Evaluating benefits of non-structural measures in flood risk management feasibility studies

At left: Example of a house on an open foundation
Source - Asheville, NC (undated)

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Abstract

The California Department of Water Resources (DWR) 2017 Central Valley Flood Protection Plan (CVFPP) Basin-Wide Feasibility Studies (BWFS) project team is considering non-structural measures to mitigate residual flood risk—risk that remains after structural measures are implemented. The goal of this study was to develop a systematic, repeatable, and rigorous approach for (a) assigning the appropriate non-structural measure to a given structure and (b) evaluating the benefits of that measure. This information will be used to compare alternatives and inform BWFS plan formulation. This study only focused on 1 subset of non-structural measures—those implemented for individual structures (i.e., buildings and contents): elevation, flood proofing, installation of non-structural berms, and acquisition.

KEYWORDS

Central Valley Flood Protection Plan; Basin-Wide Feasibility Studies; residual flood risk; non-structural measures; benefits

Situation: the need for non-structural flood risk reduction measures

Project context

In response to historical flooding in California and the lessons of Hurricane Katrina in 2005, and motivated by an understanding of the lives and property at risk from flooding, California enacted legislation that required the California Department of Water Resources to implement a long-term

What is at risk from flooding in the Central Valley?

- Population at risk – about 1 million
- Assets at risk – about $70 billion

Source: 2012 CVFPP

strategy to reduce flood risk throughout the state. An important planning document from that effort is the Central Valley Flood Protection Plan (CVFPP), which guides California's participation (along with federal and local agencies) in managing flood risk in the Sacramento and San Joaquin river basins.

The first version of the CVFPP was adopted by the Central Valley Flood Protection Board in 2012. The 2012 CVFPP, which is required to be updated every 5 years, proposed a State Systemwide Investment Approach (SSIA) for sustainable, integrated flood management in areas currently protected by facilities of the State Plan of Flood Control (SPFC)—essentially the Sacramento and San Joaquin basins. (The SPFC Planning Area excludes the Sacramento-San Joaquin Delta region.)

The 2012 CVFPP primarily focused on potential benefits and costs of system structural measures, such as modifications to levees and bypasses, required to meet the legislatively mandated goal of providing urban areas with protection against the p=0.005 ("200-year") flood.

However, non-structural measures were also included in the CVFPP. The 2012 CVFPP acknowledged that residual flood risk would remain after implementation of structural measures. In particular, the SSIA includes a variety of structural and non-structural measures to protect small communities in the SPFC Planning Area from a p=0.01 ("100-year") flood. It also committed the state to making investments to preserve agricultural activities within the SPFC Planning Area (DWR 2012).

What are non-structural measures?

Non-structural measures are measures that improve flood system performance and/or reduce exposure, vulnerability, and consequences of flooding by adapting to the natural floodplain or inherent features of the floodplain without changing the characteristics of the flood hazard. Examples include elevation, wet and dry floodproofing, installation of non-structural berms, acquisition, enhanced flood warning systems, land use regulations, increased use of flood insurance, and public education.

DWR is conducting Basin-Wide Feasibility Studies (BWFS) to evaluate alternative flood management system improvements, ecosystem enhancements, and regional improvements identified by regional planning efforts, consistent with the SSIA. The 2017 CVFPP Update will incorporate results from the BWFS and other planning efforts.

Figure 1. The 2017 CVFPP will promote non-structural measures in rural Central Valley communities like the one in this photo that will not receive p=0.01 ("100-year") flood protection. Such measures include those designed to protect individual structures, improve flood warning systems, and implement agricultural flood easement programs.

Motivation for this study

Prior to the start of this study, the DWR BWFS study team compiled a master list of possible non-structural measures for inclusion in BWFS alternatives. After accomplishing that, the DWR BWFS study team:

- Needed to identify a subset of non-structural measures that could be implemented for individual structures.
- Needed to develop a method for deciding which measure(s) should be applied to a given structure.
- Needed to evaluate the benefits of implementing the selected measure.
- Wanted to test the approach by applying it to 1 small study area before scaling it up to more study areas throughout the Sacramento and San Joaquin basins.

Study goal

The goal of this study was to develop an approach for:

- Selecting the appropriate non-structural measures for individual structures.
- Estimating the benefits of those non-structural measures to inform BWFS plan formulation.

Our task: Develop a method for estimating the benefits of non-structural measures for individual structures

To select and assess non-structural measures for individual structures, we:

- Identified a BWFS-specific set of non-structural measures for implementation on individual structures.
- Developed a method for assigning an appropriate non-structural measure to each individual structure.
- Developed a method for evaluating the benefits of the selected measures.
- Conducted a pilot study to test our approach.

Our starting point for identifying and assigning non-structural measures: existing DWR and USACE guidance

DWR non-structural measures master list

DWR prepared a master list of non-structural measures to be considered for the BWFS:

- Elevation: raise a structure such that its first floor is above the projected flood elevation.
- Flood-proofing: modify a structure to either keep water out (dry floodproofing) or allow water to enter with a minimum of damage (wet floodproofing).
- Non-structural berm: place a permanent mound of earth around 1 or more structures.
- Acquisition: acquire/demolish a structure and relocate its occupants out of the flood hazard zone.
- Flood warning system improvements, such as adding gages at new river forecasting sites, upgrading emergency radio hardware, and improving public information dissemination.
- Agricultural flood easement programs, under which DWR would pay growers who are growing non-permanent crops to continue growing those crops, rather than switch to higher-value permanent crops more vulnerable to potential flood damage.

