Smith Canal closure structure: inundation-reduction benefit analysis

November 29, 2010

Prepared for:
Peterson Brustad, Inc.

David Ford Consulting Engineers, Inc.
2015 J Street, Suite 200
Sacramento, CA 95811
Ph. 916.447.8779
Fx. 916.447.8780

Engineer's certification

I, Natalie King, hereby certify on November 29, 2010 that I am a professional engineer licensed in the state of California and that the accompanying report was prepared by me or under my supervision.

NATALIE KING
Natalie King
74694
Exp. 12/31/11
CIVIL

Contents

Tables

Figures

Executive summary

Situation

The Smith Canal is a backwater slough of the Sacramento-San Joaquin Delta in the City of Stockton, just north of the Deep Water Ship Channel. The north bank levee of Smith Canal is maintained by Reclamation District No. 1614 (RD 1614) and the south bank levee is maintained by Reclamation District No. 828 (RD 828). The floodplains on either side of the canal could be inundated from flood waters from the San Joaquin River backing up into the canal. Improvements to the canal's border levees that protect these floodplains are not feasible because the levees are highly encroached upon with development. These encroachments also prevent the levees from being certified by FEMA as protecting against the p=0.01 flood. As part of a larger program by the San Joaquin Area Flood Control Agency (SJAFCA) to protect the area against a p=0.005 flood, the construction of a closure structure near the mouth of Smith Canal is being considered to limit back-flooding from the Delta. The location of the Smith Canal and proposed closure structure is shown in Figure 1.

Figure 1. Overview of proposed project on Smith Canal (SJAFCA 2008)

The proposed closure structure will be composed of a dual sheet pile wall, a gate opening with an inflatable Obermeyer gate to maintain navigation, levee modifications, and facilities to allow storm water passage. During flood events, and in the case of an imminent or existing levee breach, the gate would be raised (inflated), preventing the flow of water from the Delta into Smith Canal. When the flood gate is closed, the canal would function like a detention basin, and the interior storm runoff entering Smith Canal would be pumped out of the canal. The closure structure is designed to protect against a p=0.005 (200-year) flood event.

SJAFCA is partnering with Reclamation Districts 828 and 1614 to develop technical information on the Smith Canal closure structure, develop a risk-benefit analysis to quantify economic benefit of the proposed project, and obtain FEMA's concurrence that the closure structure will be certified.

Task

We completed an inundation-reduction (IR) benefit analysis of the proposed Smith Canal closure structure using available information and following procedures consistent with those used by the State and the Corps to the extent possible.

Actions

We gathered the following data and information:

- A structure inventory with parcel elevations (from Kjeldsen, Sinnock & Neudeck, Inc. (KSN)).
- A water surface elevation (stage)-frequency function from the Burns Cutoff gage station (provided by Peterson Brustad, Inc. (PBI)), which was used as the Smith Canal floodplain stage-frequency function.
- Floodplain stage-damage functions for the study area.

We followed State and Corps economic analysis procedures, incorporating uncertainty analysis, using the best-available information. (Hereinafter, we refer to this analysis as the inundation-reduction benefit analysis or IR benefit analysis.) We:

- Identified the requirements and conditions of the IR benefit analysis, including 5 hypothetical without-project conditions (representing no improvement) and the with-project condition (representing completion of the closure structure and a p=0.01 level of protection).
- Configured computer program HEC-FDA to use the assembled economic and hydraulic information.
- Computed expected annual damage (EAD) for without-project and with-project conditions.
- Using the State's discount rate (6.0%) and a 50-year analysis period beginning in the base year 2010, computed 5 values (1 for each hypothetical existing level of protection) for the present value total IR benefit and the annual IR benefit of the proposed project.

Hypotheses used in this analysis

Without-project and with-project condition

This IR benefit analysis used readily available information only and includes assumptions on annual probabilities of flooding. While this study is based on a detailed hydraulic and economic analysis, sufficient geotechnical data about the existing Smith Canal levees were not available to define accurately the without-project condition. Instead, we selected 5 different floodplain flood frequencies to represent 5 hypothetical without-project conditions:

- p=0.93.

- p=0.20.
- p=0.10.
- p=0.04.
- p=0.02.

We used a p=0.01 level of protection for the with-project condition.

Results

Using a 50-year period of economic analysis and the current state discount rate of 6%, we calculated the present value of the IR benefit, which is the accrued benefit over the life of the project. The present value IR benefit of the project ranges from $51.4 million to $3.69 billion, depending on the current without-project annual exceedence probability (AEP) (which has not been determined as levee fragility curves have not yet been developed).

We also calculated the annual IR benefit, which is the difference between with- and without-project EAD. The annual IR benefit of the project ranges from $3 million to $234 million, depending on the current without-project AEP.

The annual IR benefit and present value of the IR benefit are shown in Table 1 for the 5 hypothetical without-project conditions.

Table 1. IR benefit for the Smith Canal closure structure considering 5 hypothetical without-project conditions

Hypothesized without-project condition (existing annual probability of flooding)[1] (1)	**Annual value IR benefit ($1,000) (2)**	**Present value IR benefit[2] ($1,000) (3)**
0.93[3]	234,289	3,692,831
0.20	61,305	966,285
0.10	30,146	475,162
0.04	10,327	162,780
0.02	3,262	51,422

1. With-project annual probability of flooding is 0.01.
2. Present value computed using the current state discount rate of 6.0% and a 50-year project life.
3. AEP = 0.93 (1-year event) represents the no levee condition.

Analysis

For the Smith Canal closure structure inundation-reduction (IR) benefit analysis, we used the best-available information and followed State and Corps economic analysis procedures, incorporating uncertainty analysis, to calculate expected annual damage (EAD) for a with-project condition (of protection against a p=0.01 flood event) and 5 hypothetical without-project conditions.

Information that HEC-FDA requires

We computed EAD and accounted for the uncertainty associated with that using the statistical sampling procedure developed by the Corps (USACE 1996). This commonly is known as the risk and uncertainty analysis procedure, or R&U. This procedure is included in the Corps' computer program HEC-FDA (USACE 2010). We used version 1.2.5 of this program. Details of the configuration for HEC-FDA for these damage computations are included in Attachment 3. To compute EAD with HEC-FDA, the following are required:

- Index points and impact areas to represent the study area. These analysis locations are used for aggregating and representing system performance. Index points are selected locations that represent hydrologic, hydraulic, and geotechnical characteristics for a reach of a stream. Impact areas are delineations of the floodplain with similar flooding depths.

  For the Smith Canal closure structure IR-benefit analysis, we used only 1 index point and 1 corresponding impact area to compute EAD.

- Channel water surface elevation (stage)-frequency function for each index point. This describes the annual probability, or frequency, of water surface in the river (exterior) reaching a specified elevation (stage).

  For the Smith Canal closure structure IR-benefit analysis, a channel water surface elevation (stage)-frequency function, developed from data from the Burns Cutoff gage station, was provided by PBI. More information about the use of the Burns Cutoff stage-frequency function is provided in Attachment 2.

- Levee fragility function. This is the relationship between channel water surface elevation and probability of levee failure. Factors in this function traditionally include seepage, underseepage, and seismic factors.

  A levee fragility function is not yet available for the Smith Canal closure structure IR-benefit analysis. To achieve the 5 hypothesized existing without-project conditions, we adjusted the levee point of failure elevation.

- Interior-exterior function for each impact area. This function relates channel stage (exterior) at the index point to the water surface elevation in the floodplain (interior) adjacent to the channel.

  For the Smith Canal closure structure IR-benefit analysis, we used a 1:1 interior-exterior relationship because the channel base flood elevation (BFE) is the same as the interior BFE at this location (Email correspondence with PBI on October 20, 2010).

- Interior stage-damage function for each impact area. This function relates economic damage in the interior floodplain to water surface elevation in the floodplain.

  To develop the floodplain stage-damage function, information about property in the floodplain is combined with a depth-damage function. All depth-damage functions used in the Smith Canal closure structure IR-benefit analysis were consistent with the Corps' *Draft economic reevaluation report: American River watershed project, Folsom Dam modification and Folsom Dam raise project* (ERR) (USACE 2007).

