flows at a specified location.

b. Configuring a levee system using methods presented in this ECB, includes setting top of levee profile, determining overtopping reach length and depth, considering resiliency measures in the overtopping reach (see Paragraph 7.b. for definition of overtopping discharge) and managing residual risk. It is important to note that this ECB addresses the engineering aspects of managing overtopping along levee segments and must be used in concert with the current planning guidance. Resiliency measures provided by various forms of surface hardening, armoring, or resistance to overtopping scour, define one of the driving parameters in sizing the overtopping reach and establishing overtopping rates and overtopping volumes. Resiliency in the overtopping reach provides a higher degree of confidence in levee performance at the point of overtopping to assist floodplain managers. This methodology in this ECB is consistent with the flood risk framework concepts and guidance as presented in ER 1105-2-101, EM 1110-2-1619 and EM 1110-2-1913 and the ideas and concepts of the USACE National Flood Risk Management Program and the USACE Levee Safety Program. USACE established the National Flood Risk Management Program (http://www.nfrmp.us/) in order to advance the goals of flood risk identification, communication, response, and management services across all levels of government in order to save lives and reduce property damage in the event of floods and coastal storms. The mission of the USACE Levee Safety Program is to ensure levee systems provide benefits to the Nation by working with sponsors and stakeholders to assess, communicate, and manage the flood risks to people, property, and the environment. The level of study effort should align with SMART (Specific, Measurable, Attainable, Risk Informed, Timely) Planning Principles which promote balancing the level of uncertainty and risk with the level of detail of the study. The level of detail required to make planning decisions will grow over the course of the study, as the study team moves from an array of alternatives to a single recommended alternative. Details of SMART Planning Principles can be found at http://planning.usace.army.mil/toolbox/smart.cfm.

3. **Managed Overtopping and Life Safety.**

a. Flood risk is a fact of life for those living in areas subject to flooding. No matter what project or action is proposed, evaluated, adopted, and implemented for life safety, complete containment or total mitigation is never possible. Further, information used to estimate flood risk, formulate and evaluate plans, and consequent results of the analyses, are uncertain. All measured or estimated values in project development are to various degrees inaccurate, reflecting both inherent natural variability in flooding phenomena, (e.g., cyclical rainfall patterns) and uncertainty in estimating various parameters (e.g., estimation of n-value) relevant to project works and their performance.

b. The risk framework (comprised of risk assessment, risk management, and risk communication) is an explicit means of better understanding both the flooding and associated consequences, and thus should support development of robust strategies for managing flood risk. Implementing the concept of 'superiority' is one such strategy for managing risk. Superiority simply means providing higher levees at all points except where initial overtopping is desired when practicable in a given system. Not all systems may be able to accommodate superiority measures. Superiority is an increment of the levee height that increases the likelihood that when the system approaches capacity, flooding will occur at a specified overtopping section. Designs that include superiority can initiate overtopping in the least hazardous location. Water surface profiles (WSP) and distribution of overtopping volumes and the subsequent consequences need to be examined to understand where superiority should exist and where overtopping reaches should be located. Documenting overtopping consequences in the leveed area is an element of the strategy in flood hazard and emergency action plans including a local flood warning system. Overtopping reaches may only provide relief up to the capacity of the superiority reach and beyond that capacity the system is assumed to have been overwhelmed. The overtopping reach is to provide a known initial exceedance location and to provide some warning/evacuation time before total system exceedance.

c. A levee system is expected to exclude flood waters from the floodplain up to a given flood elevation. A levee system may be overtopped during a future event that is high enough to exceed the top of the levee. As a result, there will always be a residual flood risk that must be acknowledged and managed. Note that residual risk can consist of more than just the risk due to water overtopping the levee; the potential for a breach either prior to or subsequent to overtopping also contributes to incremental risk of a levee system. Superiority is a levee feature that can be used to reduce and manage residual risks.