DWR decision tree for assigning non-structural measures to individual structures

DWR prepared a non-structural management action decision tree (Figure 2) for use in the BWFS that specifies when non-structural measures are to be implemented for individual structures based upon land use and other criteria. For small communities (with a population less than 10,000 persons), these non-structural measures would be implemented when (a) proposed 2017 CVFPP system improvements will not provide at least p=0.01 level of protection and (b) as further determined using these additional criteria:

- Structure type
- Depth of flooding
- Frequency of flooding
- Number of stories
- Density of structures

Agricultural areas that would not receive at least p=0.04 ("25-year") level of protection from 2017 CVFPP system improvements would receive non-structural measures such as crop easements. Urban areas (with population greater than 10,000) targeted to receive at least p=0.005 level of protection from proposed 2017 CVFPP system improvements would not receive non-structural improvements for individual structures.

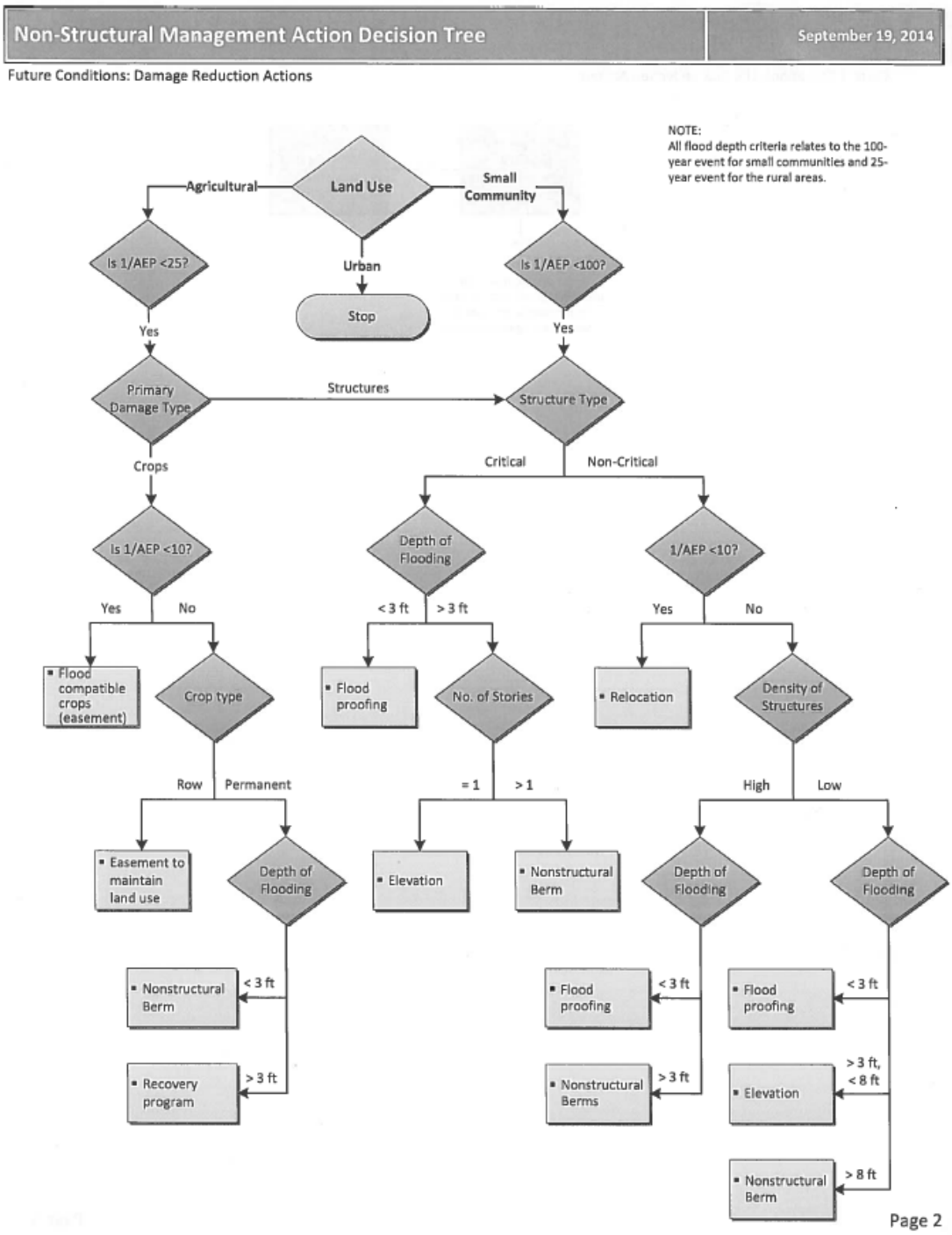
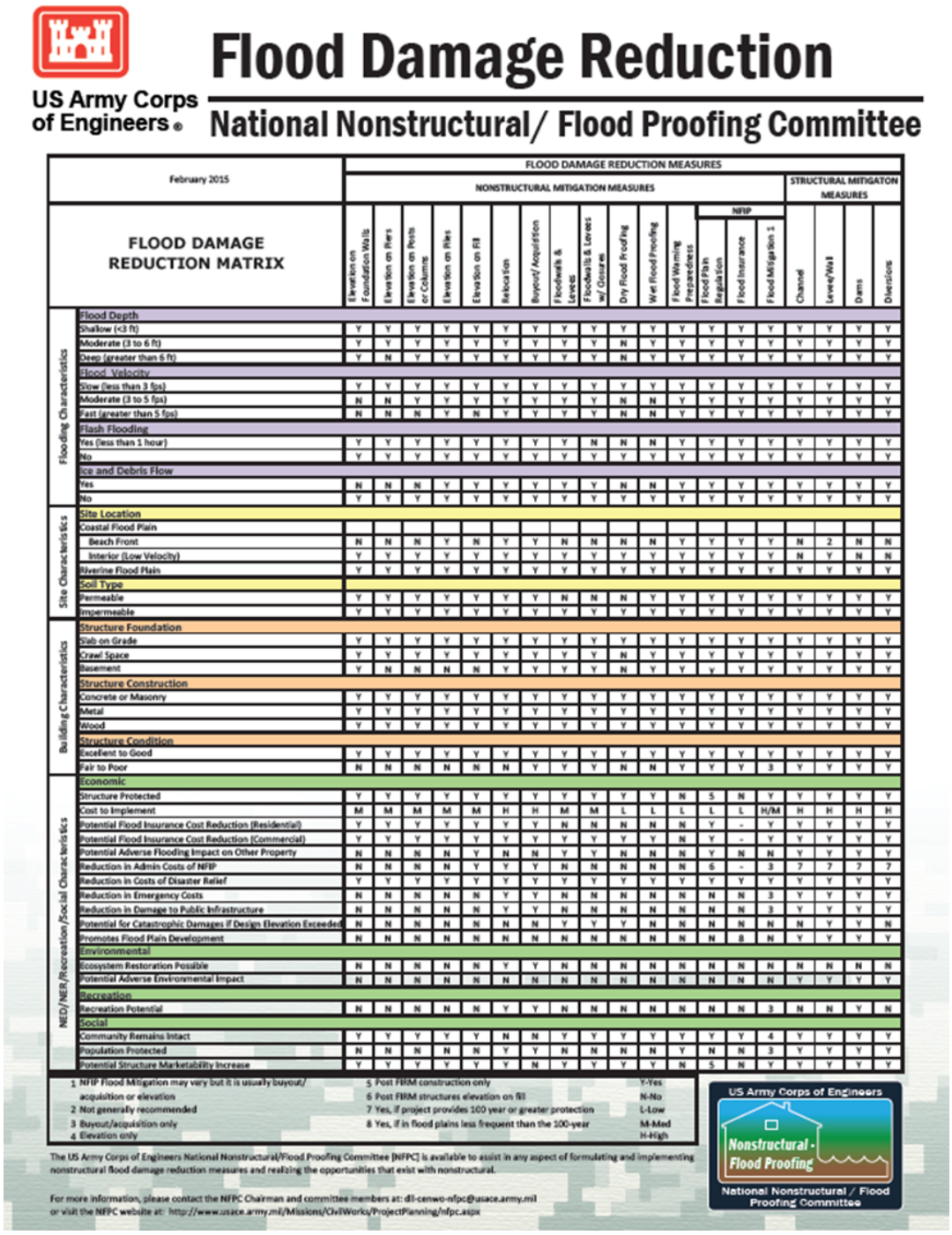


