Above: Crew members place sandbags during flood fighting effors (DWR).

An assessment of the benefits of DWR's levee inspection program in California's Central Valley

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Abstract

This technical note describes how David Ford Consulting Engineers, Inc. (Ford Engineers) developed and demonstrated a method for estimating the benefit of the levee inspection program that the California Department of Water Resources (DWR) carries out on over 1,600 miles of levees in the Central Valley. Ford Engineers measured the benefit of DWR's levee inspection program by computing the reduction in flood risk attributable to levee flood fighting and maintenance activities—the activities that result directly from the inspection program. Specifically, Ford Engineers assessed flood risk reduction as economic damage avoided and reduction in statistical lives lost (SLL) due to flood fighting at four sites and attributable to levee maintenance at five sites. In addition, at one of the sites for levee maintenance assessment, ecosystem benefit was assessed as the reduction in the acreage of giant garter snake habitat. This risk assessment employed available tools and information common to planning studies. The study found that levee maintenance reduces expected annual damage, SLL, and expected annual loss of habitat acreage. Similarly, the study found that flood fighting reduces expected annual damage and SLL. The study developed and applied successfully a systematic, repeatable, and understandable procedure for assessing risk reduction attributable to flood fighting and levee maintenance activities, using expert opinion elicitation to provide information otherwise unattainable. This procedure can be applied to other facilities of the State Plan of Flood Control (SPFC) to assess the benefit of DWR programs.

KEYWORDS: benefit assessment; levee inspection program; levee flood fighting; levee maintenance; flood risk; life risk; ecosystem benefit

Situation

SPFC LEVEE SYSTEM DESCRIPTION

The State Plan of Flood Control, which comprises a significant portion of the flood control facilities within the Central Valley, includes over 1,600 miles of levees, in addition to weirs, channels, and other features located in the Sacramento and San Joaquin River basins. The federal government acting through the U.S. Army Corps of Engineers (USACE) designed and constructed many of these federal levees. Other levees were incorporated into the Sacramento and San Joaquin systems through passage of federal statutes. The Lower San Joaquin River Flood Control Project was designed and constructed to federal standards by the state.

Local public agencies, called levee maintaining agencies (LMAs), have the responsibility, liability, and duty to maintain and operate the levees and other flood protection works on a day-to-day basis in accordance with USACE's standard operation & maintenance (O&M) manuals (USACE revised 1955, USACE April 1959). DWR is the LMA for certain levee reaches within the SPFC system (under provisions of Water Code sections 8361 and 12878).

DWR'S LEVEE INSPECTION PROGRAM

The USACE O&M Manual requires each LMA to perform detailed levee inspections every 90 days, as well as prior to flood season, immediately following each major high-water period, and at any other time deemed necessary by the responsible party at the LMA (DWR 2010). The state completes these inspections for the levee reaches for which it is the LMA.

In addition, DWR performs a verification inspection of the maintenance provided by the LMAs. DWR completes annual spring inspections in May, documenting the location, size, type, and rating of maintenance deficiencies while working with the LMAs to assist in planning maintenance activities prior to the flood season. DWR completes annual fall inspections in November, verifying the status of previously noted and additional deficiencies that should be corrected to help ensure adequate performance during the flood season. (LMAs conduct inspections in winter and summer, thus completing the requirement to conduct four inspections each year.)

Staff members prepare a report presenting the results of the levee inspections. They submit the report to the Central Valley Flood Protection Board (CVFPB).

QUESTIONS POSED BY DWR

DWR sought to demonstrate the return on investment of its levee inspection program. As a proof of concept, Ford Engineers developed a procedure for this case study that demonstrated the benefit of the levee inspection program by identifying the flood risk reduction attributable to that program at selected locations in the Central Valley. For these locations, Ford Engineers answered these questions:

- What is the economic benefit attributable to flood fighting?
- What is the life safety benefit attributable to flood fighting?
- What is the economic benefit attributable to levee maintenance?
- What is the life safety benefit attributable to levee maintenance?
- What is the ecosystem benefit attributable to levee maintenance, as measured by avoided loss of giant garter snake habitat at one site?

Flood risk assessment

DEFINITION OF FLOOD RISK

Flood risk describes the likelihood (probability) of adverse consequences from flooding for a given area with a specified climate condition, land use condition, and flood risk management system (existing or planned).