4. **Risk-Based Levee Design Concepts.**

a. Levees and floodwalls are flood risk management structures meant to keep flood waters out of a floodplain area. These structures have upper limits beyond which larger floods cannot be contained or managed. Since the structure will someday experience floods that overtop and flood the interior, overtopping becomes a design concern. The hazard of inundation by overtopping can be significant for flood risk management levees or floodwalls, and the consequences can be costly and potentially catastrophic. The rate of breach of a levee or floodwall is difficult to predict with sudden breach a possibility, even when flood fighting practices are employed. Sudden breaching in an urban setting could cause a catastrophe. Proper design to predict and manage overtopping helps manage residual risk. Flood overtopping of a structure into a previously leveed area is a hazard inherent in any levee or floodwall system. This risk varies with the overtopping probability of the structure and can be significant even for areas with design levels for rare floods. Levees are evaluated at specific locations currently referred to as index locations. After the top of levee elevation is defined at the index location, that elevation is used to set the profile as described in Paragraph 5.

b. Risk Assessments and Top of Levee Design. When a risk assessment is applied in a flood risk management study, the goal is a comprehensive approach in which the values of key variables, parameters, and components of flood risk management studies are subject to probabilistic assessment. Risk assessments will be used as a part of decision-making for levee systems throughout planning and design. Risk assessments during a study evaluate variables and their uncertainties to determine which variables are critical to decision-making. Critical variables then become the focus of plan formulation and evaluation. Not all variables are critical to decision-making. If one of the measures identified during the planning phase is a levee system, then a risk assessment will be used to further evaluate and refine design aspects of the system, including various levee heights, reliability, benefits, and costs. However, care must be taken to avoid attempts to reasonably maximize net economic benefits during initial plan formulation. Once a levee height is determined, a risk assessment can then be used to select the most appropriate location or locations for managed overtopping by seeking the least hazardous reaches. After design, risk assessment information, including inundation mapping for the leveed area, can be used to further manage residual risk. For policies and procedures regarding risk assessments and managing residual risk, see ER 1105-2-101, EM 1110-2-1619 and other applicable levee safety policies.

c. Levee System Features for Capacity Exceedance. Levee systems should have features to accommodate capacity exceedance. The concept is that, where feasible and practical, the system should be designed and constructed to take into account that capacity exceedance. Should capacity exceedance result in overtopping or breaching of the levee system, the breaching will occur in a predictable location, allowing orderly floodplain evacuation and minimize reconstruction requirements (time and cost) after an exceedance or breach. Levee superiority is the concept of designing one levee reach at an elevation different than another adjacent reach so that one overtops before the other in a predictable fashion. Levee superiority is one physical means for such accommodation; hardening sections to withstand overtopping helps minimize levee reconstruction efforts. Superiority and its accompanying increased resiliency (resistance to erosion from overtopping) at overtopping sections may be used. Identifying a feasible and practical overtopping location includes the requirement that with reasonable confidence, the location be designated and maintained for the life of the levee system. Additional superiority measures such as additional overtopping reaches or increased overtopping resiliency may be added if the evaluation of such measures produce benefits in excess of costs or are required in order to realize the benefits identified. Overtopping resiliency measures, if used, should be formulated and included in the recommended plan when justified by net economic benefits or tolerable risk guidelines for life safety.

5. **Top of Levee or Floodwall Elevation and Profile.**

a. In the analysis of a levee system, the system is expected to perform up to the top of levee (TOL) or floodwall grade and hereafter will be referred to as TOL. The TOL should include other increments added to a particular base levee to account for settlement, superiority, and maintenance access, etc. (Figure 1). As the crest elevation changes over time, which it will for a variety of reasons (settlement, subsidence, erosion, etc.), then the prior computed overtopping probability, amount of superiority, and other performance indices (economic, life safety, and engineering) will also change. Typical levee elevation increments that would collectively define the TOL elevation are described in the following paragraphs; the list may not be all inclusive (see Paragraph 5e.). Once the top of levee elevation is set at the index location, that elevation is used to then set the profile using the associated water surface profile. The final levee system configuration, including the TOL and overtopping reach, is used to determine system performance and economic indices (see Paragraphs 9a and 9c).