Figure 2. DWR guidance: non-structural management action decision tree

USACE Non-structural measures guidance

The US Army Corps of Engineers (USACE) has developed a comprehensive flood damage reduction matrix (USACE guidance) that specifies when non-structural and structural measures would be implemented based upon various flooding, site, building, and social characteristics (Figure 3).



US Army Corps of Engineers®

Flood Damage Reduction

National Nonstructural/ Flood Proofing Committee

February 2015

FLOOD DAMAGE REDUCTION MATRIX	FLOOD DAMAGE REDUCTION MEASURES																			
	NONSTRUCTURAL MITIGATION MEASURES															STRUCTURAL MITIGATON MEASURES			
													NFIP						
	Elevation on Foundation Walls	Elevation on Piers	Elevation on Posts or Columns	Elevation on Piles	Elevation on Fill	Relocation	Buyout/ Acquisition	Floodwalls & Levees	Floodwalls & Levees w/ Closures	Dry Flood Proofing	Wet Flood Proofing	Flood Warning Preparedness	Flood Plain Regulation	Flood Insurance	Flood Mitigation 1	Channel	Levee/Wall	Dams	Diversions
Flooding Characteristics																			
Flood Depth																			
Shallow (<3 ft)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Moderate (3 to 6 ft)	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Deep (greater than 6 ft)	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Flood Velocity																			
Slow (less than 3 fps)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Moderate (3 to 5 fps)	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Fast (greater than 5 fps)	N	N	N	Y	N	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Flash Flooding																			
Yes (less than 1 hour)	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ice and Debris Flow																			
Yes	N	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Site Characteristics																			
Site Location																			
Coastal Flood Plain																			
Beach Front	N	N	N	Y	N	Y	Y	N	N	N	N	Y	Y	Y	Y	N	2	N	N
Interior (Low Velocity)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N
Riverine Flood Plain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Soil Type																			
Permeable	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Impermeable	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Characteristics																			
Structure Foundation																			
Slab on Grade	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Crawl Space	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Basement	Y	N	N	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Structure Construction																			
Concrete or Masonry	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Metal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Wood	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Structure Condition																			
Excellent to Good	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fair to Poor	N	N	N	N	N	N	Y	Y	Y	N	N	Y	Y	Y	3	Y	Y	Y	Y
NED/NER/Recreation/Social Characteristics																			
Economic																			
Structure Protected	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	5	N	Y	Y	Y	Y	Y
Cost to Implement	M	M	M	M	M	H	H	M	M	L	L	L	L	L	H/M	H	H	H	H
Potential Flood Insurance Cost Reduction (Residential)	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	Y	-	Y	Y	Y	Y	Y
Potential Flood Insurance Cost Reduction (Commercial)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	-	Y	Y	Y	Y	Y
Potential Adverse Flooding Impact on Other Property	N	N	N	N	Y	N	N	Y	Y	N	N	N	Y	N	N	Y	Y	Y	Y
Reduction in Admin Costs of NFIP	N	N	N	N	Y	Y	Y	N	N	N	N	N	6	-	3	7	7	7	7
Reduction in Costs of Disaster Relief	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Reduction in Emergency Costs	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	3	Y	Y	Y	Y
Reduction in Damage to Public Infrastructure	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	3	Y	Y	Y	Y
Potential for Catastrophic Damages if Design Elevation Exceeded	N	N	N	N	N	N	N	Y	Y	Y	N	N	N	N	N	N	Y	Y	N
Promotes Flood Plain Development	N	N	N	N	N	N	N	N	N	N	N	N	N	8	N	Y	Y	Y	Y
Environmental																			
Ecosystem Restoration Possible	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Potential Adverse Environmental Impact	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y
Recreation																			
Recreation Potential	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N	3	N	N	Y	N
Social																			
Community Remains Intact	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	4	Y	Y	Y	Y
Population Protected	N	N	N	N	N	Y	Y	N	N	N	N	Y	N	N	3	Y	Y	Y	Y
Potential Structure Marketability Increase	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	5	N	Y	Y	Y	Y	Y