Models of uncertainty about that information

The required functions are not known with certainty:

- Uncertainty about future precipitation events, watershed conditions, and channel conditions leads to uncertainty about discharge frequency. For example, we do not know with certainty the magnitude of the p=0.01 event discharge at any point in the system. This leads, in turn, to uncertainty about the floodplain stage-frequency function.
- Economic and social uncertainties, including lack of information about the relationship between depth and inundation damage, lack of accuracy in estimating structure values and locations, and lack of ability to predict how the public will respond to a flood, lead to uncertainty about the stage-damage function.

Computer program HEC-FDA, consistent with *Risk-based analysis for flood damage reduction studies, EM 1110-2-1619* (USACE 1996), allows models of uncertainty about the hydrologic, hydraulic, and economic functions to be described. We provided model parameters for uncertainty about the floodplain stage-frequency function and floodplain stage-damage function.

Conditions evaluated

Without-project condition

Annual exceedence probability (i.e., level of protection) is a function of both hydraulic and geotechnical input. Sufficient geotechnical data are not available about the existing Smith Canal levees to define accurately the without-project condition. Thus, we selected 5 different annual probabilities of floodplain flooding to represent 5 hypothetical without-project conditions:

- p=0.93: represents a condition in which the existing levee provides no protection for the interior floodplain as water rises in the canal.
- p=0.20: existing levees provide protection against all floods less than those with a 1 in 5 chance of occurring each year.
- p=0.10: existing levees provide protection against all floods less than those with a 1 in 10 chance of occurring each year.
- p=0.04: existing levees provide protection against all floods less than those with a 1 in 25 chance of occurring each year.
- p=0.02: existing levees provide protection against all floods less than those with a 1 in 50 chance of occurring each year.

If geotechnical data become available, these could be incorporated in the study to refine the analysis.

We adjusted the levee point of failure elevation to achieve the hypothesized existing annual probabilities of flooding for each event. These levee point of failure elevations are shown in Table 2. Note that the levee elevation point of failure is not the same as the stages in Table 9 of Attachment 2. The elevations in Table 2 take into account the uncertainty in the hydrologic and hydraulic information.

With-project condition

The with-project condition is characterized by the completion of a fully functional project. The project includes a closure structure composed of a dual sheet pile wall, a gate opening with an inflatable Obermeyer gate to maintain navigation, levee modifications, and facilities to allow storm water passage on Smith Canal. The Smith Canal closure structure has a design level of protection of p=0.005. However, consistent with the guidelines for a system analysis, other flooding sources must be considered. For example, even when the closure structure is inflated, the area may be subject to flooding from more frequent events from the Calaveras River or other flooding sources. Given that the system's levees are presumed to protect against a p=0.01 event, we analyzed the Smith Canal closure only up to the level of protection provided by the system as a whole.

For our IR benefit analysis, we have defined the with-project condition as protecting against a p=0.01 flood event, as noted earlier in this report.

Table 2. Floodplain stage-frequency function used for the Smith Canal IR-benefit analysis: data from Burns Cutoff gage station

Hypothesized annual probability of flooding (1)	Levee point of failure elevation (ft NAVD88)[1] (2)
Without-project condition	
0.93[2]	5.50
0.20	8.33
0.10	8.93
0.04	9.24
0.02	9.39
With-project condition	
0.01	9.50

1. Levee point of failure includes the uncertainty in the hydrologic and hydraulic information.
2. AEP=0.93 (1-year event) represents the "no levee" condition. This accounts for the fact that the Smith Canal levees are not FEMA-certified. The median interior toe elevation was used for this analysis, provided by KSN (Email correspondence on September 16, 2010).

Base year and future development of the floodplain

The area has reached buildout. Therefore the number or nature of structures is not expected to change in the future. The floodplains are occupied primarily by residential neighborhoods, with a relatively small number of commercial and light industrial properties.

Measurement of project benefit

Overview of inundation-reduction (IR) benefit

Inundation-reduction (IR) benefit is the value of damage prevented: damage incurred without the project less damage incurred with the project in place. For example, if floods would cause average damage of $1 million to property in an impact area without the proposed risk-reduction features, and if the same floods would cause only an average of $0.4 million with the project, then the IR benefit (the money saved due to the project) is $0.6 million for that flood. Here, the IR benefit is considered to be composed of reductions in:

- Structure damage to residential, commercial, industrial, and public facilities.
- Content damage to those facilities.
- Damage to automobiles.
- Displacement and temporary housing costs.

For comparison purposes, all benefits can be expressed either as average annual values over the analysis period or as present values.

Overview of expected annual damage (EAD)

In urban settings such as Stockton, flood damage analysis commonly is restricted to an accounting of damage due to the largest event that occurs in a year. The time required for recovery, repair, and reconstruction will limit the loss incurred by a second or third flood, so the total loss in that year is a function of the largest of the floods.

Of course, in some years, no flooding will occur. In those years, a flood-damage reduction project will provide little or no benefit. In other years, large floods could cause significant damage, so by protecting people and property, the project will yield a great benefit. The random nature of flooding makes it impossible to predict the damage prevented in any particular year of the project's life because we cannot predict flood flows years in advance. Consequently, for evaluation of flood-damage reduction plan performance, *Economic and environmental principles and guidelines for water and related land resources implementation studies* (US Water Resources Council 1983) stipulates use of the statistical average damage value. This average is known commonly as the expected annual damage (EAD).

Expected annual damage (EAD) is the standard measure of flood risk. It is a function of the probability of a given area flooding and the associated flood damage. The difference between the EAD for the without-project condition and the EAD for the with-project condition is a measure of benefit of that project. State and Corps economic analysis procedures incorporate the best-available hydrologic, hydraulic, geotechnical, and economic information to compute EAD, accounting explicitly for uncertainty in the information.

We compute and use the EAD herein as an index of risk reduction and project benefit.

Computation of project benefit for the Smith Canal closure structure

Using the available data provided, we calculated:

- EAD for 5 hypothetical without-project conditions, as noted above.
- EAD for the with-project condition (i.e., the closure structure protects against a flood event with p=0.01).
- 5 values for damage prevented (EAD without-project less EAD with-project), which is the annual IR benefit.

The concept of EAD and its computation are described in more detail in Attachment 1 of this report. Later sections of this report describe the information we used in our computations and our results.

Floodplain structure stage-damage functions

Development of floodplain structure stage-damage functions for this study

The floodplain stage-damage function relates inundation damage to water surface elevation within the impact area. This damage relationship is developed from information about location and value of property in the floodplain. We divided damages for the study area into damage categories, which are summarized in Table 3.

Table 3. Damage categories used in the Smith Canal closure structure IR benefit analysis

Damage category (1)	**Description (2)**
Residential	Single family residential structures, multi-family residential structures, mobile homes (MH)
Commercial	Offices, retail facilities, hotels and motels, public buildings
Industrial	Manufacturing plants; oil refineries; meat packing plants, canneries, and similar facilities; farm buildings
Public	Municipal buildings, theaters, churches, schools

Table 4 summarizes the depth-damage functions applied in the Smith Canal closure structure IR benefit analysis. The development of the structure inventory used to develop the stage-damage function is described in greater detail in Attachment 3.

Table 4. Sources of structure and content depth-damage functions for the Smith Canal closure structure IR benefit analysis

Category (1)	**Residential (SFR1 & 2, MFR1 & 2) (2)**	**Residential (MH) (3)**	**Non-residential (4)**
Structure	EGM 04-01	Morganza to the Gulf feasibility	ARWI
Content	EGM 04-01	Morganza to the Gulf feasibility	Corps ERR

Description of uncertainty about floodplain structure stage-damage functions

As with other functions used for the analysis reported herein, the damage functions are not known with certainty. Table 5 lists how we described uncertainty in the inputs. These values are consistent with recent studies in the area.