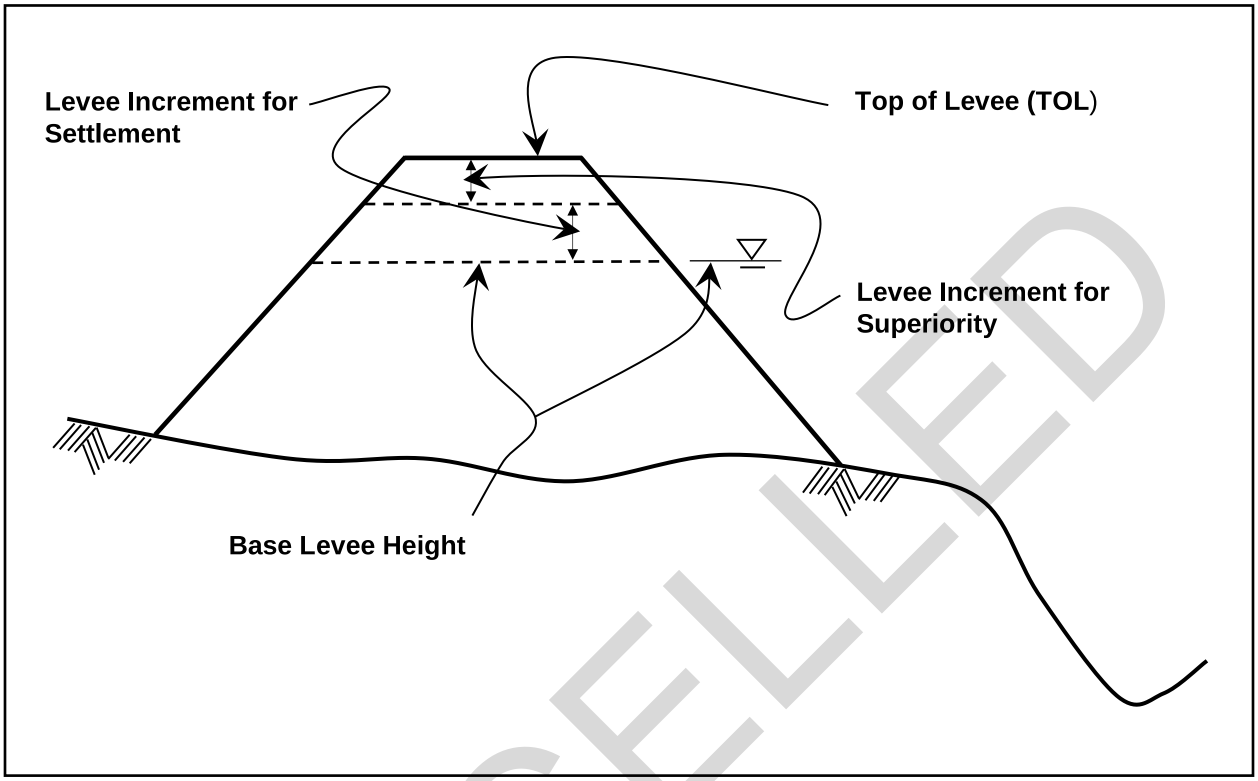


Figure 1. Arriving at Top of Levee Elevation (not all possible increments are shown)

b. Base Levee Height. The base levee heights are typically based on the range of stillwater stages as defined by the stage-discharge or stage-frequency functions. For lake and coastal/estuarine levee systems or for riverine levee situations where fetches are sufficiently long, a proper analysis of wind conditions that can accompany extreme water levels must be done and an increment for wave setup should be included in the base levee height. Wave overtopping is defined here as the condition in which individual waves break on the levee slope, broken wave bores advance up the slope, onto and across the levee crest, and down the landward side. The potential exists for wave overtopping to occur while the stillwater level is below the levee crest. The final exceedance frequency and other performance indices of the base levee result from an iterative planning process that evaluates a range of levee system configurations. This planning process includes the variations of TOL and the overtopping reach (base levee height and overtopping width).