1 NFIP Flood Mitigation may vary but it is usually buyout/ acquisition or elevation
2 Not generally recommended
3 Buyout/acquisition only
4 Elevation only
5 Post FIRM construction only
6 Post FIRM structures elevation on fill
7 Yes, if project provides 100 year or greater protection
8 Yes, if in flood plains less frequent than the 100-year

Y-Yes
N-No
L-Low
M-Med
H-High

The US Army Corps of Engineers National Nonstructural/Flood Proofing Committee (NFPC) is available to assist in any aspect of formulating and implementing nonstructural flood damage reduction measures and realizing the opportunities that exist with nonstructural.

For more information, please contact the NFPC Chairman and committee members at: dl-cenwo-nfpc@usace.army.mil or visit the NFPC website at: http://www.usace.army.mil/Missions/CivilWorks/ProjectPlanning/nfpc.aspx

US Army Corps of Engineers
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Figure 3. USACE flood damage reduction matrix

Our development of a method for assigning non-structural measures to individual structures

Enhancement of DWR's non-structural measure assignment criteria

We developed a method to select non-structural measures for individual structures by using the DWR guidance as a base and adding criteria from the USACE guidance. As shown in Table 1, the criteria we chose to use in the assignment of a non-structural measure to a particular structure are:

- Depth of flooding
- Velocity of flooding
- Frequency of flooding
- Density of structures
- Number of stories
- Structure type
- Structure condition
- Soil type

Table 1. Comparison of DWR and USACE guidance and BWFS method developed by Ford Engineers. The BWFS method is based on DWR guidance and supplemented with elements from the USACE guidance. Elements used in the BWFS method are in bold italics.

Feature (1)	DWR guidance (2)	USACE guidance (3)	BWFS method (4)
Source	Non-Structural Management Action Decision Tree, September 2014	Non-structural Flood Damage Reduction Matrix, February 2015	Non-structural analysis flowchart (developed in this project)
Non-structural measures for individual structures	• Elevation • Relocation (acquisition) • Flood proofing (dry and wet) • Non-structural berm	• Elevation • Relocation • Buyout/acquisition • Flood proofing (dry and wet) • Floodwalls & levees • Flood warning preparedness • Measures related to the National Flood Insurance Program (NFIP)	Same as DWR guidance.
Criteria	• ***Depth of flooding*** • ***Frequency of flooding*** • ***Density of structures*** • ***Structure type*** • ***Number of stories***	• Depth of flooding • ***Velocity of flooding*** • Flash flooding • Ice and debris flow • Site location • ***Soil type*** • Structure foundation • Structure construction • ***Structure condition*** • Economic factors • Environmental factors • Recreation factors • Social factors	Same as DWR guidance but add the following from USACE guidance: • ***Velocity of flooding*** • ***Soil type*** • ***Structure condition***

Modification of the DWR decision tree

We modified the DWR decision tree shown in Figure 2 to include the 7 criteria listed above, and designed it for use with small communities. Because of its size, the resulting decision tree was divided into 2 decision trees: critical structures that provide services to a community which should be functional after a flood (e.g., police and fire stations, schools, government administrative offices, churches, and utilities), shown in Figure 4, and non-critical structures, shown in Figure 5. These 2 decision trees describe when specified non-structural measures for individual structures are to be implemented based on several specified criteria.

Although the selection of a non-structural measure for a specific structure usually depends upon a combination of criteria, in general:

- Flood proofing is selected when depth of flooding is less than 3 feet, velocity of flooding is less than 3 feet/second, and structure condition is good to excellent. If the soil type is permeable, wet flood proofing is to be used. If the soil type is impermeable, dry flood proofing is to be used.
- Elevation is selected when density of structures is low (less than 4 structures per acre), depth of flooding is greater than 3 feet but less than 8 feet (or depth is less than 3 feet but velocity of flooding is greater than 3 feet/second), and structure condition is good to excellent. Since we did not have detailed information regarding structure condition, we used the age of the stucture as a proxy: structures built before 1982 were assumed to be in "poor to fair" condition and after 1982 "good to excellent" condition.
- Non-structural berms are selected when depths are greater than 3 feet (or depth is less than 3 feet but velocity of flooding is greater than 3 feet/second), structure condition is poor to fair, and soil types are impermeable.
- Acquisition is selected for non-critical structures when flooding occurs more frequently than 10 years or as a "last resort" when no other measure seems applicable.