ASSESSMENT OF FLOOD RISK

The components of a flood risk assessment are:

- Hazard, which is the probability and magnitude of flood flows.
- Performance of flood risk reduction measures.
- Exposure of people, property, and ecological habitat to the hazard.
- Vulnerability of people, property, and ecological habitat to harm from the hazard.
- Consequence, which is the harm that results from a single occurrence of the hazard.

In a flood risk assessment, interrelationships among the flood risk components are used to compute flood risk, which is an expression of the probability of each of many consequence outcomes for a separable geographic area.

MEASUREMENT OF BENEFIT

Benefit is measured by consequence prevented. In this assessment, Ford Engineers compared the expected annual damage (EAD) without flood fighting and with flood fighting, and without and with levee maintenance. In other words:

- Economic benefit of flood fighting = [EAD without flood fighting] – [EAD with flood fighting]
- Economic benefit of levee maintenance = [EAD without levee maintenance] – [EAD with levee maintenance]

Life safety benefit (measured in the change in SLL) and ecosystem benefit (measured in the change in habitat acres lost) were similarly computed.

TOOL USED FOR FLOOD RISK COMPUTATIONS

To compute EAD and other measures of risk, Ford Engineers used the US Army Corps of Engineers, Hydrologic Engineering Center (HEC) software application Flood Damage Analysis (HEC-FDA) (USACE 2008). HEC-FDA is a standard-of-practice risk assessment tool. The program incorporates descriptions of hazard, system performance, exposure, and vulnerability to compute a consequence-probability function. Statistics of the function, including expected annual value, are computed and reported.

SITES USED IN THIS RISK ASSESSMENT

Flood risk is assessed and reported for an impact area, which is a separable geographic area within a floodplain. Flood hazard for the impact area, described by channel water surface elevation-probability functions and interior-exterior functions, is represented at a single index point. An index point represents a homogenous river reach in terms of consistent hydrologic, hydraulic, and geotechnical characteristics. An index point represents an interface between the impact area and the channel.

For this risk assessment, DWR, with the help of a panel of experts, selected five impact areas in the SPFC system to represent the diversity of conditions present in the system. These impact areas are described in Table 1. As an example of an impact area, Figure 1 shows the RD 1001 impact area and its associated index point.

Figure 1. Example impact area (RD 1001) and its associated index point.

Name	CVFPP[1] IA	LMA	Location	Urban or non-urban	Boundaries	Acreage	Population Remaining	Purpose in this study
Reclamation District (RD) 1001	SAC30	RD 1001	Sutter County	Non-urban	Bounded on the west by the Feather River; on the north by the Bear River; and on the south by the Natomas Cross Canal.	35,294	224	• Economic benefit of flood fighting & levee maintenance • Life safety benefit of flood fighting & levee maintenance
Maintenance Area (MA) 9	SAC63	DWR	Sacramento County	Urban	Bounded on the west by the east bank of the Sacramento River and on the north by the American River.	52,348	316,873	• Economic benefit of flood fighting & levee maintenance • Life safety benefit of flood fighting & levee maintenance
RD 17	RD17	RD 17	San Joaquin County	Urban	Bounded on the west side by the San Joaquin River and on the north side by French Camp Slough.	19,682	11,358	• Economic benefit of flood fighting & levee maintenance • Life safety benefit of flood fighting & levee maintenance
RD 2064	SJ28	RD 2064	San Joaquin County	Non-urban	Bounded on the west side by the San Joaquin River and on the south side by the Stanislaus River.	18,302	251	• Economic benefit of flood fighting & levee maintenance • Life safety benefit of flood fighting & levee maintenance
Sutter Bypass East Levee	SAC24	DWR	Sutter County	Non-urban	Bounded on the west side by the east levee of the Sutter Bypass, on the east side by the Feather River, and by the Wadsworth Canal to the northwest.	59,167	1,696	• Giant garter snake ecosystem benefit • Economic benefit of levee maintenance • Life safety benefit of levee maintenance

Table 1. Impact areas used in this pilot study to develop and demonstrate a method for estimating the benefit of DWR's levee inspection program

1. Central Valley Flood Protection Plan.
2. Reflects the total number of persons remaining in structures after a flood warning has been issued.

CONDITIONS EVALUATED IN THIS ASSESSMENT

For this risk assessment, the following conditions were evaluated:

- With flood fighting (and maintenance).
- Without flood fighting (and maintenance).
- With maintenance.
- Without maintenance.