Table 5. Description of uncertainty about floodplain stage-damage functions for the Smith Canal closure structure IR benefit analysis

Property characteristic (1)	Residential structures (2)	Non-residential structures (3)
Structure damage	Normal probability distribution with a standard deviation consistent with EGM 04-01.	Normal probability distribution with a standard deviation equal to 10% of the mean structure value, consistent with recent studies in the area.
Content damage	Normal probability distribution with a standard deviation consistent with EGM 04-01.	Triangular probability distribution with a standard deviation consistent with the Corps' American River ERR.
Structure value	Normal distribution with a standard deviation ranging from 11% to 20%, depending on the structure type. This is consistent with a recent study in West Sacramento which used the Marshall Valuation Service cost manual published by Marshall & Swift/Boeckh, LLC.	Normal distribution with a standard deviation ranging from 11% to 20%, depending on the structure type. This is consistent with a recent study in West Sacramento which used the Marshall Valuation Service cost manual published by Marshall & Swift/Boeckh, LLC.
1st floor elevation	Normal distribution with a standard deviation of 0.5 ft, consistent with recent studies in the area.	Normal distribution with a standard deviation of 0.5 ft, consistent with recent studies in the area.

Direct tangible costs other than real property damage

Displacement and temporary housing costs

Displacement costs are a consequence of the time occupants are displaced from their homes due to flood damages. We followed FEMA procedures for estimating displacement times and temporary housing costs as described in *Benefit-cost analysis tool, Version 4.5.5.0* (FEMA 2009). Attachment 4 describes how the temporary housing and displacement costs were computed and integrated into the HEC-FDA calculations.

Automobile damages

For automobiles we used depth-damage functions from *Economic guidance memorandum 09-04, Generic depth damage relationships for vehicles* (USACE 2009). To develop automobile stage-damage functions we followed procedures consistent with the Corps' ERR, which is described in greater detail in Attachment 3.

What we found

Inundation-reduction benefits

Table 6 shows total EAD values computed for the with- and without-project conditions. We hypothesized 5 different without-project conditions, as discussed earlier in this report. As the annual probability of flooding increases, without-project EAD increases.

Table 6. Expected annual flood damage for without- and with-project conditions: EAD increases with increased annual probability of flooding

Hypothesized annual probability of flooding (1)	**EAD[1] ($1,000) (2)**
Without-project condition	
0.93[2]	237,872
0.20	64,888
0.10	33,729
0.04	13,910
0.02	6,845
With-project condition	
0.01	3,583

3. EAD values include damage to structures, contents, autos, and cost for displacement and temporary housing.
4. AEP = 0.93 (1-year event) represents the no levee condition.

Table 7 shows the annual IR benefit, computed as the difference between with- and without-project EAD, and the IR benefit, which is the accrued benefit over the life of the project. Using a 50-year period of economic analysis and the current state discount rate of 6%, the present value of the IR benefit is shown in column 3. For a with-project condition providing a level of protection up to a p=0.01 flood event the present value IR benefit ranges from $51.4 million to $3.69 billion, depending on the current without-project annual exceedence probability.

Table 7. IR benefit for the Smith Canal closure structure considering 5 hypothetical without-project conditions

Hypothesized without-project condition (existing annual probability of flooding)[1] (1)	**Annual value IR benefit ($1,000) (2)**	**Present value IR benefit[2] ($1,000) (3)**
0.93[3]	234,289	3,692,831
0.20	61,305	966,285
0.10	30,146	475,162
0.04	10,327	162,780
0.02	3,262	51,422

1. With-project annual probability of flooding is 0.01.
2. Present value computed using the current state discount rate of 6.0% and a 50-year project life.
3. AEP = 0.93 (1-year event) represents the no levee condition.

For our hypothesized existing levels of protection, we found that a reduction in damage exists with construction of the Smith Canal closure structure. If the existing level of protection is from a p=0.93 event, the difference between the with-project and without-project condition (the present value benefit) is $3.69 billion. If the existing level of protection is from a p=0.20 event, the present value benefit is $966 million. If the existing level of protection is from a p=0.10 event, the present value benefit is $475 million. If the existing level of protection is from a p=0.04 event, the present value benefit is $163 million. And if the existing level of protection is from a p=0.02 event, the present value benefit is $51 million.

For completeness, Table 8 shows the breakdown of EAD by damage to flooded property and cost for displacement and temporary housing of floodplain residents.

Table 8. Expected annual damage for without- and with-project conditions by damage category

Hypothesized annual probability of flooding (1)	**EAD ($1,000s)**		
	Structure, content, and automobiles (2)	**Displacement and temporary housing (3)**	**Total EAD (4)**
Without-project condition			
0.93[1]	200,944	36,928	237,872
0.20	53,624	11,264	64,888
0.10	27,748	5,981	33,729
0.04	11,407	2,503	13,910
0.02	5,604	1,241	6,845
With-project condition			
0.01	2,927	655	3,583

1. AEP = 0.93 (1-year event) represents the no levee condition.

References

Federal Emergency Management Agency (FEMA). (2005). *What is a benefit? Draft guidance for benefit-cost analysis, Mitigation BCA toolkit CD, Version 2.0*.

FEMA. (2009). *Benefit-cost analysis tool, Version 4.5.5.0*.

National Auto Dealer Association (NADA). (2008). *NADA data 2009, Economic impact of America's new-car and new-truck dealers, a dealership and industry review*, McLean, VA.

Peterson Brustad, Inc. (2010). *San Joaquin River Delta base flood elevation refinement stage frequency analysis*. San Joaquin Area Flood Control Agency.

San Joaquin Area Flood Control Agency (2008). *Smith Canal closure structure conceptualization*, technical memorandum, Folsom, CA.

US Army Corps of Engineers (USACE). (1991). *American River watershed investigation*, Sacramento District, Sacramento, CA.

USACE. (1995). *Procedural guidelines for estimating residential and business structure value for use in flood damage estimations, Report 95-R-9*, Institute for Water Resources, Alexandria, VA.

USACE. (1996). *Engineering Manual (EM) 1110-2-1619, Risk-based analysis for flood damage-reduction studies*, Office of the Chief of Engineers, Washington, DC.

USACE. (1997). *Depth-damage relationships for structures, contents, and vehicles and content-to-structure value ratios (CSVR) in support of the lower Atchafalaya reevaluation and Morganza to the Gulf, Louisiana feasibility studies*, New Orleans District, New Orleans, LA.

USACE. (2000). *Economic guidance memorandum 01-03, Generic depth-damage relationships*. Office of the Chief of Planning and Policy Division, Washington, DC.

USACE. (2002). *Sacramento and San Joaquin river basins comprehensive study*, Sacramento District, Sacramento, CA.

USACE. (2003). *Economic guidance memorandum 04-01, Generic depth-damage relationships for residential structures with basements*, Office of the Chief of Planning and Policy Division, Washington, DC.

USACE. (2007). *Draft economic reevaluation report: American River watershed project, Folsom Dam modification and Folsom Dam raise projects*, Sacramento District, Sacramento, CA.

USACE. (2009). *Economic guidance memorandum 09-04, Generic depth-damage relationships for vehicles,* Office of the Chief of Planning and Policy Division, Washington, DC.

USACE. (2010). *HEC-FDA flood damage reduction analysis, CPD-72, ver. 1.2.5,* Hydrologic Engineering Center, Davis, CA.

US Census Bureau. (2008). US Census Bureau American FactFinder (http://factfinder.census.gov/servlet/QTTable?_bm=y&-geo_id=86000US95204&-qr_name=DEC_2000_SF3_U_DP4&-ds_name=DEC_2000_SF3_U&-_lang=en&-redoLog=false&-_sse=on)

US Water Resources Council. (1983). *Economic and environmental principles and guidelines for water and related land resources implementation studies*, US Government Printing Office, Alexandria, VA.

Attachment 1. Expected annual damage computation procedure

Theoretical background

In mathematical terms, if X represents the value of annual flood damage, then the expected value of annual damage, $E[X]$, is computed as

$$E[X] = \int_{-\infty}^{\infty} x \, f_X(x) \, dx \tag{1}$$

in which x represents the random value of annual damage that occurs with probability $f_X(x)dx$. With this, all the information about the probability of occurrence of various magnitudes of damage is condensed into a single number by summing the products of all possible damage values and the likelihood of their occurrence.