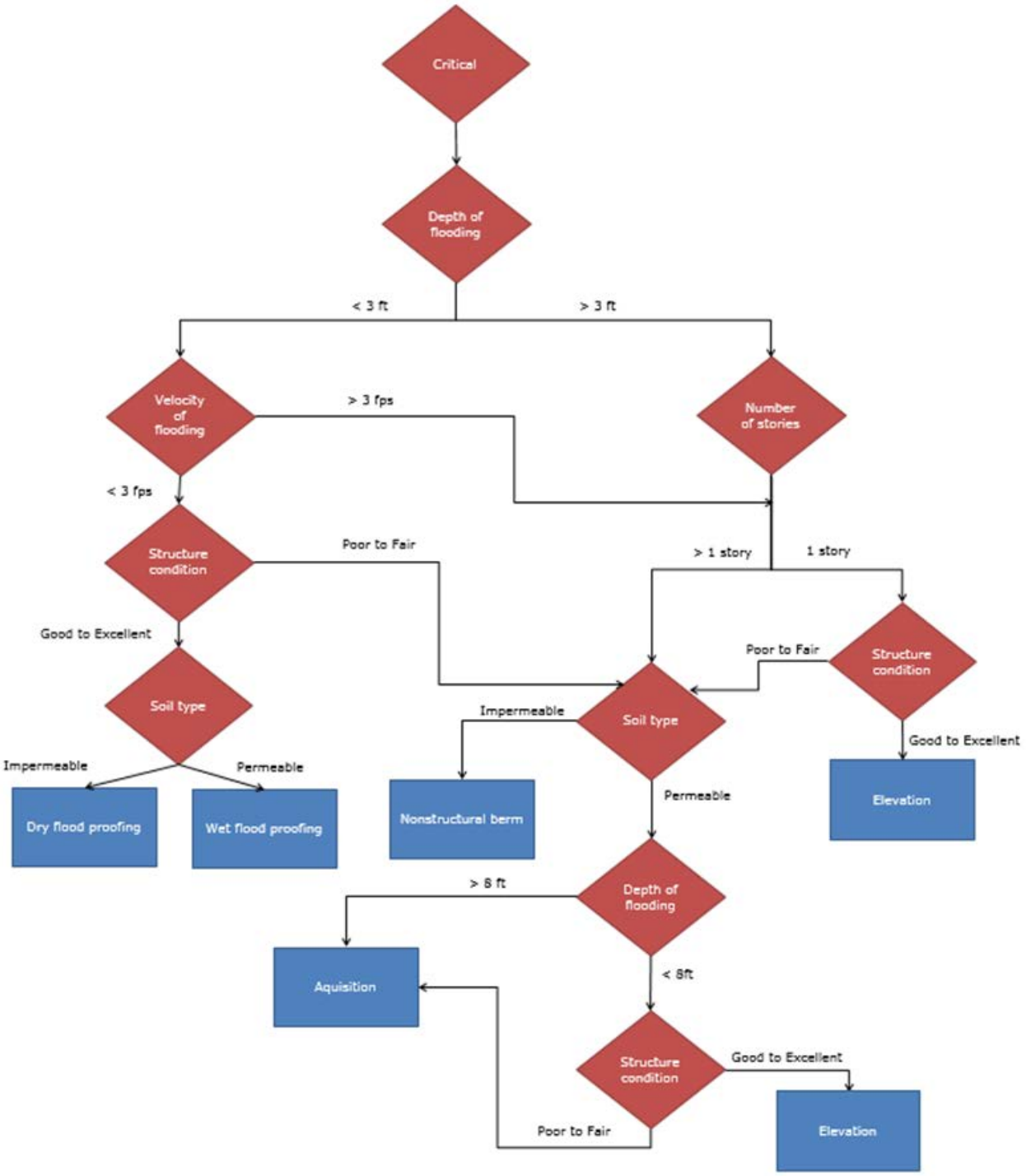

Figure 4. BWFS method: critical structures

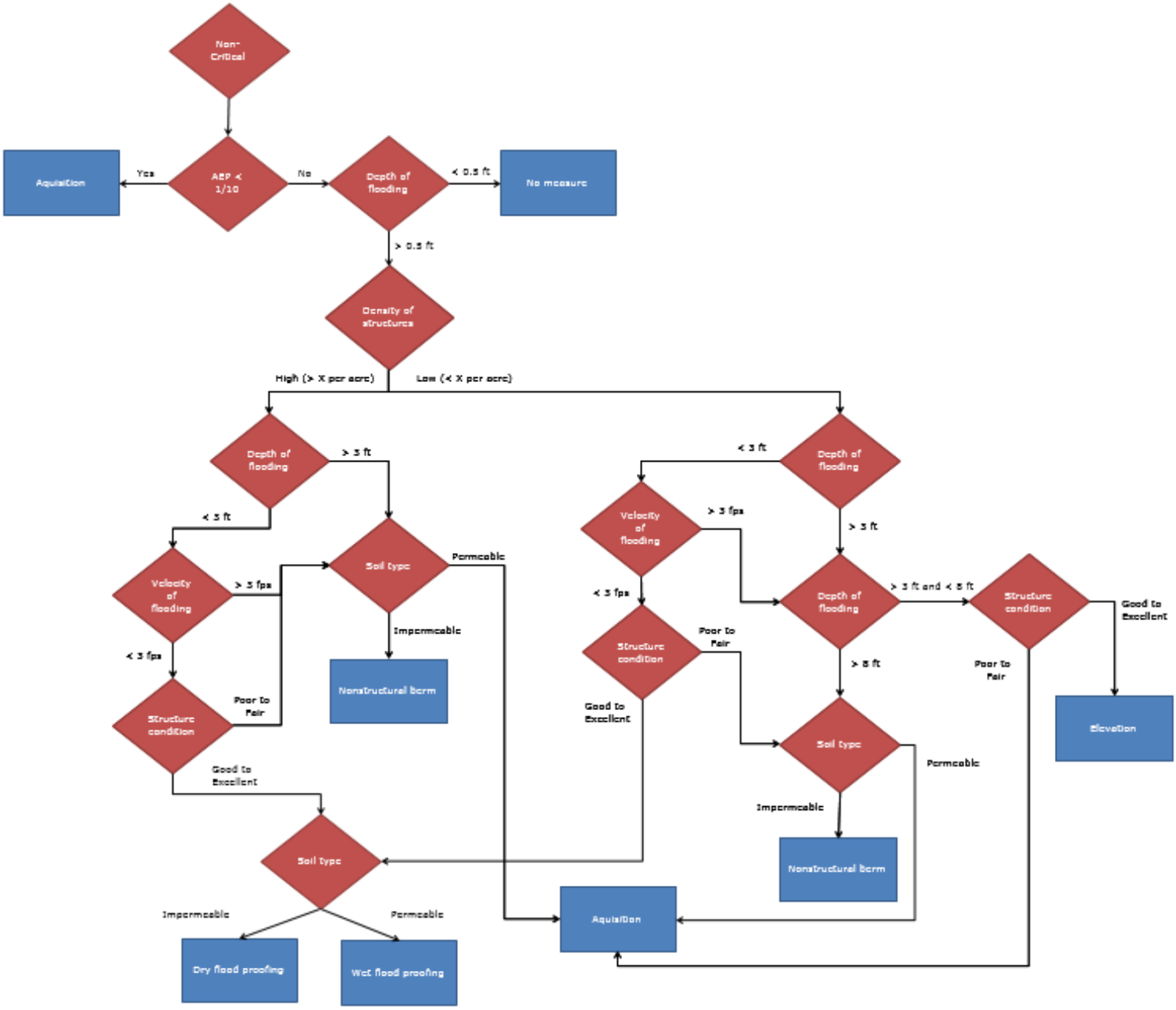

Figure 5. BWFS method: non-critical structures

Our starting point for evaluating benefits of non-structural measures: the 2012 CVFPP risk analysis methods

After a non-structural measure is assigned to an individual structure, the benefit of that measure must be evaluated. The methods developed for the 2012 CVFPP risk analyses were our starting point for determining how to do this evaluation.

Benefits defined as reductions in flood risk

Flood risk is the relationship of probability and consequences (typically adverse) for a given area with a specified climate, land use, and flood management system (existing or planned). The consequences may be expressed in terms of economic damage, loss of life, environmental impact, or other flood effect, with reduction in adverse consequence defined as a benefit attributable to an alternative.

For simplicity of comparison, the consequence-probability relationship may be summarized with statistics; the most common and useful of these statistics is the expected annual value of consequence. For example, economic risk with alternative plans can be compared using the expected value of annual damage (EAD). Actions taken as part of a flood management plan will alter the consequence-probability relationship, leading to a change in EAD. A reduction in EAD due to an alternative is a benefit.

CVFPP method for computation of benefits

DWR is computing economic and life risk for the BWFS with standard USACE methods using the USACE Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) software program (USACE 2008). Inputs to HEC-FDA describe the hazard, performance, exposure, and vulnerability, which are defined below:

- Hazard is the natural cause of the consequence. For the BWFS, hazard is described with a river stage-frequency function and a model of interior (floodplain) stage as a function of river stage, conditional on levee breach.
- Performance describes the water management system's reaction to the hazard. For the BWFS, the performance of levees that protect the floodplain is described with levee performance (fragility) functions; performance of diversions and bypasses is described with an unsteady-flow hydraulics model that assesses flow changes; and performance of reservoirs is simulated with a reservoir system model.