Note that the flood-fighting baseline condition includes levee maintenance. Flood fighting actions defend against causes of levee failure, such as seepage, erosion, and overtopping. Examples include:

- Building sandbag walls.
- Raising low reaches with lumber and sack topping.
- Placing temporary levees/sausage rolls.
- Building emergency spillways.
- Constructing muscle walls.
- Controlling landside boils with sandbag rings.
- Protecting levees from wave wash with plastic sheeting (raincoats).
- Building seepage berms.
- Filling canals or ditches.
- Building stability berms.
- Dumping rock to protect against erosion.

The with-flood fight condition represents the implementation of any and all the above actions, as needed. The without-flood fight condition represents the complete absence of any of those actions.

- Levee maintenance activities are actions required on a regular basis so that a levee continues to provide the protection for which it was designed. Examples include:
- Animal burrow control.
- Vegetation control.
- Encroachment control.
- Repair and cleaning of flap gates.
- Maintenance of the crown road.
- Repair of sloughing or transverse cracking.
- Routine inspections.
- Repair of erosion sites.
- Removal of hazardous trees.
- Maintenance of pipes in the embankment or foundation.
- Raising low spots.
- Maintenance of the toe road.
- Maintenance of ramps/access roads and gates.
- Patrolling during high water events.

The with-maintenance condition includes any and all necessary conventional maintenance actions, such as those listed above. The hypothetical without-maintenance condition presumes the complete absence of such actions.

Role of levee performance functions in this flood risk assessment

To assess the risk reduction attributable to flood fighting and levee maintenance, our risk assessment method focused on changes to levee performance as represented with a levee performance function. This function, also called a fragility curve, specifies the conditional probability of levee failure, given a channel water surface elevation between the landside toe elevation of the levee and the crest elevation. The performance function is developed through technical analysis of each levee failure mode, combining probabilities of failure by each mode to compute the total failure probability for a given channel water surface elevation.

Flood fighting and levee maintenance have an impact on this performance function. Flood fighting reduces the probability of failure by enhancing levee performance. Whereas, levee maintenance prevents increases in probability of failure by sustaining the existing level of performance. Figure 2 shows an example of changes in levee performance curves due to lack of maintenance. In Figure 2, (a) shows a levee performance curve at a site. With proper maintenance, the curve will represent levee performance over time. In that case, EAD will remain the same for each year of the analysis period (if the flood hazard and other conditions remain fixed). However, without maintenance, the levee will degrade over time with performance represented by the second curve shown in (b). With that modified curve, the probability of failure at a selected stage is greater than before, so the risk is greater, and EAD would increase. If maintenance continues to be neglected, the levee will degrade further with performance represented by the third curve in (c). The risk will further increase, and EAD will be even greater. Our strategy for assessing benefit is to compute EAD without change—as would be the case with proper maintenance—and compare that to EAD with changes to the performance curve that would result from lack of maintenance.

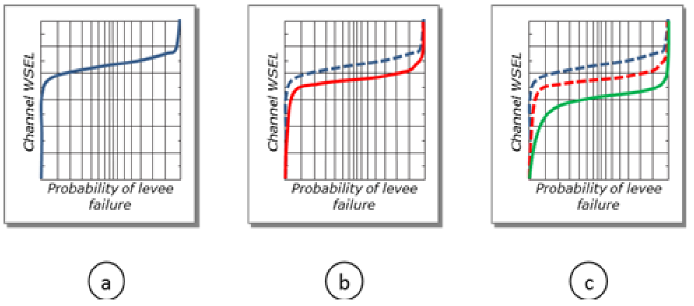

Figure 2. Example levee performance curves that reflect degradation over time due to lack of maintenance.

We developed a set of levee performance functions at each index point that reflects the contribution to levee integrity over time of DWR's flood fight program, and conversely, the degradation of levee integrity over time without DWR's flood fight program. Thus, for a given channel water surface elevation, the probability of failure increases if no flood fighting occurs.

We also developed and used a set of levee performance functions that reflect the contribution of DWR's levee maintenance program to levee integrity over time, and conversely, the degradation of levee integrity over time without DWR's levee maintenance program. Similar to the flood fight analysis, for a given water surface elevation in the channel, the probability of levee failure increases if levee maintenance programs are neglected over the years.