In the equation, $f_X(x)$ is what statisticians refer to as the *probability density function* (PDF). In hydrologic engineering, an alternative representation of the same information, the so-called *cumulative distribution function* (CDF), is more commonly used. This is defined as

$$F_X[x] = \int_{-\infty}^{x} f_X(u) du \tag{2}$$

This probability distribution function, also known as a *frequency function*, defines the probability that annual maximum damage will not exceed a specified value X. Alternately, by exchanging the limits of integration, the CDF could define the probability that the damage will exceed a specified value. In either case, the CDF and PDF are related as

$$\frac{dF_X[x]}{dx} = f_X(x) \tag{3}$$

so the expected value of annual damage can be computed as

$$E[X] = \int_{-\infty}^{\infty} x \frac{dF_X(x)}{dx} dx \tag{4}$$

Method of computation

Mechanically, then, finding the expected value of annual damage is equivalent to integrating the annual damage cumulative frequency function. The function could be integrated analytically if it were written as an equation. This approach is of little practical value because analytical forms commonly are not available. In fact, the damage-frequency function required for expected-annual-damage computation commonly is not available in any form. Theoretically, the function could be derived by collecting annual damage data over time and fitting a statistical model. In most cases, such damage data are not available or are very sparse for existing conditions, and they *never* are available for modified conditions.

Instead, the damage-frequency function is derived commonly via transformation of available hydrologic, hydraulic, and economic information, as illustrated in Figure 2. A stage-frequency function (Figure 2*a*) is developed using principles of hydrology and hydraulics. An elevation-damage function (Figure 2*b*) is developed from information about location and value of damageable property in the floodplain. With this, the stage-frequency function can be transformed to yield the required damage-frequency function (Figure 2*c*). Finally, to compute the expected damage, the resulting damage-frequency function can be integrated.

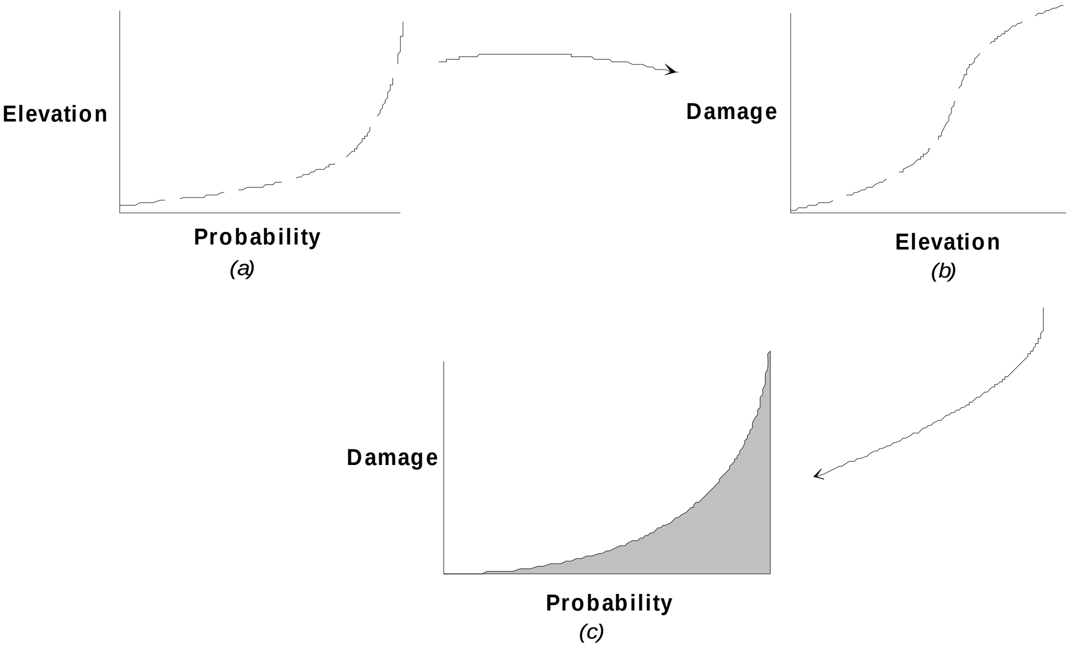

Figure 2. EAD computed by transformation and integration: Combination of the stage-frequency function and elevation-damage function yields a damage-frequency function. EAD is computed by integrating the damage-frequency function

This integration task was completed for the study reported herein using the Corps' computer program HEC-FDA (USACE 2008). The program is based on the concept that the average of damages that are incurred over a very long period will approach the true EAD. It uses a statistical model to generate a long sequence of flood elevations, uses the elevation-damage transformation to create an equally long record of annual damages, and averages those.

Attachment 2. Stage-frequency function

Peterson Brustad, Inc. (PBI) provided the water surface elevation (stage)-frequency function we used for this analysis. This function was published in the *San Joaquin River Delta base flood elevation refinement stage frequency analysis* (September 2010) for the Burns Cutoff gage station (B95660), which is located near the Stockton Deep Water Ship Channel. This function includes events ranging from p=0.500 (1 in 2 years) to p=0.002 (1 in 500 years). Table 9 and Figure 3 show this stage-frequency function. The Burns Cutoff channel stage-frequency function is fairly flat. The difference in stage between the p=0.100 event and the p=0.010 event is only 4.8 inches.

The interior-exterior relationship relates a channel (exterior) water surface elevation to a floodplain (interior) water surface elevation. We used a 1:1 interior-exterior relationship because the channel base flood elevation (BFE) is the same as the interior BFE at this location (Email correspondence with PBI on October 20, 2010). Therefore, we used the water surface elevation (stage)-frequency function from the Burns Cutoff gage station as the Smith Canal floodplain stage-frequency function.

To describe the hydrologic and hydraulic uncertainty in the floodplain stage-frequency function, we used an equivalent record length of 57 years. This is the period of record used for the channel water surface elevation-frequency analysis for Burns Cutoff. With the equivalent record length, the uncertainty about the stage-frequency function changes with the probability of a given elevation being exceeded: The rarer the event, the greater the uncertainty. For completeness, we report the uncertainty within 1 standard deviation about the p=0.01, p=0.004, and p=0.002 events in Table 10. This uncertainty represents the total uncertainty of both the hydrologic and hydraulic evaluation. This uncertainty is also a function of the specified equivalent record length and the "shape" of the stage-frequency function. Thus, 2 functions with the same equivalent record length could have different uncertainty for a selected design probability if the shapes of the functions are different.

All elevations provided by PBI are based on the North American Vertical Datum of 1988 (NAVD88).

Table 9. Floodplain stage-frequency function used for the Smith Canal IR-benefit analysis: data from Burns Cutoff gage station

Annual exceedence probability (1)	**Stage (ft NAVD88) (2)**
0.999[1]	3.6
0.500	7.3
0.200	8.3
0.100	9.0
0.050	9.1
0.020	9.3
0.010	9.4
0.005	9.5
0.002	9.6

1. As required by HEC-FDA, we linearly extrapolated the 0.999 value.

Table 10. Uncertainty (1 standard deviation) about the Burns Cutoff stage-frequency function

Annual exceedence probability (1)	**Stage (ft) (2)**
0.010	0.19
0.004	0.19
0.002	0.18