- Exposure describes who or what may be harmed by the flood hazard. For the BWFS, exposure is based on a structure inventory of residential, commercial, industrial, and public buildings and contents, and estimates of their depreciated replacement values.
- Vulnerability describes susceptibility to harm of people, property, and the environment exposed to the flood hazard. For the BWFS, vulnerability of structures and contents is accounted for with USACE depth-damage relationships.

Consequence is the outcome—the harm (or good) that results from the occurrence of the hazard. The components of flood risk are shown in Figure 6.

In addition to economic risk, the BWFS is also computing life risk using HEC-FDA and the inputs described above, except that the depreciated value of structures (exposure) is replaced with persons/structure estimates adjusted for flood warning times and the depth-damage relationships (vulnerability) are replaced with depth-mortality relationships (Cowdin, et. al 2015).

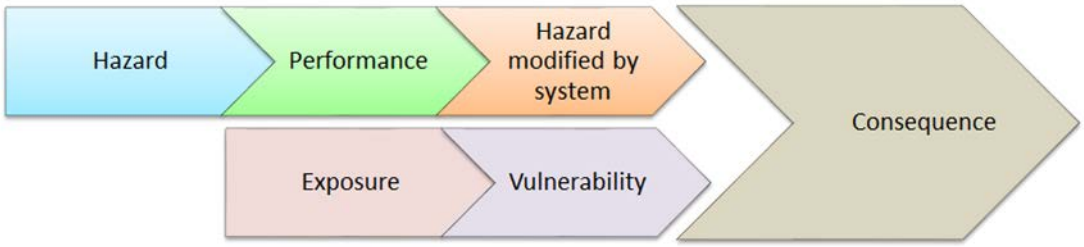

Figure 6. Conceptual illustration of the relationship among flood risk analysis components

Existing HEC-FDA models of CVFPP impact areas

Economic and life risk are computed for a defined geographic area called an impact area. An impact area is defined as a study unit in which flooding characteristics, land use, population density, or effect of a proposed measure are similar throughout (DWR 2012). HEC-FDA models previously developed for the 2012 CVFPP for 108 impact areas are being used for the BWFS, with appropriate updates to the inputs described above. These models contain inputs specific for the current and future baseline (without-project) and 4 alternative system configuration (with-project) conditions. The system configurations currently reflect proposed changes in the structural flood management facilities (for example, revised levee performance functions due to levee improvements), but not for non-structural measures. Thus, these models need further modifications to reflect implementation of the non-structural measures for individual structures (as well as other non-structural measures not described herein), as described below.