Increased probability of failure leads to increased flood risk, measured here as damage, SLL, and habitat lost. By flood fighting and maintaining the levees, the increase in flood risk is avoided. The benefit of DWR's flood fighting activities is quantified as consequence with flood fighting subtracted from consequence without flood fighting. Similarly, maintenance prevents increase of the probability of failure, and the benefit of maintenance can be assessed by comparing consequence values.

Use of expert opinion elicitation in this analysis

A detailed engineering analysis to assess changes to levee performance function attributable to flood fighting is preferred, but here was not attainable. The same was true for levee maintenance. Therefore, this analysis used the process of expert opinion elicitation (EOE) to describe these changes to the levee performance functions. EOE is a formal, heuristic process that uses a synthesis of expert opinions to gain information when historical performance information is unavailable or when analytical methods are not practical or would give little insight into the issue being addressed (USACE 2009). EOE is a method for dealing with uncertainty in a system when the issues are vague or unknown.

One EOE workshop was held to quantify the effects of flood fighting on the baseline levee performance functions (described below). Another EOE workshop was held to quantify the effects of discontinuing levee maintenance on the levee performance functions. The EOE participants comprised a facilitator (David Ford), a panel of geotechnical engineering experts, and a group of observers.

Baseline levee performance functions

The baseline levee performance functions represented the probabilities of levee failure with maintenance but without flood fighting. The with-maintenance/without-flood fighting performance functions were provided from DWR's Urban Levee Evaluation (ULE) and Non-urban Levee Evaluation (NULE) studies. These functions showed levee failure probabilities due to underseepage, through-seepage, loss of slope stability, erosion, and overtopping for various hydraulic loadings at the five selected index points for well-maintained levees pursuant to DWR's current flood maintenance program (Murray and Wetenkamp, 2015).

Assessment of flood fighting benefits

DESCRIPTION OF CHANGES TO LEVEE PERFORMANCE FUNCTIONS DUE TO FLOOD FIGHTING

To assess the risk reduction attributable to flood fighting, changes to levee performance functions due to flood fighting first had to be identified. Because engineering analyses to analyze the impacts of flood fighting on levee integrity were not available, EOE results were used instead. Each study site was considered separately.

For each failure mode (underseepage, through-seepage, loss of slope stability, erosion, and overtopping), we asked the expert panel to consider how the implementation of flood fighting would change the levee performance function for a given levee reach. Specifically, the experts recorded their best estimates of the probability that the levee would fail when the channel water surface elevation reached the toe, the design water surface elevation (DWSE), and the crest. For the overtopping failure mode, the experts provided the elevation of the new flood fighting crest at which overtopping would be certain (probability of failure equal to 100%).

Following the EOE for flood fighting benefit assessment, Ford Engineers calculated the total probability of failure at the levee toe, crest, and design water surface elevation for the with-flood fighting condition by combining the five individual failure mode performance functions.

The final median probabilities of failure at the levee toe, design water surface elevation, and crest for four failure modes (underseepage, through-seepage, slope stability, and erosion) were used within a fitting algorithm to define a smooth composite probability of failure function for each levee site.

DETERMINATION OF FLOOD FIGHTING BENEFIT

Using the USACE computer program HEC-FDA, with the levee performance functions developed from the EOE to represent the without-flood-fighting condition, Ford Engineers determined economic benefit of flood fighting using an assessment period of 50 years and a discount rate of 6%. The computation for life risk was similar, with a depth-percent mortality function substituted for a depth-percent damage function. The results of these computations for four sites are shown in Table 2.

Levee site	Present value of benefit attributable to flood fighting ($, US, June 2014)[1,2]	Equivalent annual benefit attributable to flood fighting ($, US, June 2014)[1,2]	Reduction in SLL[3]
RD 1001	$10,205,000	$647,000	0.02
MA 9	$19,002,000	$1,206,000	1.52
RD 17	$31,391,000	$1,992,000	0.12
RD 2064	$6,961,000	$442,000	0.02

Table 2. Benefit attributable to flood fighting over 50-year assessment period
1. Values given in 2014 US dollars and rounded.
2. Present value and equivalent annual benefit computed using 6% discount rate and 50-year assessment period.
3. Expected annual value.

Change in project performance due to flood fighting

Ford Engineers computed project performance statistics for the with-flood fighting and without-flood fighting conditions. For all levee sites, the likelihood of inundation in the impact area in any year is decreased with flood fighting. Table 3 shows the annual exceedance probability (AEP) values for the with-flood fighting and without-flood fighting conditions for four levee sites.