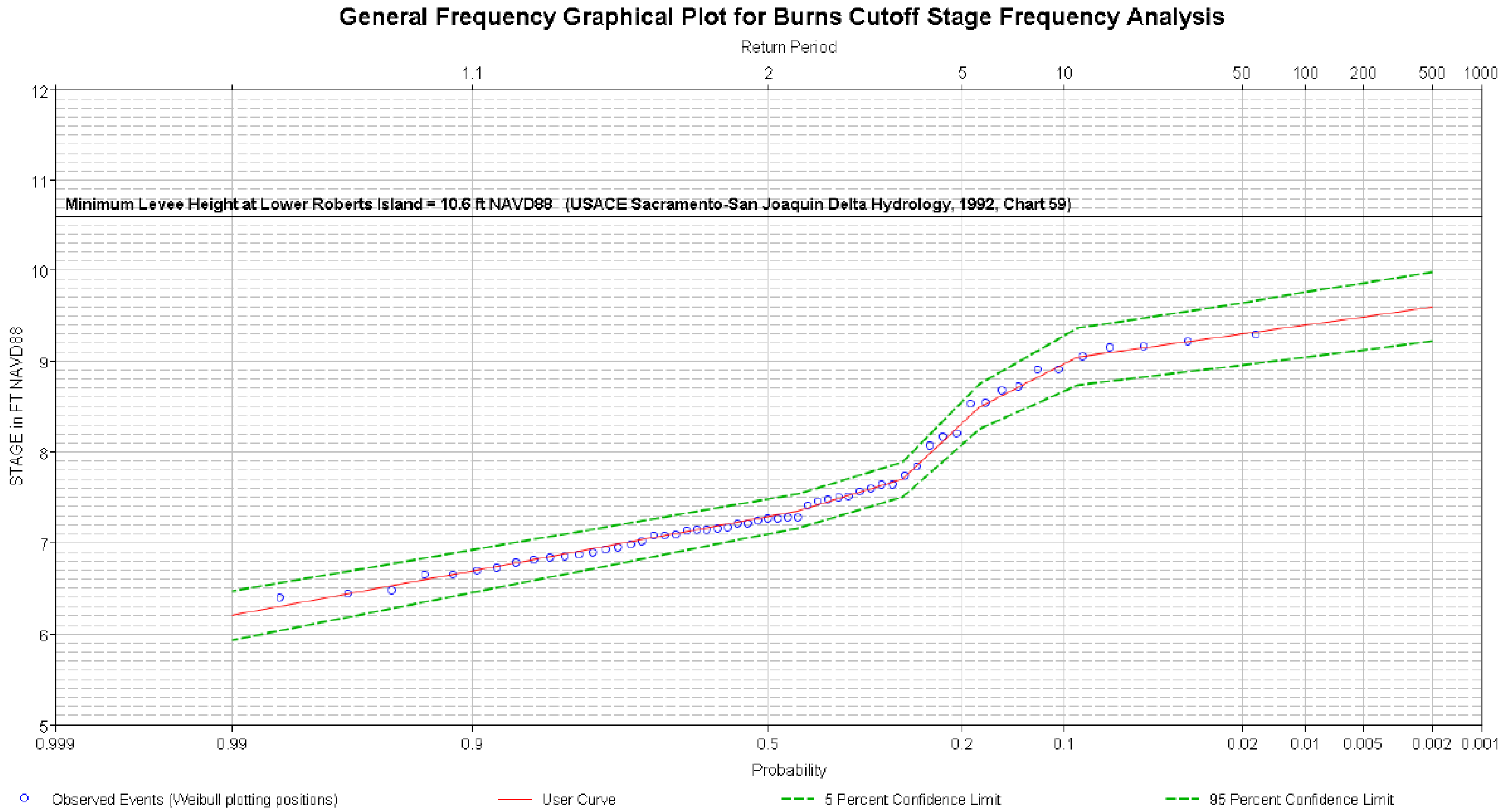

Figure 3. Channel water surface elevation (stage)-frequency function for Burns Cutoff gage station, used for Smith Canal floodplain stage-frequency function (PBI 2010)

Attachment 3. Elevation-damage functions for expected annual damage calculations

Overview

To the extent possible, we used for the Smith Canal closure structure analysis elevation-damage functions that were developed by the Corps and used for the *Draft economic reevaluation report: American River watershed project, Folsom Dam modification and Folsom Dam raise projects* (ERR) (USACE 2007) and other recent studies. Here we provide key data and brief descriptions of steps taken in development of the functions.

Structure depth-damage functions

For the Smith Canal closure structure analysis, we used depth-percent damage functions consistent with the Corps' ERR and other recent nearby studies. These functions predict damage to a structure and content as a function of the depth of inundation at the structure. Damage is expressed as a percentage of total value, and depth is measured relative to the first floor elevation at each structure. In application, the functions are transformed to stage-damage functions by multiplying the percent damage values by the total value and by adding the first floor elevation to depths.

For residential structures, structure and content depth-damage functions are from the Corps' *Economic guidance memorandum 04-01, Generic depth-damage relationships for residential structures with basements* (USACE 2003). These functions predict flood damage to 1-story homes and homes with 2 or more stories. We used the EGM 04-01 functions for both single family and multi-family residential structures. Table 11 and Table 12 present these depth-damage functions.

For mobile homes, structure and content depth-damage functions are from the May 1997 final report, *Depth-damage relationships for structures, contents, and vehicles and content-to-structure value ratios (CSVR) in support of the lower Atchafalaya reevaluation and Morganza to the Gulf, Louisiana feasibility studies* (USACE 1997). This is consistent with the Corps' ERR. These functions predict flood damage to mobile homes over a long duration. Table 13 and Table 14 present these depth-damage functions.

Non-residential structure depth-damage functions were taken from the *American River watershed investigation* (ARWI) (USACE 1991) and are consistent with the Corps' ERR. Content depth-damage functions for non-residential structures were taken from the Corps' ERR. The ARWI structure depth-damage functions are shown in Table 15. The ERR includes content depth-damage functions for 25 structure types developed specifically for the Sacramento area. All content depth-damage functions are included in the Corps' documentation (USACE 2007).

Table 11. Residential structure without basement depth-damage functions for 1 and 2 story structures (EGM 04-01)

First-floor depth (ft) (1)	1 story, without basement		2 or more stories, without basement	
	Structure damage[1] (2)	Standard deviation (3)	Structure damage[1] (4)	Standard deviation (5)
-2.0	0	0.0	0.0	0.0
-1.0	2.5	2.7	3.0	4.1
0.0	13.4	2.0	9.3	3.4
1.0	23.3	1.6	15.2	3.0
2.0	32.1	1.6	20.9	2.8
3.0	40.1	1.8	26.3	2.9
4.0	47.1	1.9	31.4	3.2
5.0	53.2	2.0	36.2	3.4
6.0	58.6	2.1	40.7	3.7
7.0	63.2	2.2	44.9	3.9
8.0	67.2	2.3	48.8	4.0
9.0	70.5	2.4	52.4	4.1
10.0	73.2	2.7	55.7	4.2
11.0	75.4	3.0	58.7	4.2
12.0	77.2	3.3	61.4	4.2
13.0	78.5	3.7	63.8	4.2
14.0	79.5	4.1	65.9	4.3
15.0	80.2	4.5	67.7	4.6
16.0	80.7	4.9	69.2	5.0
25.0	85.2	8.5	82.7	8.6

[1] Values shown are damage as percentage of structure value.

Table 12. Residential content without basements depth-damage functions for 1 and 2 story structures (EGM 04-01)

First-floor depth (ft) (1)	**1 story, without basement**		**2 or more stories, without basement**	
	Content damage[1] (2)	**Standard deviation (3)**	**Content damage[1] (4)**	**Standard deviation (5)**
-2.0	0.0	0.0	0.0	0.0
-1.0	2.4	2.1	1.0	3.5
0.0	8.1	1.5	5.0	2.9
1.0	13.3	1.2	8.7	2.6
2.0	17.9	1.2	12.2	2.5
3.0	22.0	1.4	15.5	2.5
4.0	25.7	1.5	18.5	2.7
5.0	28.8	1.6	21.3	3.0
6.0	31.5	1.6	23.9	3.2
7.0	33.8	1.7	26.3	3.3
8.0	35.7	1.8	28.4	3.4
9.0	37.2	1.9	30.3	3.5
10.0	38.4	2.1	32.0	3.5
11.0	39.2	2.3	33.4	3.5
12.0	39.7	2.6	34.7	3.5
13.0	40.0	2.9	35.6	3.5
14.0	40.0	3.2	36.4	3.6
15.0	40.0	3.5	36.9	3.8
16.0	40.0	3.8	37.2	4.2
25.0	40.0	6.5	39.9	7.8

[1] Values shown are damage as percentage of structure value.

