State of California
The Resources Agency

DEPARTMENT OF WATER RESOURCES

and

THE CENTRAL VALLEY FLOOD PROTECTION BOARD

# INTERIM RISK AND UNCERTAINTY PROCEDURE

## For Evaluating Potential Hydraulic Impacts Associated With The State of California's Early Implementation Projects That Modify State-Federal Project Levees in the Central Valley

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### Purpose

This paper provides an interim methodology for evaluating the potential hydraulic impacts that might be induced by any of the State of California's Early Implementation Projects in the Central Valley. These procedures are intended to examine the effect that any such project modification may have on the State-Federal flood protection system as a whole. The methodologies found herein are proposed as an interim standard set of analyses that would be submitted to the United States Army Corps of Engineers (Corps) as part of a Section 408 approval process to allow the State and local agencies to proceed with modifications/improvements of State-Federal levees in advance of Corps participation. The ideas contained in this paper have been discussed with staff of the Corps' Sacramento District and with the Corps' Hydrologic Engineering Center. Over the next four years, the State and local agencies will continue to collaborate with the Corps to develop more refined processes and procedures for hydraulic impact analyses, and such refined procedures would be expected to be incorporated into the Central Valley Flood Protection Plan that will be adopted in 2012.

### Background

Recently, the people of California passed two bond measures that provide approximately $5 billion over the next ten years for flood improvements to reduce flood risk. Much of this money will be spent in the Central Valley for improvements on the State-Federal levee system. As a result of recent legislation, the State of California is now also initiating a new strategic plan for flood risk reduction in the Central Valley. This plan, known as the Central Valley Flood Protection Plan (CVFPP), will provide a system-wide approach for managing floods within the Sacramento and San Joaquin River Valleys. State law mandates that the CVFPP be completed and adopted by the State by July 1, 2012.

While the State and its partners develop the CVFPP, there are also urgently needed flood risk reduction projects that need to proceed before the completion of the CVFPP four years from now. Most of these critically-needed projects are to improve woefully inadequate flood protection for existing urban areas in deep floodplains within the

Sacramento River Flood Control Project (SRFCP) and the San Joaquin Flood Control System (SJRFCS). California cannot afford to defer these flood improvements. Flood risk reduction projects proceeding in advance of the CVFPP are known as ***Early Implementation Projects*** (EIP). Most Early Implementation Projects will be lead by the State and local agencies in advance of Corps participation due to the fact that the Corps does not currently have funding and/or authorizations in place for such projects. EIPs lead by the State and local agencies are referred to as California's EIPs. Even though California's EIPs will proceed ahead of the CVFPP, these projects are "no regrets" types of projects since: (1) California's EIPs need to meet certain eligibility criteria designed to ensure that they do not eliminate opportunities or prejudice flood risk reduction alternatives that would provide regional or system wide benefits, and (2) providing higher flood protection to existing urban areas is already part of the status quo in the SRFCP and SJRFCS, and will be a major element in the Central Valley Flood Protection Plan to be developed over the next four years.

Before the State and local agencies can proceed with these EIPs, the Corps must approve them under the Section 408 process to assure that such projects will not result in significant, unmitigated impacts to the flood protection system. Evaluating potential hydraulic impacts of California's EIPs will be an important element of the Section 408 review and approval process.

## Risk-Based Evaluations

The Corps' recent September 12, 2007 Draft paper on levee certification, ETL 1110-2-570, contains the following definitions:

> **Risk Analysis** - An approach to evaluation and decision making that is based on the probability of undesirable consequences.
>
> **Risk and Uncertainty Analysis -** Risk analysis that explicitly, and analytically, incorporates consideration of uncertainty of parameters and functions used in the analysis to determine the undesirable consequences.