CHANGE IN PROJECT PERFORMANCE DUE TO FLOOD FIGHTING

Ford Engineers computed project performance statistics for the with-flood fighting and without-flood fighting conditions. For all levee sites, the likelihood of inundation in the impact area in any year is decreased with flood fighting. Table 3 shows the annual exceedance probability (AEP) values for the with-flood fighting and without-flood fighting conditions for four levee sites.

Levee site	AEP without flood fighting	AEP with flood fighting
RD 1001	0.0761	0.0403
MA 9	0.0138	0.0063
RD 17	0.0027	0.0018
RD 2064	0.1314	0.0686

Table 3. Change in AEP attributable to flood fighting

Assessment of levee maintenance benefits

DESCRIPTION OF CHANGES TO LEVEE PERFORMANCE FUNCTIONS DUE TO LEVEE MAINTENANCE

As with the assessment of risk reduction attributable to flood fighting, the assessment of benefit attributable to levee maintenance focused on changes to levee performance functions due to such maintenance. If the levee is well maintained, the levee performance function should be nearly static over time. In other words, the failure probabilities should not change over a given time period. However, if the levee is not maintained, levee degradation results in increased probabilities of levee failure with the age of the unmaintained levee. This, in turn, increases flood risk.

For each failure mode (underseepage, through-seepage, loss of slope stability, erosion, and overtopping), members of the expert panel provided opinions about the without-maintenance condition failure probabilities for each levee reach (five reaches in total). The experts also specified the number of years when the levee would reach a point at which it would not degrade further (i.e., in which the failure probabilities would remain the same for the remainder of the 50-year assessment period). This number of years differed by failure mode.

To account for the time-varying failure probabilities provided by each expert, the median probability of failure at each 10-year increment at the DWSE and levee crest for each individual mode of failure was used to define a smooth composite probability of failure function at each 10-year increment for each levee site.

DETERMINATION OF LEVEE MAINTENANCE BENEFIT

Using HEC-FDA in the same configuration as for the flood-fighting analysis, Ford Engineers determined the economic benefit of levee maintenance using an assessment period of 50 years and a discount rate of 6%. Note that:

- If the levee is maintained properly throughout the assessment period, EAD remains constant each year in the absence of other changes. Thus, for this assessment, the EAD for Year 1 is the same as the EAD for Year 2, and so forth, through Year 50.
- The without-maintenance EAD was computed for each year of the assessment period, except Year 1. Year 1 reflects the current condition. For future years, we used the degraded levee performance functions at each 10-year interval to compute EAD at the end of that same 10-year interval.

To determine life safety benefit, we computed the change in SLL from the with-maintenance condition to the without-maintenance condition at each index point. We used a depth-percent mortality function in place of the depth-percent damage function used to compute EAD, and, to compute without-maintenance potential lives lost, we used the without-maintenance levee performance functions derived from the EOE. The results of these computations for five sites are shown in Table 4.

Levee site	Present value of benefit attributable to flood fighting ($, US, June 2014)[1,2]	Equivalent annual benefit attributable to flood fighting ($, US, June 2014)[1,2]	Reduction in SLL[3]
RD 1001	9,335,000	592,000	0.02
MA 9	19,169,000	1,216,000	2.17
RD 17	13,306,000	844,000	0.04
RD 2064	1,141,000	72,000	0.01
Sutter Bypass east levee	19,522,000	1,239,000	0.01

Table 4. Benefit attributable to levee maintenance over 50-year assessment period

1. Values given in 2014 US dollars and rounded.
2. Present value and equivalent annual benefit computed using 6% discount rate and 50-year assessment period.
3. Expected annual value.

CHANGE IN PROJECT PERFORMANCE DUE TO LEVEE MAINTENANCE

Ford Engineers computed project performance statistics for the with-maintenance and without-maintenance conditions. For all levee sites, the likelihood of inundation in the impact area in any year is decreased with maintenance. Table 5 shows the annual exceedance probability (AEP) values for the with-maintenance and without-maintenance conditions for five levee sites.

Levee site	AEP with maintenance	AEP without maintenance
RD 1001	0.0761	0.1699
MA 9	0.0138	0.0428
RD 17	0.0027	0.0145
RD 2064	0.1314	0.3881
Sutter Bypass east levee	0.0471	0.0967

Table 5. Change in AEP attributable to maintenance

Assessment of giant garter snake ecosystem benefit attributable to levee maintenance

BACKGROUND

The giant garter snake (GGS) is endemic to California's Central Valley, where it originally inhabited natural wetlands. Scientists estimate that 90 percent of its habitat has been rendered unsuitable for the species, and the snakes now rely on rice fields and managed marsh areas. The GGS is listed as threatened under the federal Endangered Species Act.