Table 13. Mobile home structure depth-damage functions (USACE 1997)

First-floor depth (ft) (1)	**Structure damage[1] (2)**	**Minimum damage[1] (3)**	**Maximum damage[1] (4)**
-2.0	0.0	0.0	0.0
-1.0	6.4	6.1	8.3
-0.5	7.3	6.9	9.5
0.0	9.9	9.4	12.9
0.5	43.4	41.2	56.4
1.0	44.7	42.5	58.1
1.5	45.0	42.8	58.5
2.0	45.7	43.4	59.4
3.0	96.5	91.6	100.0
4.0	96.5	91.6	100.0
5.0	96.5	91.6	100.0
6.0	96.5	91.6	100.0
7.0	96.5	91.6	100.0
8.0	96.5	91.6	100.0
9.0	96.5	91.6	100.0
10.0	96.5	91.6	100.0
11.0	96.5	91.6	100.0
12.0	96.5	91.6	100.0
13.0	96.5	91.6	100.0
14.0	96.5	91.6	100.0
15.0	96.5	91.6	100.0
25.0	96.5	91.6	100.0

1. Damage values shown are percentage of structure value.

Table 14. Mobile home content depth-damage functions (USACE 1997)

First-floor depth (ft) (1)	Content damage[1] (2)	Minimum damage[1] (3)	Maximum damage[1] (4)
-2.0	0.0	0.0	0.0
-1.0	0.0	0.0	0.0
-0.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.5	85.0	75.0	90.0
1.0	85.0	80.0	95.0
1.5	90.0	85.0	98.0
2.0	95.0	95.0	100.0
3.0	99.0	95.0	100.0
4.0	99.0	95.0	100.0
5.0	99.0	95.0	100.0
6.0	99.0	95.0	100.0
7.0	99.0	95.0	100.0
8.0	99.0	95.0	100.0
9.0	99.0	95.0	100.0
10.0	99.0	95.0	100.0
11.0	99.0	95.0	100.0
12.0	99.0	95.0	100.0
13.0	99.0	95.0	100.0
14.0	99.0	95.0	100.0
15.0	99.0	95.0	100.0
25.0	99.0	95.0	100.0

1. Damage values shown are percentage of structure value.

Table 15. Non-residential structure depth-percent damage functions for 1 and 2 story structures (USACE 2007)

First-floor depth (ft) (1)	**Commercial 1-story[1] (2)**	**Commercial 2-story[1] (3)**	**Industrial 1-story[1] (4)**	**Public 1-story[1] (5)**	**Public 2-story[1] (6)**
-2.0	0.0	0.0	0.0	0.0	0.0
-1.0	0.0	0.0	0.0	0.0	0.0
0.0	4.0	4.0	4.0	7.0	5.0
1.0	9.0	7.0	9.0	10.0	9.0
2.0	13.0	9.0	13.0	14.0	13.0
3.0	18.0	12.0	18.0	26.0	18.0
4.0	22.0	14.0	22.0	28.0	20.0
5.0	27.0	16.0	27.0	29.0	22.0
6.0	31.0	19.0	31.0	41.0	24.0
7.0	35.0	21.0	35.0	43.0	26.0
8.0	38.0	23.0	38.0	44.0	31.0
10.0	49.0	28.0	49.0	46.0	38.0
13.0	60.0	38.0	60.0	49.0	38.0
15.0	60.0	43.0	60.0	50.0	38.0
19.0	60.0	52.0	60.0	50.0	38.0
21.0	60.0	58.0	60.0	50.0	38.0
25.0	60.0	60.0	60.0	50.0	38.0

1. Damage values shown are percentage of structure value.

Automobile depth-damage functions

Damages to autos were developed based on a function of average value, number of vehicles per residential structure, estimated evacuation rate, depth of flooding, and depth-damage percent loss. To develop automobile stage-damage functions we followed procedures consistent with the Corps' ERR. We developed the stage-damage function by:

1. Assigning 1.45 automobiles per residential structure (US Census Bureau 2008).
2. Assigning an average depreciated-replacement value of $15,200 per automobile (NADA 2008).
3. Estimating 50% of the automobiles are removed from the damage area during flood events.
4. Assigning ground elevation at each structure as the elevation of the automobile.
5. Using the depth-percent damage function from EGM 09-04: *Generic depth-damage relationships for vehicles* (USACE 2009), shown in Table 16.

Table 16. Automobile depth-damage functions

First-floor depth (ft) (1)	Automobile damage[1] (2)	Standard deviation (3)
0.0	21.8	0.0
1.0	40.5	7.4
2.0	56.9	5.8
3.0	71.1	4.5
4.0	83.2	3.6
5.0	91.9	4.5
6.0	96.1	6.5
7.0	99.2	6.9
8.0	100.0	7.3
9.0	100.0	7.6
10.0	100.0	7.6
25.0	100.0	7.6

1. Damage values shown are percentage of structure value.

Structure identification

Kjeldsen, Sinnock & Neudeck (KSN) provided the structure inventory and parcel elevations for the Smith Canal closure structure analysis. The inventory included 4,050 parcels with structures, all within the 100-year floodplain. These structures are outlined in red in Figure 4. For this analysis, we used only those structures with provided square footage and/or improvement values, totaling 3,852 structures. We assumed the number of structures remains constant for the without-project and with-project conditions over the 50-year analysis period.

Structure types

We assigned each structure to a category based on the type of structure identified in the inventory (provided by KSN). We categorized structures into 1 of the 4 structure types: residential; commercial; industrial; and public. Table 17 shows the number of structures identified for each structure category.

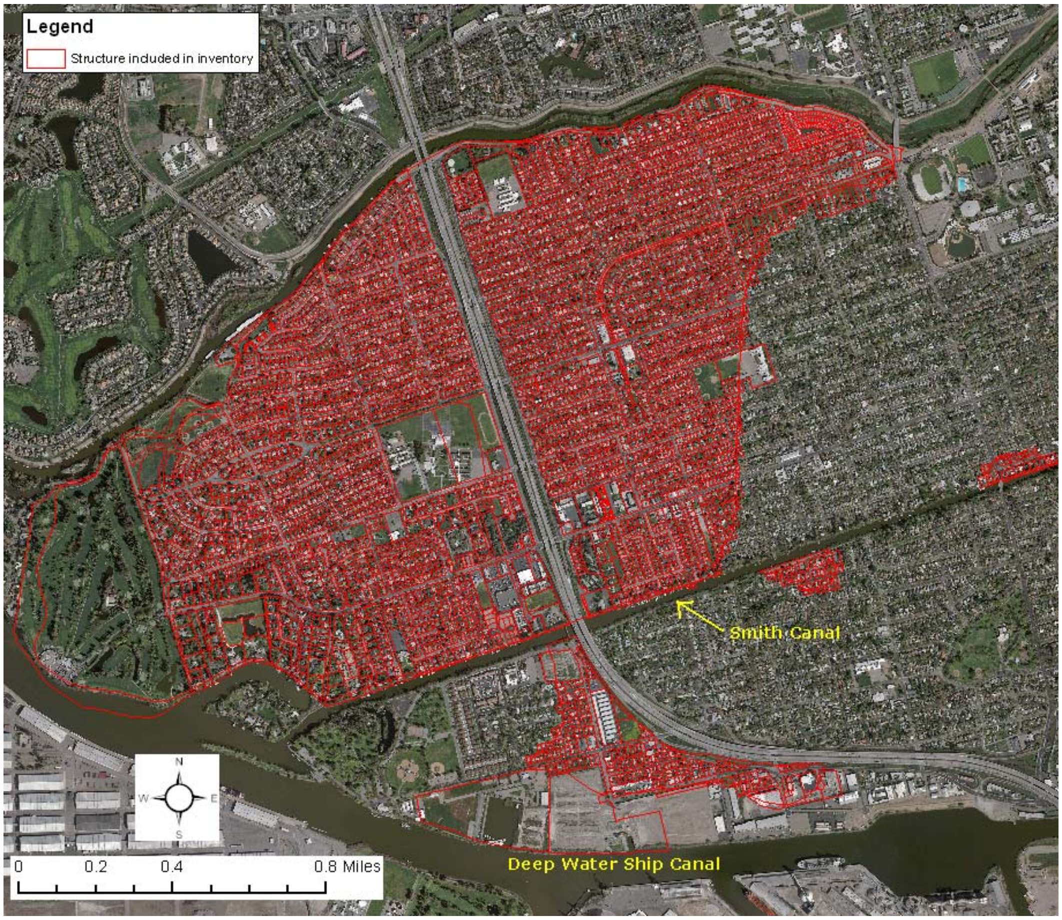

Figure 4. Location of structures within the Smith Canal closure structure IR-benefit analysis structure inventory

Table 17. Smith Canal closure structure IR-benefit analysis structure inventory categories and number of structures

Structure category (1)	**Number of structures (2)**
Residential (including mobile homes)	3777
Commercial	54
Industrial	9
Public	12
Total	3,852

Structure value

The structure value was calculated based on the average unit values by structure type. For structures with reported square footage, we computed the structure value by multiplying the structure area by an average unit construction cost used in other regional studies (shown in Table 18). For structures without reported square footage, we used the improvement value provided by KSN as the surrogate structure value.