c. Increment for Superiority. Superiority in overtopping is designing adjacent levees or levee reaches to overtop one before the other. Superiority simply means providing higher levees at all points except where initial overtopping is desired. A more complex example involves two separate levees across the river from one another; one surrounding highly urbanized areas, the other mostly agricultural area, but both having similar levee elevations. Decision making could allow overtopping into the agricultural area before the urban area to reduce potential consequences. Superiority could be used to reduce this potential of a "chain failure" of adjoining independent levees when breach of one levee may trigger the breach of the next by providing relief structures at the upstream end of the adjoined systems. Another example involves a situation with flank or tie-back levees along tributaries to the river. The hydrology for the tributary may provide higher water surface profiles than a river. In addition the tributary may be flashy with short warning times and potential dangers from quick overtopping. Superiority along the tributary reaches over the mainstem reaches may be appropriate. For long or complex levee systems, multiple overtopping reaches should be considered.

d. Increment for Settlement. The geotechnical engineer will provide estimates of settlement in the foundation and embankment, embankment shrinkage, cracking, and geologic subsidence. The increase in risk due to lowering of the TOL shall be accounted for a levee system with site geology that is undergoing long term regional settlement and/or on coastlines where future sea level rise is occurring (see ER 1100-2-8162 for sea level rise guidance). For the levee system to be reliable, the top of the flood protection must be able to provide the required design height over the service life of the project. To ensure reliability of the system, and to account for local settlement caused by the weight of levees, or from general lowering of an area due to regional subsidence and/or sea level rise, levee systems could be initially constructed to a height sufficient to maintain the required design elevation for the service life of the project. Alternatively, levee systems could also be constructed to the design level for current conditions with allowance for raising in the future to meet "design" heights as settlement and/or subsidence occurs. The alternative selected would be based on which alternative is more cost effective over time. If future raising is not proposed and the future levee height is the intended final "settled/design" height, then the final height should be recognized in the planning study as the most likely future condition. Project benefits and engineering performance could reflect the initial constructed height and the final height, assumed to the "most likely future" condition, via an equivalent annual damage analysis.

e. Other Increment Considerations. In certain situations, other increments may be included as a separate levee increment. These increments could include superelevation through curved channels, debris blockage at bridges, impacts to water surface elevations due to ice flow, impacts due to sediment loads, and impacts to water surface due to vegetation in channels and overbanks inside of levees. Generally, all increments (5.a.thru 5.e.) are deterministically defined and their associated uncertainties should be captured in the probabilistic risk and performance.

f. Establishing General TOL. TOL profiles are typically set using computed water surface profiles either from an unsteady or steady state hydraulic model such as HEC-RAS (Hydrologic Engineering Center's (HEC) River Analysis System) as depicted in Figure 2. The procedures presented here use an unsteady hydraulic analysis as the primary method for generating these profiles, as unsteady analyses speak directly to defining overtopping flows, establishing an overtopping length and defining residual flooding volumes. If a steady hydraulic analysis is used to generate the profiles, define overtopping location, and establish an overtopping length, then defining residual flooding would be made as a separate assessment dependent on knowledge of the flow hydrographs. Figure 2 illustrates the hydraulic routing of a specific flood hydrograph and the resultant water surface profile traced from the maximum stage generated at each channel cross-section. To understand the hydraulic nature of the system, one should produce a set of profiles using a range of target hydrographs noting that all profiles may not be parallel (Figure 3). The selected profile would be the one identified through the planning process and the levee height would equal the stage of a particular hydrograph at the point of evaluation/index location.

g. Detailed TOL Profile Evaluation Procedure. The identification of the TOL profile is an iterative process, defined as follows:

(1) Water surface elevations are computed for a number of frequency based events (e.g. 0.02, 0.01, 0.002 exceedance events) at an index point location and defined as a range of base levee heights; one such instance is shown in Figure 1.

(2) Various increments, as discussed in the sections above, are added to each of the alternative base levee heights to create initial TOL heights at the index point; also illustrated in Figure 1.

(3) The initial TOL heights at the index point must be translated into TOL profiles to support the planning analysis process. This translation is done by determining the exceedance frequency events that match the initial TOL heights at the index location and then evaluating the corresponding flows in a hydraulic model to generate the range of TOL profiles. Note: the events used to determine the TOL profiles should be larger than the events used to determine base levee heights because the TOL height is greater than the base levee height, given that various levee increments are usually added.

(4) The final levee alignment and levee height is identified through an iterative process where alternative levee heights and alignments are assessed until the recommended levee height has been found. The recommended levee system is likely to be somewhere between the frequency based events that were originally evaluated.