Current Corps policy requires the utilization of risk-based analyses for planning and design of flood control systems. The policy has been implemented, but a detailed explanation of specific guidance on the implementation of the policy has yet to be developed. All guidance to date has been focused on project planning and design implementation of new flood control projects. A description of the procedures to be implemented for the evaluation of hydraulic impacts resulting from a project modification has not yet been presented. However, the great advantage that a Risk Analysis (throughout this paper the term Risk Analysis means risk and uncertainty analysis) has

over a conventional “Deterministic” Analysis is that variability in the factors affecting flood system performance is addressed. In the past a single design event would be used to establish project performance and possible impacts. Risk Analysis requires a clear evaluation of the factors (including recognition of the intrinsic uncertainty in the value of these factors) that could impact project performance as a result of a project modification.

## Historical Setting for Risk Analysis

Federal project sponsors have agreed to operate and maintain the flood system in accordance with the original design intent of the project. Further, the Corps has required every local sponsor to agree to maintain the project to a high state of readiness. Thus, it is not the intent of the 408 permit process to obstruct or frustrate the correction of either project maintenance deficiencies or latent defects that escaped detection under the original construction of the project. Project modifications that include raising existing levees (beyond authorized levels) or levee setbacks, however, could potentially have hydraulic impacts on other portions of the project. The design of the existing SRFCP and the SJRFCS were based upon a single set of steady state flood flows and no levee failures within the larger system were assumed in the design. The concept of freeboard was utilized to provide for uncertainty in the flow and stage design parameters. The Sacramento and San Joaquin River levees were designed with 3 feet of freeboard and the Bypass levees were designed with up to 6 feet of freeboard. Since the completion of the projects, many levee reaches have been found not to have the original design freeboard, either due to errors during the original construction or settlement over time. This is particularly true in rural areas. It is possible that the restoration of freeboard on rural levees to meet the original “as constructed” conditions would have significant hydraulic impact for floods greater than the 100-year flood. However, the need to mitigate for restoration of an original project design condition is currently unclear in the Section 408 process.

## Uncertainty Factors Affecting Project Modifications

There are three general types of uncertainty categories to be considered in evaluating hydraulic impacts: (1) hydrologic uncertainty, (2) hydraulic uncertainty, and (3) operational uncertainty. Operational uncertainty includes levee system performance, flood fight activities, and reservoir operation uncertainty. The applicability of each of these uncertainties for a Risk Analysis of a project modification Section 408 evaluation is described below:

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**Hydrologic Uncertainty:** This uncertainty is associated with the potential storm water that may pass through a flood system. In very large drainage basins such as the SRFCP and SJRFCP, there are innumerable storm centerings that could generate flood waters to stress the area where the proposed project modification is located. Many of the storm centerings do not stress the project area and, as a result, do not elicit potential project impacts. It is proposed to adopt the storm centerings expected to cause the greatest stress on the system at the proposed project location. It is acknowledged that such an assumption may overstate the potential for project impacts but this knowledge can be included in the determinations of significance of the potential impact that a proposed EIP project may have. Another hydrologic uncertainty is the inability to know with certainty the magnitude of flood flows for different probabilities of occurrence (such as the 100-year or 200-year floods). With a limited sample (period of record) and possible changing atmospheric conditions it is impossible to define with any assurance the flow probability function. This is especially true for the higher, more extreme events (which may only include one or two events in the historical record). It is proposed to address this issue by providing impact analyses for a range of flood events, not just for the current best estimate for the design of the EIP, typically set at a 200-year level of flood protection. Therefore, the impact analysis of a proposed project modification would include an evaluation of floods ranging in size from the original project design to the currently proposed project modification design, and even up to the 500-year-flood. This would provide sufficient analysis of the hydrologic uncertainty.

**Hydraulic Uncertainty:** The uncertainty in a water surface profile for a given flow has been well documented. The uncertainty results from topographic uncertainty and channel hydraulic roughness uncertainty. In addition, the hydraulic cross section of the river changes in a sand bed channel during the flood event as the bottom of the channel is scoured during peak flow periods. Calibrating a hydraulic model to high water marks is considered to be highly successful if the model calibrates within 0.3' of the documented high water marks. In determining the hydraulic impacts of a project, the hydraulic uncertainty of a levee improvement does not change between the "Existing", "Without" and "With" project conditions. Although this uncertainty will affect overall project performance it does not affect the incremental change associated with the hydraulic impact analysis. Therefore, hydraulic uncertainty will not be explicitly addressed in the hydraulic analyses submitted for the Section 408 approval process.