Table 18. Average unit construction cost factors

Structure type (1)	**Unit construction cost ($/ft^2)** (2)
Commercial	70
Industrial	50
Public	70
Residential	60

Depreciated structure and content value

Consistent with the Corps' standards, we used the structure's depreciated replacement value for the economic analysis. The depreciated replacement value is the cost of replacing the structure less any depreciation, which accounts for a reduction in a structure's value due to deterioration prior to flooding. To calculate this, we completed the following steps:

1. We estimated structure replacement cost, as described earlier in this report.
2. PBI categorized the condition of each property as good (Email correspondence with PBI on July 27, 2010). A structure in good condition is described as "a structure that shows some signs of aging but for which no obvious maintenance is required. The resulting remaining life is approximately 70-75% of the average life expectancy" (USACE 1995).
3. We estimated the remaining life for each structure using a function from *IWR Report 95-R-9*. We then estimated the percent depreciation as a function of the remaining life, again using a function from *IWR Report 95-R-9*. These functions are summarized in Table 19.
4. For each structure, we computed the depreciated replacement value as: *replacement cost* X (100 — *percent depreciated value*)/100

Table 19. Relation of structure category to remaining life and percent depreciation (USACE 1995) used for depreciation calculations in the Smith Canal closure structure IR-benefit analysis

Structure category (1)	**Remaining life (years)** (2)	**Percent depreciation (%)** (3)
Single family residential	40	15
Multifamily residential	45	12
Commercial	35	11
Industrial	35	11
Public	40	8

When using the Corps' depth-damage function in *EGM 04-01*, we need not estimate separately a content value for residential structures. Those depth-damage relationships include damage to content as a function of the structure value. Thus, the content value is not explicitly calculated, but based on structure value. However, for reporting purposes of the value of the inventory as shown in Table 21, we assume a content-to-structure ratio of 0.5, which is consistent with recent studies such as the Corps' American River ERR.

For non-residential structures, we estimated a content value using ratios of values established by the Corps and DWR for the *Sacramento and San Joaquin river basins comprehensive study* (Comp Study) (USACE 2002). These ratios are provided in Table 20. For example, if an industrial structure's depreciated replacement value was estimated as $100,000, we estimated the contents value of that structure as: $100,000 X 1.5 = $150,000.

Table 20. Structure to content value ratios

Structure type (1)	Structure to content value ratio (2)
Residential	NA[1]
Commercial	1.0
Industrial	1.5
Public	0.5

1. Depth-percent damage curves require residential content damages to be calculated using full structure value rather than a percentage of the structure value.

After all the structures and contents were valued, we calculated a total damageable property value by summing the structure and content values for each category as shown in Table 21.

Table 21. Structure, content, and total damageable property value by structure category for the Smith Canal structure inventory

Structure category (1)	Structure value ($1,000) (2)	Content value ($1,000) (3)	Total damageable property ($1,000) (4)
Residential	303,388	151,694[1]	455,082
Commercial	31,053	31,053	62,106
Industrial	7,136	10,704	17,840
Public	5,717	2,858	8,575
Total	347,294	196,309	543,603

1. Residential content is assumed 50% of residential structure value for this table. For EAD computations, the content damage is computed as a function of the structure value.

Stage-damage relationships

For the Smith Canal structure inventory, we used the depth-damage functions and the structure properties described above to develop floodplain stage-damage relationships.

When combining this information, we also needed an estimate of the first-floor elevation of each structure. The ground elevation of each parcel was provided by KSN in the structure inventory. To convert the ground elevation to a first-floor elevation, we used typical foundation heights consistent with the Corps' ERR and shown in Table 22.

Table 22. Foundation heights used to determine first floor elevations for the Smith Canal structure inventory

Structure category (1)	**Foundation height (ft) (2)**
Commercial	0.5
Industrial	0.5
Public	1.0
Residential (single family residential, multi-family residential)	1.14
Residential (mobile home)	2.0

We used the tools within HEC-FDA to integrate the structure value and depth-damage relationships. In addition, we used the tools in HEC-FDA to develop aggregated stage-damage functions for each of the impact areas.

Attachment 4. Displacement and temporary housing cost

Direct tangible costs other than property damage described in Attachment 3 are incurred during a flood. For example, displacement cost is a significant cost. This is a consequence of the time occupants are displaced due to flood damages. Our method for computing these costs is described below.

Displacement times

When flood damage to structures is relatively minor, occupants do not relocate to temporary quarters while repairs are made. However, when damages are more severe, occupants do relocate. In this context, the term "displacement" means that occupants are displaced from their buildings because flood damage is sufficiently severe that occupying buildings while repairs are made is not practical. Occupants who are displaced to temporary quarters incur a range of incremental costs, including rental costs for temporary space, other monthly costs such as furniture rental or extra commuting costs, and fixed costs that are independent of length of displacement, such as moving costs.

The threshold for displacement, the length of displacement, and the costs of displacement vary, depending on a host of factors. These include whether the buildings are residential, commercial, public, or industrial, along with many other economic and personal conditions of the occupants. For the Smith Canal closure structure, we used FEMA's method of estimating typical displacement times and costs, which is incorporated into software for benefit-cost analysis of flood mitigation projects (FEMA 2009). Typical displacement times are proportional to flood depth above the first floor and are estimated using the following algorithm:

- If flood depth is ≤ 1 ft, no displacement time.
- If flood depth is 1.0 ft, displacement for 45 days.
- If flood depth is > 1.0 ft, add 45 days of displacement for each foot above 1.0.
- Displacement times are capped at 16 ft of flood depth and 720 days for residential structures. Displacement times are capped at 450 days for flood depths of 9.0 ft or higher for non-residential structures.

Thus, for example, 3 ft of flooding in a residential structure results in a typical displacement time of 45 days for 1 ft of flooding plus 2 times 45 days, or a total of 135 days. The 720-day cap on residential displacement times means that occupants of buildings with more than 16 ft of flooding are assumed to be displaced for close to 2 years. For non-residential structures, the 450-day cap results in occupants displaced over a year with 9 or more ft of flooding.

For levee failures in the study area, a large number of occupants would be displaced. Thus, the approximate 2-year (720-day) cap is appropriate for the displacement time because the large number of damaged structures will result in longer repair times, and the number of displaced occupants will likely exceed the available rental inventory in the region. Some displaced occupants will find temporary quarters only at some distance from the study area, with increased displacement costs.

What may add to displacement time that is not captured in the FEMA algorithms is the impact of potential long duration flooding. In a levee breach scenario, flood water would pond behind the levees and require pumping or other measures to drain the flood water.

Displacement cost

The displacement cost is broken into 3 components: 1) a 1-time initial cost, 2) an additional cost per month, and 3) monthly rental costs for residential, commercial, public, and industrial structures.

For computation of displacement cost, we developed functions that relate depth of flooding to displacement cost expressed as a percentage of the structure value. By doing so, we were able to include the functions in HEC-FDA, thereby computing expected displacement cost for the without-project condition and with-project condition. The values we used for these computations are shown in Table 23.