6. **Selection of Superiority and Managed Overtopping Reaches.** For initial overtopping, the overriding concern is choosing the least hazardous location to minimize consequences for initial inundation of the interior leveed area. A least hazardous location could be a golf course, an oxbow lake, a ponding area, the least developed area, or a downstream reach. In some cases, overtopping may be partially controlled in open spaces or by routing to ponding areas. In other situations internal dikes or high ground may control overtopping volumes. Long-term development restrictions through acquisition of real estate may need to be considered as part of the project to ensure the overtopping design is not compromised.

7. **Overtopping Reach.**

a. Overtopping Design. Several design types can be used to manage initial overtopping. One is to use a sloping superiority profile from reach to reach to force overtopping in a desired location. Other designs use notches, openings, or weirs in the structure. The inverts for these features are at the base levee height elevation of the structure and could include an increment for settlement, depending on how settlement is accounted (Paragraph 5d). Examples are railroad or road openings and rock weirs.

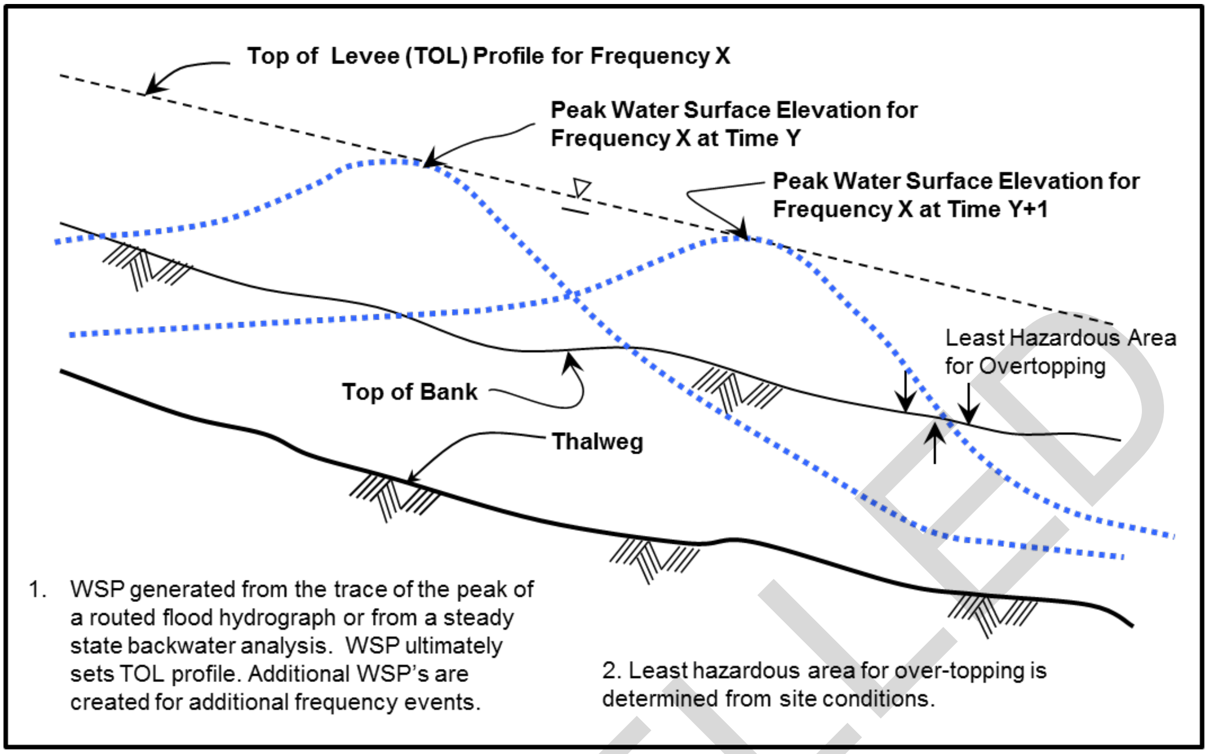


Figure 2. Top of levee (TOL) profiles