**Levee System Performance Uncertainty:** A critical factor in calculating the water surface elevation for a flood event is the performance of the entire levee

system. The failure of a levee within a hydraulically connected system can substantially change flood stages upstream and downstream from the breach in the levee. When evaluating the potential impacts of a project modification the levee performance uncertainty may produce the greatest variability of all the uncertainty factors. FEMA has dealt with this uncertainty by specifying that for the Base Flood calculations (100-year flood) no levee failures are assumed to occur for areas outside the point of analysis. This conservative and deterministic approach (design stage +3 feet of freeboard) may be appropriate for mapping flood prone areas but represents an extreme condition in the Risk Analysis procedures to define a possible impact from a project modification. Engineering judgment as to the likelihood of levee system failures for any given flood needs to be made and incorporated in a true Risk Analysis procedure. This is a difficult task and many factors must be included in the judgment. A few of these factors are the original project design intent; the state of the system as it currently exists; the possibility that maintenance will change, deficiencies will be repaired, or system improvements will be constructed; the effect that a flood fight would have on system performance; and the history of system performance, etc.

Conducting an analysis that relies on a single value worst case assumption may be appropriate for a deterministic design or for setting insurance rates, but may be wholly inappropriate by itself for a project impact evaluation. The history of the Sacramento and San Joaquin River flood project performance shows that numerous levee failures have occurred when the water surface has been well below the top of the levee. The probability that levees will not fail if overtopped is generally considered to be extremely low and must be assigned a commensurate probability in the Risk Analysis evaluation. For the purpose of the Section 408 impact analysis, the assumption that no levees fail, regardless of the amount of levee overtopping, represents a very high assurance level assumption based on the actual performance of the levee system to date. A more realistic, but still conservative assumption is that no levee failures occur until water reaches the tops of the levees. This latter case is both a definable condition and one that has the high potential of occurring. It is generally agreed by engineering experts within the Corps, State and local agencies that the SRFCP and SJRFCP levees would experience significant failures if the water level should reach the tops of the levees. This condition would undoubtedly have an assurance level significantly greater than 50% (i.e., substantially greater than the most likely scenario).

A third scenario, based on the most likely levee failure condition, is difficult to address at this time because of the lack of information needed to properly define this condition for hundreds of miles of levees, the possibility that current defects

would either become worse or be rectified, and because of the amount of speculation that would be required to do the analysis prior to completing an evaluation of the fragility of the levees throughout the system.

**Other Operational Uncertainty Issues:** Reservoir operation uncertainty is the uncertainty of the human operation of the reservoir and/or unavailability of key operational features, such as outlet facilities, because of maintenance or other issues. None of California's EIPs includes construction or reoperation of a reservoir. In order to understand the response of the EIPs and the flood system as a whole to flow regimes that exceed prescribed flows below the flood control reservoirs, floods larger than the design floods for the key reservoirs would be analyzed, namely the 200-year and 500-year floods. The resultant discharges from the reservoirs exceed the authorized design flows downstream and provide reasonable evaluation of the potential impacts of reservoir operational uncertainties on the performance of the levee system and the potential for hydraulic impacts of proposed EIPs. It is important to stress that the operational uncertainties at the reservoirs do not change as a result of the proposed EIPs. Flood fighting is another important operational uncertainty. Flood fight operations were not evaluated directly but were implicitly considered under the levee system performance uncertainty evaluation. A highly successful flood fight capability, however unlikely, would be encompassed within a no levee failure analysis. A less effective flood fight capability would be encompassed under a levee failure scenario.