Table 23. Displacement and temporary housing costs by structure category

Structure category (1)	1-time cost ($) (2)	Additional cost per month ($) (3)	Actual displacement rental cost per month	
			Average structure size in study area (ft^2) (4)	**Rental rate ($/$ft^2$/month) (5)**
Residential	500	500	1,776	1.44
Commercial	19,152	6,384	12,768	1.78
Industrial	16,952	8,476	33,903	0.50
Public	25,434	8,478	16,956	1.78

Typical FEMA values used for residential rental rates are \$1.44/ft^2/month. Other monthly and 1-time costs are \$500 per month and \$500, respectively (FEMA 2009).

For commercial and public buildings, rental rates are approximately \$1.78/ft^2/month. For these, other monthly costs depend on the size and type of facility. For example, a typical value is approximately \$0.50/ft^2/month. For 1-time costs, a typical value is approximately \$1.50/ft^2.

For industrial properties, typical rental rates are \$0.50/ft^2/month. For these types of buildings, other monthly costs are estimated to be \$0.25/ft^2/month, and 1-time costs are estimated to be \$0.50/ft^2.

To develop the required functions, we used the structure depth-damage functions shown in Table 11 through Table 16 as the starting point. For each depth of flooding, we used the algorithm described above to estimate the displacement time. Next, we computed the displacement cost as

(1-time cost) + [(additional monthly cost) X (displacement time)] +
[(actual displacement cost) X (displacement time)]

With this, we had a depth-displacement cost relationship. To generalize the relationship and use it in HEC-FDA, we divided the displacement cost by the average structure value in each category, as shown in Table 24. The result is a depth-displacement cost, as a percent of the structure value, which we used in the expected annual damage computations.

Table 24. Average structure value for the Smith Canal closure structure IR-benefit study area by structure category

Structure category (1)	**Average structure value ($) (2)**
Residential	121,000
Commercial	906,000
Industrial	1,654,000
Public	1,212,000

The functions used for the displacement cost calculations in HEC-FDA are shown in Table 25 through Table 29.

Table 25. Displacement cost depth-damage function for residential 1-story structures

Depth (ft) (1)	**Structure damage[1] (2)**	**Displacement time (days) (3)**	**Displacement cost ($) (4)**	**Displacement cost[1] (5)**
-2	0	0	-	0
-1	2.5	0	-	0
0	13.4	0	-	0
1	23.3	45	5,086	4.2
2	32.1	90	9,672	8.0
3	40.1	135	14,258	11.8
4	47.1	180	18,845	15.6
5	53.2	225	23,431	19.4
6	58.6	270	28,017	23.2
7	63.2	315	32,603	26.9
8	67.2	360	37,189	30.7
9	70.5	405	41,775	34.5
10	73.2	450	46,362	38.3
11	75.4	495	50,948	42.1
12	77.2	540	55,534	45.9
13	78.5	585	60,120	49.7
14	79.5	630	64,706	53.5
15	80.2	675	69,292	57.3
16	80.7	720	73,879	61.1
25	80.7	720	73,879	61.1

1. Values shown are percentage of structure value.

Table 26. Displacement cost depth-damage function for residential 2-story structures

Depth (ft) (1)	**Structure damage[1] (2)**	**Displacement time (days) (3)**	**Displacement cost ($) (4)**	**Displacement cost[1] (5)**
-2	0	0	-	0
-1	3	0	-	0
0	9.3	0	-	0
1	15.2	45	5,086	4.2
2	20.9	90	9,672	8.0
3	26.3	135	14,258	11.8
4	31.4	180	18,845	15.6
5	36.2	225	23,431	19.4
6	40.7	270	28,017	23.2
7	44.9	315	32,603	26.9
8	48.8	360	37,189	30.7
9	52.4	405	41,775	34.5
10	55.7	450	46,362	38.3
11	58.7	495	50,948	42.1
12	61.4	540	55,534	45.9
13	63.8	585	60,120	49.7
14	65.9	630	64,706	53.5
15	67.7	675	69,292	57.3
16	69.2	720	73,879	61.1
25	69.2	720	73,879	61.1

1. Values shown are percentage of structure value.

Table 27. Displacement cost depth-damage function for commercial structures

Depth (ft) (1)	**Structure damage[1] (2)**	**Displacement time (days) (3)**	**Displacement cost ($) (4)**	**Displacement cost[1] (5)**
-10.0	0	0	-	0
-3.0	0	0	-	0
-2.0	0	0	-	0
-1.0	0	0	-	0
0.0	4	0	-	0
0.5	7	0	-	0
1.0	9	45.0	62,761	6.9
1.5	11	67.5	84,566	9.3
2.0	13	90.0	106,370	11.7
2.5	16	112.5	128,175	14.1
3.0	18	135.0	149,979	16.6
3.5	20	157.5	171,784	19.0
4.0	22	180.0	193,588	21.4
4.5	25	202.5	215,393	23.8
5.0	27	225.0	237,198	26.2
5.5	29	247.5	259,002	28.6
6.0	31	270.0	280,807	31.0
6.5	33	292.5	302,611	33.4
7.0	35	315.0	324,416	35.8
7.5	37	337.5	346,220	38.2
8.0	38	360.0	368,025	40.6
8.5	44	382.5	389,829	43.0
10.0	49	450.0	455,243	50.2
25.0	49	450.0	455,243	50.2

1. Values shown are percentage of structure value.

Table 28. Displacement cost depth-damage function for industrial structures

Depth (ft) (1)	**Structure damage[1] (2)**	**Displacement time (days) (3)**	**Displacement cost ($) (4)**	**Displacement cost[1] (5)**
-10.0	0	0	-	0
-3.0	0	0	-	0
-2.0	0	0	-	0
-1.0	0	0	-	0
0.0	4	0	-	0
0.5	7	0	-	0
1.0	9	45.0	55,092	3.3
1.5	11	67.5	74,163	4.5
2.0	13	90.0	93,233	5.6
2.5	16	112.5	112,304	6.8
3.0	18	135.0	131,374	7.9
3.5	20	157.5	150,445	9.1
4.0	22	180.0	169,515	10.2
4.5	25	202.5	188,585	11.4
5.0	27	225.0	207,656	12.6
5.5	29	247.5	226,726	13.7
6.0	31	270.0	245,797	14.9
6.5	33	292.5	264,867	16.0
7.0	35	315.0	283,938	17.2
7.5	37	337.5	303,008	18.3
8.0	38	360.0	322,079	19.5
8.5	44	382.5	341,149	20.6
10.0	49	450.0	398,360	24.1
25.0	49	450.0	398,360	24.1

1. Values shown are percentage of structure value.

Table 29. Displacement cost depth-damage function for public structures

Depth (ft) (1)	**Structure damage[1] (2)**	**Displacement time (days) (3)**	**Displacement cost ($) (4)**	**Displacement cost[1] (5)**
-10.0	0	0	-	0
-3.0	0	0	-	0
-2.0	0	0	-	0
-1.0	0	0	-	0
0.0	7	0	-	0
0.5	8	0	-	0
1.0	10	45.0	83,347	6.9
1.5	12	67.5	112,304	9.3
2.0	14	90.0	141,260	11.7
2.5	20	112.5	170,217	14.0
3.0	26	135.0	199,174	16.4
3.5	27	157.5	228,130	18.8
4.0	28	180.0	257,087	21.2
4.5	28	202.5	286,043	23.6
5.0	29	225.0	315,000	26.0
5.5	35	247.5	343,957	28.4
6.0	41	270.0	372,913	30.8
6.5	42	292.5	401,870	33.2
7.0	43	315.0	430,827	35.5
7.5	43	337.5	459,783	37.9
8.0	44	360.0	488,740	40.3
8.5	44	382.5	517,696	42.7
10.0	46	450.0	604,566	49.9
13.0	49	450.0	604,566	49.9
15.0	50	450.0	604,566	49.9
25.0	50	450.0	604,566	49.9

1. Values shown are percentage of structure value.