b. Overtopping Discharge. The evaluation of overtopping measures and associated residual risks should be performed for a range of overtopping events, with the goal of identifying cost-effective resilience and risk management measures (See ER 1105-2-101). The overtopping discharge for a particular flood event is the portion of the containment hydrograph (hydrograph that maps to the TOL) that spills over the overtopping reach and is usually expressed in cfs/feet. The Allowable Overtopping Discharge (AOD) is the maximum recommended overtopping flow in cfs/feet for a given resiliency type, as discussed in Paragraph 8. The AOD should be selected so that the overtopping reach can pass the peak overtopping discharge without levee breach. Given that the AOD is the maximum recommended overtopping flow in cfs/feet based on resiliency type (and not based on an event size), an initial length and depth are selected, and the overtopping discharge hydrograph is routed through the "notch" to determine if the overtopping discharge exceeds the AOD for the selected resiliency type. If yes, then adjust resiliency type, length, depth or all, and then reassess. The total volume of flow that spills via the overtopping reach may also be of interest for residual floodplain mapping.

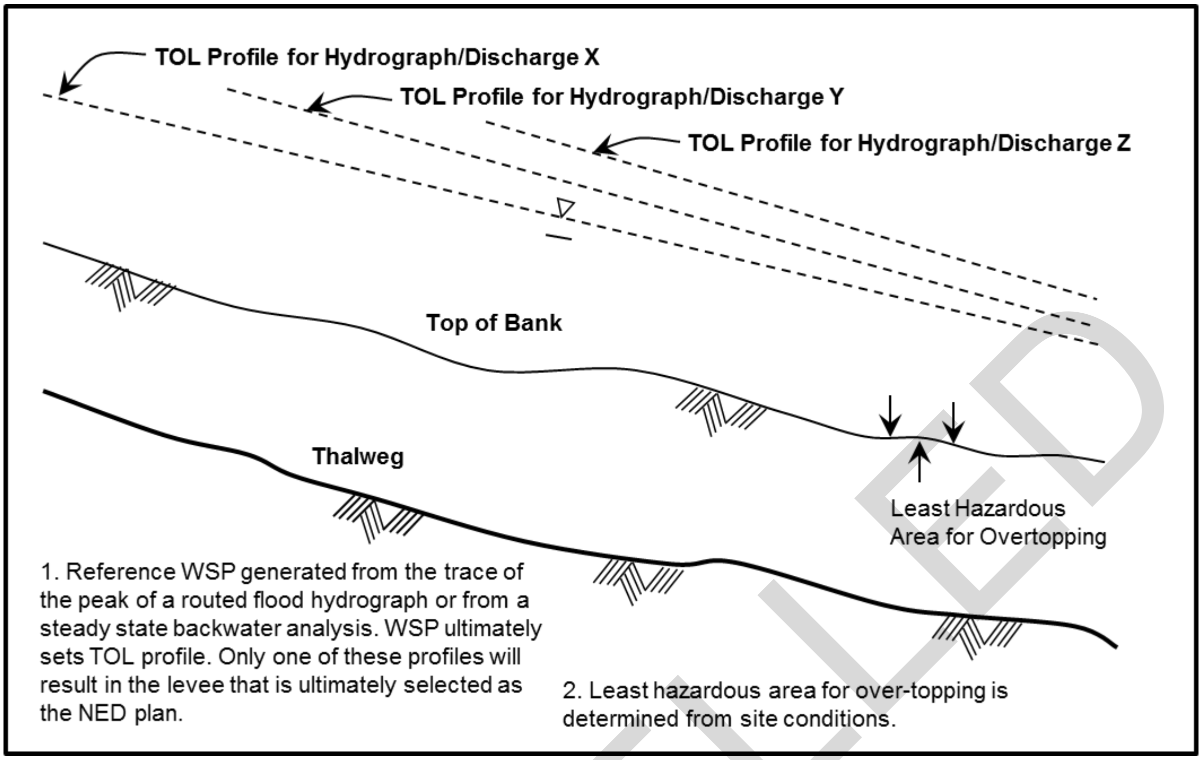


Figure 3. Pairing of profiles to each levee height.

c. Overtopping Reach Length and Depth. Determination of the overtopping length and depth is based on one or more project design constraints. Typical project design constraints include:

(1) Maximum desired overtopping discharge or volume. This may be a function of the interior floodway flow or volume capacity.