## Evaluation of Project Modification Impacts

The evaluation of potential hydraulic impacts for California's EIPs will be completed by performing a number of hydraulic analyses that encompass the range of potential risks and uncertainties associated with each specific EIP. Stage frequency curves are developed based on the following assumptions and variations in hydraulic parameters:

1. Levee System Conditions: Perform analyses for Without Project and With Project Conditions considering three potential levee system conditions
   a. Existing (2008)
      i. No Change from Existing
      ii. Existing levees + the Specific EIP
   b. Future (say ~ 2025)
      i. Urban Project levees (EIP areas are improved to 200-year flood protection with 3-foot freeboard) and Folsom Joint Federal Project (JFP) in place w/o the Specific EIP

ii. Urban Project levees (EIP areas are improved to 200-year flood protection with 3-foot freeboard) and Folsom JFP in place, with the Specific EIP

2. Storm Centerings: Adopt the storm centerings that provide the greatest stress on the system at the proposed project location (multiple centerings will be analyzed to identify the one that causes the greatest stress)

3. Flood Events: Perform analyses for four flood events
   a. 1955/57 Original Design Flows
   b. 100-year Flood Event
   c. 200-year Flood Event
   d. 500-year Flood Event

4. Levee Fragility: Perform analyses for two levee fragility functions
   a. Levee fails to ground when flood flows overtop levee crown
   b. Levee does not fail, but functions as a weir

Because it would be inappropriate to consider maintenance as creating hydraulic impacts, restoration of Rural Project levee freeboard by itself should be considered to have no hydraulic impacts. There is considerable uncertainty about how many rural levees will be restored to full design height and when such restoration will occur. Therefore, the hydraulic analyses omit rural levee restoration.

By performing the analyses of "Existing", "Existing with EIP", "Future without EIP" and "Future with EIP" for the four flood events and two levee fragility conditions in Table 1, one can see that ***this approach provides for 32 hydraulic analyses that can be used for making comparisons at different points in the State-Federal Project levee system***. Table 1 displays the 8 hydraulic analyses sets of assumptions for which each of the 4 flood events is analyzed. It should be noted that for some sets of assumptions, the analyses are somewhat duplicative as the results are unaffected by the changes in assumptions, particularly for the smaller flood events employed.

These analyses are believed to conservatively encompass the probable ranges for various uncertainties in hydraulic analyses, and provide a rational, repeatable set of results for use in evaluating potential hydraulic impacts throughout the entire flood protection system. The extent of the system model for the Sacramento valley is shown in Figure 1. A similar model is used for the San Joaquin Valley.

Table 2 displays the comparisons to be made for each of the four flood events. Both incremental EIP hydraulic impacts and potential cumulative hydraulic impacts are addressed by the comparisons in Table 2. The potential cumulative impacts of all Early

Implementation Projects can be bracketed by evaluating the change in water surface for both the “Levees Fail from Overtopping” and the “No Levee Failure” fragility conditions.

An example of how data would be displayed is shown in Table 3 .

It is also possible to examine the reasonableness of the assumptions by looking at other results from the analyses. Shown in Table 4 are the miles of levee overtopping and general magnitude of overtopping that result for a 500-year flood event assuming a no levee failure fragility condition. The large number of levee miles in the system being overtopped without failure (119.2 miles) illustrates the high degree of conservatism in this particular set of assumptions.