Our development of a method to evaluate benefits of non-structural measures assigned to individual structures

Modification of HEC-FDA models to reflect implementation of non-structural measures

To implement the non-structural measures for structures in HEC-FDA, we modified HEC-FDA's inputs as summarized in Table 2 for system configuration (with-project) conditions. For example, to elevate a structure, the first-floor elevation is modified to be 1 foot above the estimated p=0.01 water surface elevation. For flood proofing (wet or dry) and non-structural berms, the depth-damage functions (vulnerability) are modified to reflect no damage below the top of the flood proofing or berm (which is set at 1 foot above the p=0.01 water surface elevation), as shown in Figure 7, for selected structures.

Table 2. Summary of how HEC-FDA inputs were modified to implement non-structural measures

Non-structural measure (1)	How modeled in HEC-FDA with-project conditions (2)
Acquisition	Set structure value = 0 in structure inventory.
Elevation	Set first floor elevation to 1 ft above p=0.01 ("100-year") water surface elevation.
Flood proofing	Revised depth-damage function to have 0% damage up until 1 foot above p=0.01 ("100-year") water surface elevation. Figure 7 shows an example.
Non-structural berm	Revised depth-damage function to have 0% damage up until 1 foot above p=0.01 ("100-year") water surface elevation. Figure 7 shows an example.

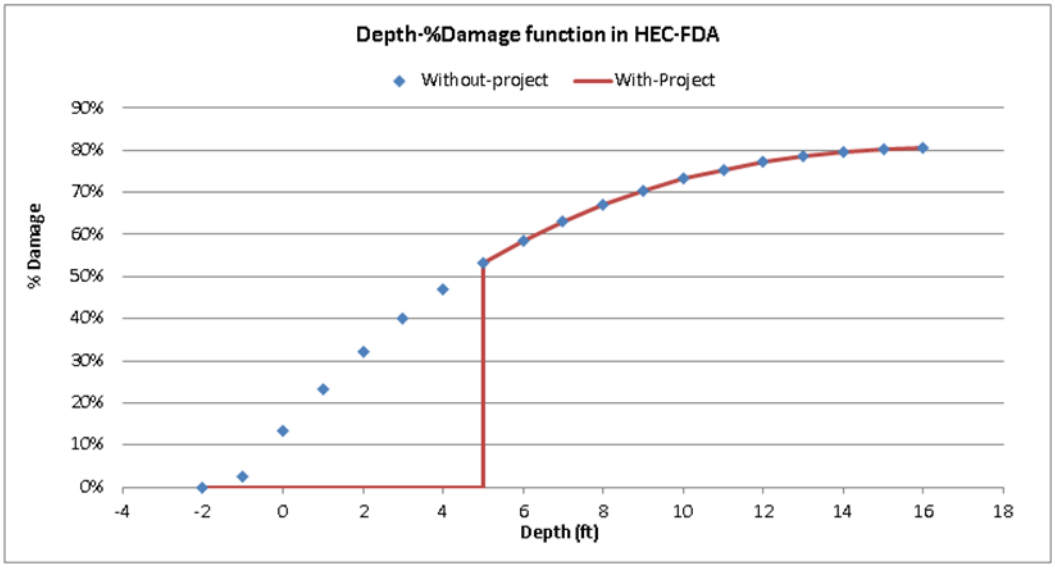

Figure 7. Modified depth-damage functions in HEC-FDA to model flood proofing or installation of a non-structural berm (with-project condition)

Computation of benefits of non-structural measures

We computed benefits for the non-structural measures by running HEC-FDA and comparing EAD for the baseline configuration without- and with-project conditions (non-structural measures only), thereby excluding the effects of structural measures attributable to the system configurations (e.g., changes in hydraulics or levee performance).

Pilot study to test our method

Before using the non-structural evaluation method described above for all 108 HEC-FDA models, we conducted a pilot study for 1 impact area to test the methods for structure selection and benefit estimation. This pilot study is described below. Any results shown for the pilot site are subject to change as methods, models, and inputs are refined.

Step 1. Identify 1 CVFPP impact area for the pilot study. The project team selected an impact area that does not have any small communities (as defined by the 2017 CVFPP) or urban areas (as defined by the *Urban Level of Protection Criteria*, DWR 2013) that would be targeted to receive p=0.01 or p=0.005 level of protection, respectively, from structural measures. However, the selected area does have a concentration of population and structures, making it a potential candidate for non-structural measures. The 2010 population of the area was about 3,567 (DWR 2013b).

Step 2. Determine floodplain boundary. This pilot study focused on structures within the p=0.01 floodplain. (The p=0.01 floodplain defined here was for planning purposes only and is not a regulatory floodplain.) To define the p=0.01 floodplain, a CVFPP FLO-2D model was used to simulate overland flow through the impact area based on levee breach hydrographs and the approximate p=0.01 water surface elevation in the channel. The p=0.01 floodplain and estimated depths are shown in Figure 8.

Step 3. Obtain CVFPP HEC-FDA model. A previously developed HEC-FDA 2012 CVFPP model for the pilot site was obtained with the required hazard, performance, exposure, and vulnerability inputs for baseline conditions, updated for the BWFS risk analyses.