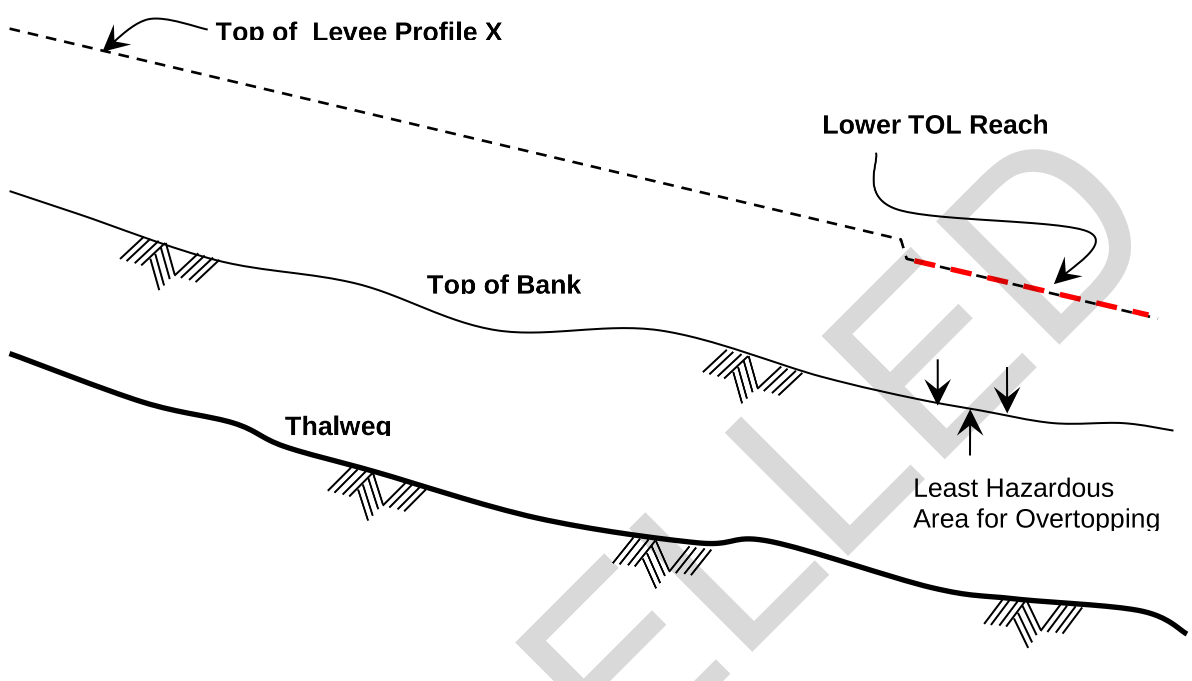
(2) Maximum possible overtopping length. This may be constrained by features such as bridge or roadway crossings, as well as interior floodplain or floodway width.

(3) Desired time to exceedance of TOL. A longer overtopping length will pass more flow before the system capacity is exceeded, and thereby provide a longer window for emergency response activities.

(4) Desired height increment for levee superiority. There may be an optimal superiority increment height that balances cost and overtopping discharge.

(5) Other site-specific constraints. For example, estimate the time and volume needed to fill the leveed area 'bathtub', determine if it will fill at all or size and design the overtopping section so that it can survive long enough for the leveed area to fill enough to reduce the chance of catastrophic breach.

d. Selection of the overtopping discharge, length, depth, and resiliency type is interrelated and iterative. The process of determining the final overtopping reach design (Figure 4) depends on solving for unknown design parameters using known or assumed design parameters. The known versus unknown design parameters will vary across projects.



Note: Water surface profile downstream of the overtopping section may be impacted due to the flow leaving the system via the overtopping section.

Figure 4. Final overtopping reach design.