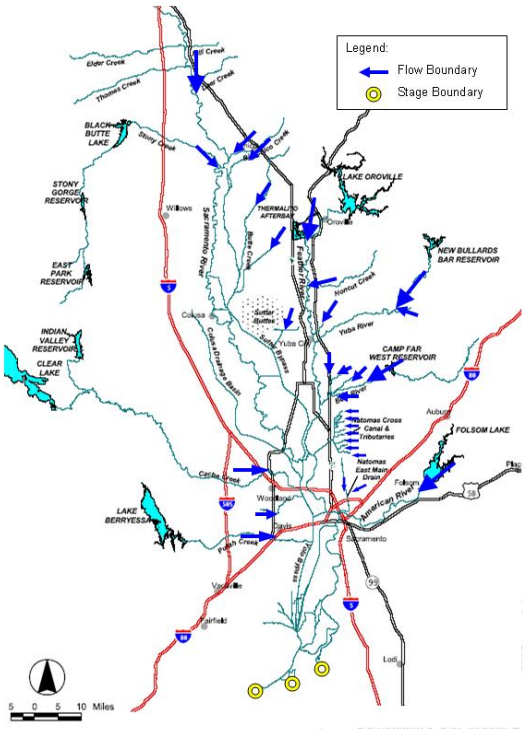


**Figure 1: Extent of Hydraulic Model for Sacramento Valley**

The model used to calculate water flows and stages has calculation points every quarter mile throughout both the San Joaquin River and Sacramento River flood systems. Since water levels are being calculated at over 4,000 locations on the Sacramento River system and over 2,000 locations in the San Joaquin River system, any potential hydraulic impact can be determined through the use of the models anywhere within or adjacent to the projects. Every model run includes the calculations throughout the system at each cross section location. When determining possible hydraulic impacts it is customary to display calculation points within the vicinity of the project modifications because those are the locations most likely to exhibit potential impacts. The extent of the SRFCP system is shown on the adjacent figure.

## Table 1: Analyses Used to Determine Potential Hydraulic Impacts

| Case[1] | Urban Levees[2] | Folsom JFP | Levee Failure |
|---|---|---|---|
| 1 Existing | Exist | No | Top of levee |
| 2 Existing + EIP | Exist | No | Top of levee |
| 3 Future w/o EIP | 200-yr +3' | Yes | Top of levee |
| 4 Future + EIP | 200-yr +3' | Yes | Top of levee |
| 5 Existing | Exist | No | No Failures |
| 6 Existing + EIP | Exist | No | No Failures |
| 7 Future w/o EIP | 200-yr +3' | Yes | No Failures |
| 8 Future + EIP | 200-yr +3' | Yes | No Failures |

[1] Each case includes analyses for four flood events: 1955/57 design flows, 100-year flood, 200-year flood, and 500-year flood

[2] Includes all urban levees outside of the specific EIP area

## Table 2: Comparisons of Cases from Table 1

| Comparison | Characterization of Comparison |
|---|---|
| **1 & 2** | Impact of specific EIP as compared to Existing Conditions (assumes levees fail with overtopping) |
| **3 & 4** | Impact of specific EIP as the last added EIP (assumes levees fail with overtopping) |
| **5 & 6** | Impact of specific EIP as compared to Existing Condition under a "No Levee Failure" assumption |
| **7 & 8** | Impact of specific EIP as the last added EIP under a "No Levee Failure" assumption |
| **1 & 4** | Cumulative impact of all EIPs as compared to Existing Condition (assumes levees fail with overtopping) |
| **5 & 8** | Cumulative impact of all EIPs as compared to Existing Condition under a "No Levee Failure" assumption |

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**Table 3: 200-year Maximum Water Surface Elevation Summary, No Levee Failure Fragility Condition (from "Summary Report on Hydraulic Impact Analyses," Natomas Levee Improvement Program, Sacramento Area Flood Control Agency, April 2008) (Comparison of Cases 7 & 8)**