Figure 3. Giant garter snake, a threatened species (Westervelt Ecological Services, published by the U.S. Fish & Wildlife Service)

Flood inundation poses a threat to GGS within the Sacramento River floodplain. Properly functioning levees prevent floodplain inundation and the resultant snake mortality. Conversely, maintenance of levees poses a threat to the GGS, e.g., mowing, burning, and grouting destroy surface cover and eliminate burrows and cracks that the GGS uses for shelter (DWR 2009). Therefore, DWR sought to determine the impact of levee maintenance on habitat area available—a surrogate for ecosystem benefit.

WHY THIS SITE WAS CHOSEN FOR HABITAT RISK ASSESSMENT

The Sutter Bypass east levee was selected for this habitat risk assessment because the landside area provides important habitat for the GGS. This area contains acres of rice fields and associated canal infrastructure that are important to the GGS. As part of this conveyance system, DWR maintains 60 miles of canals used for irrigation, drainage, and flood management. These canals drain to the three pumping plants on the east levee of the Sutter Bypass. In addition, there are private mitigation banks specifically designed and used for GGS mitigation from projects that impact the GGS and habitat elsewhere throughout the region, as well as areas under the jurisdiction of US Fish and Wildlife and California Department of Fish and Wildlife that provide habitat for the GGS.

This area is largely protected from catastrophic flooding by the east levee of the Sutter Bypass. Flooding would not only affect public safety and property, it would also affect the habitat of the GGS. Deep flooding for an extended period of time would displace and drown many GGS and adversely affect the mitigation bank habitat, rice fields, and canals that support the GGS. Flooding brings contamination and the areas would have to be rebuilt/dug out after the flood waters recede. This would adversely affect the entire population of GGS in the area protected by the east levee of the Sutter Bypass.

DETERMINATION OF GIANT GARTER SNAKE ECOSYSTEM BENEFIT FROM LEVEE MAINTENANCE

To determine the change in lost GGS habitat acreage from the with-maintenance condition to the without-maintenance condition, we used an HEC-FDA model configured with information developed by DWR about GGS habitat acreage in the protected floodplain, and a damage of 100 percent of the total GGS habitat acreage assigned to all depths greater than 5.0 ft. The benefit attributable to levee maintenance over the 50-year assessment period was computed as the difference between the expected annual with-maintenance-condition GGS habitat acres lost and the expected annual without-maintenance-condition GGS habitat acres lost.

The GGS ecosystem benefit attributable to levee maintenance is 409 acres over a 50-year assessment period.

STUDY CONDITIONS AND LIMITATIONS

Certain simplifications of actual conditions were necessary to represent the complexity of the real world with available techniques, including:

- Without DWR's inspections program, no maintenance or flood fighting activities would be conducted throughout the flood system.
- Either all levee maintenance activities are performed, or no maintenance activities are performed.
- When flood fighting is performed, all appropriate flood fighting techniques are applied as necessary.
- In the without-maintenance condition, breaches are repaired to the equivalent performance of the reach prior to the breach.
- Current under-construction levee remediations are assumed to be in place.

- The selected geotechnical cross section at an index point represents the entire segment of the levee system.
- Performance curves used included appropriate assessment water surface elevation and deterministic and qualitative analyses.
- The without-maintenance levee performance functions do not account for the effects of not maintaining:
- Channels.
- Pump stations.
- Relief wells.
- Relief trenches.
- Drainage feature components (drained seepage and/or stability berms, internal drains, toe drains).
- Landside ditches.
- Diversion weirs.
- Closure structures.
- Stop closures.
- Access gates.

EXTENSION OF FINDINGS

This study developed and applied successfully a procedure for assessing flood risk reduction attributable to flood fighting and levee maintenance activities. The procedure was applied to five sites, using expert opinion elicitation to provide information otherwise unattainable. Based on our previous experience assessing flood risk reduction for levee sites in the Sacramento and San Joaquin River basins, it is our opinion that the results obtained are reasonable. The procedure can be applied throughout the SPFC to assess the total benefit of DWR programs.

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