Step 4. Review the pilot site HEC-FDA structure inventory with a focus on public critical structures. The structure inventory in the pilot site HEC-FDA model (which was developed from assessor parcel information) contained 2,206 structures, as shown in Table 3. For this analysis, non-structural measures were to be implemented for all types of structures. Of particular importance to DWR were critical

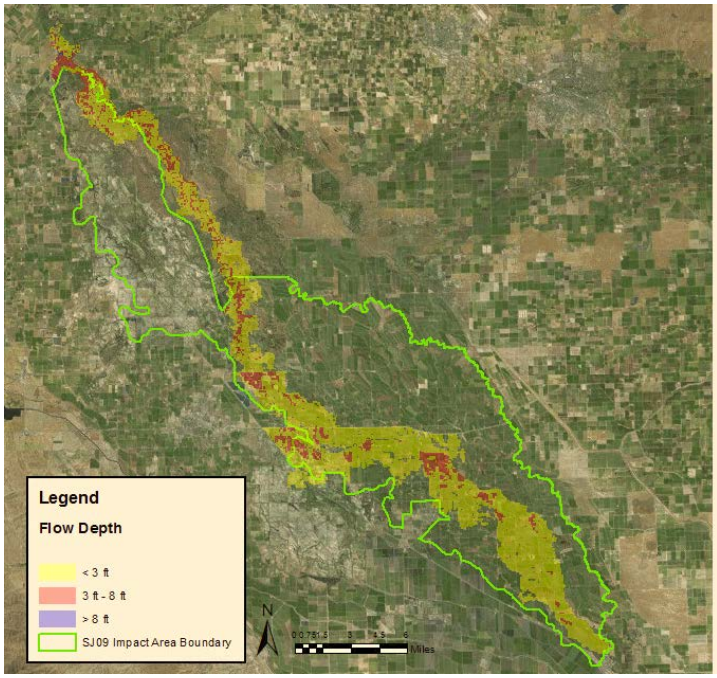

Figure 8. Composite pilot site 100-year floodplain with peak depths. Source – ESRI

facilities that provide services to a community which should be functional after a flood. These include police and fire stations, schools, government administrative offices, houses of worship, and utilities. Critical facilities are included in the public category of the structure inventory.

Table 3. HEC-FDA structure inventory for pilot site

HEC-FDA damage category (1)	Number of structures (2)
Residential	1,792
Commercial	39
Industrial	20
Public	355
Total	2,206

To identify critical facilities, a HAZUS database was used from which 1 critical facility was identified within the p=0.01 floodplain—a fire station. DWR also identified 8 critical facilities out of the 355 public structures using Google Earth, which included the 1 from the HAZUS database. Using Google Earth it was also determined that the remaining 347 public structures actually did not contain structures (i.e., buildings). Many of these were publicly owned parcels with irrigation canals and open space which were excluded from further consideration of non-structural measures.

Step 5. Assign non-structural measures to structures. The revised BWFS non-structural measure decision tree (Figure 4 and Figure 5) was used to assign 1 of the following 4 non-structural measures to individual structures in the pilot site p=0.01 floodplain:

- Elevation.
- Flood proofing (dry and wet).
- Non-structural berm.
- Acquisition.

Measures were assigned to 503 structures. Table 4 shows the number of structures assigned to each measure, based, in part, on the flood depth and velocity statistics shown in Table 5 and Table 6. Once we completed the assignments, we used Google Earth to check the assignments for appropriateness. For example, if a group of structures located close together is identified to be collectively protected by a berm but 1 structure within the group is identified to be elevated, this structure was then changed to also be protected by the berm and not elevated. Based on this review, we revised measures for 7 structures.

Table 4. Assignment of non-structural measures to structures in the HEC-FDA structure inventory

Non-structural measure (1)	Number of structures (2)
Acquisition	49
Elevation	45
Flood proofing (dry)	242
Flood proofing (wet)	30
Non-structural berm	137
Out of floodplain	1,208
No measure (shallow flooding)	148
No structure	347
Total structures	2,206

Table 5. Depths associated with structures

Depth criteria (1)	Number of structures (2)
No. of structures with depth = 0 ft	1,479
No. of structures with depth < 0.5 ft	160
No. of structures with depth > 0.5 ft and < 3 ft	481
No. of structures with depth > 3 ft and < 8 ft	85
No. of structures with depth > 8 ft	1
Total structures	2,206

Table 6. Velocities associated with structures

Velocity criteria (1)	Number of structures (2)
No. of structures with velocity = 0 ft/s	1,511
No. of structures with velocity < 3ft/s	694
No. of structures with velocity > 3ft/s	1
Total structures	2,206

Step 6. Implement the non-structural measures in HEC-FDA. To implement the non-structural measures to structures in HEC-FDA, we modified inputs as described in Table 2 for the pilot site HEC-FDA baseline with-project conditions.

Step 7. Report results. We computed EAD for the without-project (no non-structural measures implemented) and the with-project (non-structural measures implemented) conditions. The annual benefit (i.e., reduction of EAD) of implementing non-structural measures in the impact area is the difference between the without-project EAD and with-project EAD. This difference is about $61,000 (in 2014 dollars), as shown in column 4 of Table 7.

Table 7. Annual benefit of non-structural measures for pilot site baseline conditions (thousands of dollars, $2014)

Configuration (1)	Without-project (2)	With-project (3)	Benefit (4)
Baseline	71.6	10.7	60.9

The implementation of these non-structural measures could also be expected to lessen the loss of life due to flooding; however, for the 2012 CVFPP baseline life risk for the pilot site was estimated to be 0 (DWR 2012b). Thus, no additional benefit of reduced life risk could be attributed to these measures, at least for this impact area. For other impact areas, if the baseline life risk value was estimated to be greater than 0, then methods developed for the 2012 CVFPP life risk analysis could be used to estimate the life risk benefits of these non-structural measures (Cowdin, et. al 2015).

Conclusions

The approach described above provides systematic, repeatable, and rigorous methods to (a) select specified non-structural measures for inclusion in BWFS alternatives and (b) evaluate the benefits of those measures to compare plans and inform BWFS plan formulation. This approach only focused on 1 subset of non-structural measures—those implemented for individual structures (i.e., buildings and contents): elevation, flood proofing, installation of non-structural berms, and acquisition.

Individual structures were selected for implementation of specified non-structural measures based on existing DWR and USACE guidance and benefits were estimated using standard USACE risk analysis concepts and analytical methods. To complete the plan comparison, cost information for these non-structural measures would need to be developed separately by DWR.

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