| Location (Comp Study River Mile) | Maximum Water Surface Elevation (ft NGVD29) | | Change (ft.) |
|---|---|---|---|
| | Without Project | With Project | Without Project to With Project |
| Sacramento River | | | |
| at Knight's Landing (90.22) | 43.39 | 43.39 | 0 |
| at Fremont Weir, west end (84.75) | 42.47 | 42.48 | +0.01 |
| At Natomas Cross Canal (79.21) | 42.90 | 42.92 | +0.02 |
| at I-5 (71.00) | 38.24 | 38.24 | 0 |
| at Sacramento Bypass (63.82) | 33.48 | 33.48 | 0 |
| at NEMDC (61.0) | 34.06 | 34.07 | +0.01 |
| at I St. (59.695) | 33.78 | 33.78 | 0 |
| at Freeport Bridge (46.432) | 27.40 | 27.41 | +0.01 |
| Natomas Cross Canal | | | |
| u/s Hwy 99/70 (4.82) | 42.92 | 42.94 | +0.02 |
| Pleasant Grove Creek Canal | | | |
| at Sankey Rd. (3.65) | 42.65 | 42.67 | +0.02 |
| at Fifield Rd. (1.49) | 42.90 | 42.91 | +0.01 |
| Feather River | | | |
| at Nicolaus Gage (8.00) | 51.19 | 51.20 | +0.01 |
| Yolo Bypass | | | |
| at Woodland Gage (51.10) | 34.56 | 34.57 | +0.01 |
| American River | | | |
| at H St. (6.471) | 44.40 | 44.40 | 0 |

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**Table 4: Extent of Levee Overtopping, 500-year Flood Event, No Levee Failure Fragility Condition (from "Summary Report on Hydraulic Impact Analyses," Natomas Levee Improvement Program, Sacramento Area Flood Control Agency, April 2008)**

| River | Total Leveed Length | Left Bank | | Right Bank | |
|---|---|---|---|---|---|
| | | Length of Overtopped Levee | Approx. Maximum Depth of Overtopping | Length of Overtopped Levee | Approx. Maximum Depth of Overtopping |
| American River | ~13 miles | ~7 miles | ~4 ft | ~12 miles | ~3 ft |
| Feather River | ~50 miles | ~14 miles | ~3 ft | ~13 miles | ~3 ft |
| Natomas Cross Canal | ~5 miles | ~4 miles | ~1 ft | ~3.5 miles | ~2.5 ft |
| Sacramento Bypass | ~1.7 miles | ~0.5 miles | ~0.5 ft | ~0.2 miles | ~0.5 ft |
| Sacramento River upstream of Natomas Cross Canal | ~90 miles | ~13 miles | ~4 ft | ~7 miles | ~3 ft |
| Sacramento River Adjacent to Natomas | ~18 miles | ~8 miles | ~1 ft | ~6 miles | ~3 ft |
| Sacramento River downstream of American River | ~60 miles | ~2 miles | ~2 ft | ~2 miles | ~2 ft |
| Sutter Bypass | ~30 miles | ~4 miles | ~4 ft | ~7 miles | ~4 ft |
| Tisdale Bypass | ~4 miles | ~0.5 miles | ~0.5 ft | ~0.5 miles | ~1 ft |
| Wadsworth Canal | ~4 miles | ~4 miles | ~1 ft | ~4 miles | ~2 ft |
| Yolo Bypass | ~37 miles | ~5 miles | ~2.5 ft | ~2 miles | ~2 ft |

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## Impact Assessment

All potential project impacts are related to the stage frequency relationships within the river system. If the proposed project would not impact flood stages (no change in water levels between "Without Project" and "With Project" conditions at any location within the flood system), it can be concluded that the proposed project would not cause any hydraulic impacts to the flood system. If the analysis indicates an increase in water levels, a significance test must be developed for the purpose of evaluating the changed condition. Factors to be considered in the significance test are the probability of change

in stage and the possibility that the change in stage would reduce the flood system's capability to perform as designed. As an initial screening test, changes in stage of less than 0.1 feet for floods up to the 100-year flood would be considered to be insignificant. For floods equal to or larger than the 200-year flood, changes in stage of 0.3 feet would be considered to be insignificant. However, final evaluations of any potential significant impact would take into account the full range of stage changes that result from different sets of assumptions and flood levels. Engineering judgment would be employed in any final determination of the significance of impacts. Lastly, any finding of significance should consider if a taking of property is involved.

## Conclusion

The interim approach and methodologies outlined in this paper provide a reasonable basis to address hydraulic impacts considering both risk and uncertainty for a broad range of flows. The information provided using these procedures should be adequate for the Section 408 process in evaluating potential project impacts and potential cumulative impacts.

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