8. **Scour Protection at Superiority Location.** A resilient component or system is capable of absorbing energy during loading without experiencing permanent deformation, extensive damage, cumulative degradation or catastrophic failure. Relatively high resilience is required in systems which must survive occasional large overloads for a long duration and then recover to their original state after the overload event. Resiliency can be incorporated into a levee and floodwall design by constructing a scour protection apron on the protected side of the levee or floodwall for the purpose of minimizing erosion during flood events that exceed the top of wall elevation. Resiliency types can be found in EC 1110-2-6066, Design of I-Walls (expired).

9. **System Performance, Cost Evaluation, and Residual Risk.**

a. System Performance. System performance should be provided as defined in ER 1105-2-101 and presented using Annual Exceedance Probability (AEP), Assurance (formerly Conditional Non-Exceedance Probability (CNP)) and Long-Term Exceedance Probability (LTEP). For completeness, these performance indices should be presented for both the superiority reach and for the overtopping reach. The performance for the superiority reach provides general project alternative information and separately, performance for the overtopping reach and provides information for the "least hazardous" inundation area.

b. Cost Effectiveness and Incremental Cost Analyses. Cost effectiveness seeks to identify the least cost alternative for each level of output. Incremental Cost Analysis allows an assessment of whether the increase in output is worth the additional cost. The ability to identify cost effective plans is useful for evaluating and reducing economic and life safety risks. For example, if two overtopping plans can pass the overtopping flows given the resiliency treatment for each but one plan costs more, the more expensive plan would be dropped from further consideration (See ER 1105-2-100 for more on cost effectiveness and incremental analyses).

c. Residual Floodplain Mapping or Formal Flood Easement. In addition to the performance indices, residual overtopping flood mapping should be presented for floodplain management purposes or for definition of formal flood easements. Residual flooding for the planned overtopping reach should present flood boundaries for residual flood hydrographs; i.e., the hydrograph starting at the initiation of overtopping at the overtopping reach and ending at the initiation of overtopping of the TOL.

d. Adjust With-Project Damages, Net Benefits, and Life Safety Consequences. When an overtopping reach is included in a project, there may be additional areas of inundation and therefore consequences (i.e. damage or life loss). If project consequences increase substantially with an overtopping reach, it may be necessary to iteratively evaluate the overtopping design and associated consequences to find a balance between residual flooding and benefits (See ER1105-2-100).

10. **Procedure Summary.** A summary of the entire process is provided here:

a. Establish Base Levee Height at an index point using stage-frequency for a range of flows, and then add appropriate levee increments for superiority, settlement and other factors to determine TOL. This process is described in Paragraph 5 and illustrated in Figure 1.

b. Perform hydraulic water surface analysis (steady or unsteady) for the range of hydrographs mapping to the range of levee heights of interest. This creates a set of potential levee profiles.

c. Evaluate this range of levee profiles without consideration of overflow features and select an initial levee profile design.

d. Determine overtopping reach location, discharge, length and depth. These factors are interrelated, and one or more may represent a key project design constraint. Considerations include:

(1) Maximum desired overtopping discharge or volume.

(2) Maximum AOD (see Paragraph 7b) based on preferred resiliency type.

(3) Maximum possible overtopping length.

(4) Desired time to exceedance of TOL.

(5) Desired height increment (for levee superiority, settlement and other factors such as time and volume to fill the leveed area).

e. Incorporate overtopping reach design into initial levee profile to create the final levee profile design. Ensure resilient features are well defined.

f. Determine residual overtopping flood mapping.

g. If appropriate, adjust alternative evaluation based on residual overtopping mapping.

h. Evaluate cost effectiveness of superiority enhancement and overtopping resiliency measures. Check impact on alternative selection resulting from cost of levee protection in overtopping reach and changes in residual damages, if applicable.

i. NOTE: Determining the TOL levee height, overtopping length and overtopping depth (i.e., superiority increment) is an iterative process which may take several cycles through the entire procedure to reach a final design.

11. **Update.** All new requirements will be included in the next appropriate policy document update. This guidance does not affect higher level documents and does not require updating existing requirements.

12. **Points of Contact.** The implementation point of contact for this action is the District Levee Safety Program Manager (LSPM). The HQUSACE point of contact for this ECB is Sean Smith, CECW-CE, (202) 761-0301.

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LARRY D. MCCALLISTER, PHD, P.E., PMP
Chief, Engineering and Construction Division
Directorate of Civil Works