Loss Avoidance Study

Northern California Flood Control Mitigation
Part One: General Overview

July 2008

FEMA

Federal Emergency Management Agency
U.S. Department of Homeland Security
500 C Street, Southwest
Washington, DC 20472

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Flood disasters have impacted and continue to impact many regions of the United States at a significant frequency and often with devastating results to the built environment. As the nation's population continues to grow and migrate to flood-prone regions, flood related losses continue to escalate. In response, mitigation actions to reduce or eliminate long-term risk to life, property, and infrastructure posed by flooding are being taken in communities around the country.

In Northern California, tens of millions of dollars have been invested in mitigation projects in an effort to reduce the region's risk to flood hazards. The projects analyzed in this study were funded as a result of Presidential Disaster Declarations between 1994 and 1998. Various post-project flooding events provided an opportunity for the projects to be evaluated and assess the project's effectiveness.

Several individuals made up the Loss Avoidance Team for this study. Rebecca Wagoner and David Kennard envisioned the need for this study following the 2006 disaster declarations in Northern California. L. Gina White led the effort to define the scope of the study, collect data, guide the analysis, and develop the report. Daniel Powell and Robert Patten provided technical expertise and were instrumental in collecting data for the analysis. Robert Patten also provided report writing, GIS, graphics design, and photography throughout the process. Shabbar Saifee provided technical support and review of the analysis. URS participated in data collection, completed the analysis and aided report development.

FEMA Region IX would like to take this opportunity to thank the State of California for their support throughout the study. Special thanks is extended to the local governments in Butte, Contra Costa, Napa, Sonoma, and Yuba counties who spent many hours assisting the Loss Avoidance Team in data collection and whose participation in the study was tireless.

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Section One:
Introduction

Following the winter storms and flooding that impacted parts of Northern California in 2006, the Federal Emergency Management Agency (FEMA) completed a loss avoidance study to quantitatively assess the performance of flood control mitigation projects and structure elevation projects within the area.

1.1 Background

FEMA's Mitigation Directorate defines mitigation as any sustained action taken to reduce or eliminate long-term risk to people and their property from hazards and their effects. Effective mitigation reduces loss of life and property, allows communities and individuals to recover more quickly from disasters, and lessens the financial impact of disasters to individuals and all levels of government. Through a variety of programs, including the Hazard Mitigation Grant Program (HMGP), Pre-Disaster Mitigation (PDM), Flood Mitigation Assistance (FMA), Severe Repetitive Loss (SRL), and Repetitive Flood Claims (RFC), FEMA provides state and local entities financial assistance to reduce or eliminate the risks posed by natural hazards.

With significant investment being made in mitigation, demonstrating cost-effectiveness is crucial for continued support. In order to evaluate the effectiveness of mitigation projects, FEMA has developed loss avoidance study methodology. This methodology is based on the analysis of actual events that have occurred in the project study area since project completion. Using this methodology, a project sponsor can assess the benefits of a mitigation project in terms of its actual performance. The methodology used in this report was first used in California for the Loss Avoidance Study for Southern California Flood Control Mitigation (Southern California study). The study is documented in *Loss Avoidance Study: Southern California Flood Control Mitigation — Part Two: Detailed Methodology*. In the Southern California study, it was concluded that implementation of the 7 flood control mitigation projects that were studied saved $7,309,402 in losses. Each project was evaluated for only 1 flood event in a 10-year period, so this value is expected to increase as storms continue to test the projects' effectiveness over their useful lives (FEMA, 2007).

The methodology has now been applied in Northern California to study the effectiveness of flood control mitigation projects. In addition, the methodology was adapted and used to evaluate structure elevations in Sonoma County. That study was detailed in a separate report.

Southern California Study
The total losses avoided for the projects analyzed were $7.3 million which yielded an average return on investment of 37%.

1.2 Purpose

The purpose of this study is to verify the effectiveness and document the economic performance of structural flood control mitigation projects in Northern California. Flood control projects, such as stormwater drainage system modifications, channel modifications, or flood walls, reduce the severity of flood damages. This study includes a quantification of the losses avoided (damage prevented or benefits) due to the implementation of the projects through analysis of storm events that occurred after the projects were completed. Losses avoided are determined by comparing damage that would likely have been caused by the same storms without the project (Mitigation Project Absent, or MP_A) with damages that actually occurred with the project in place (Mitigation Project Complete, or MP_C).

1.3 Methodology Overview

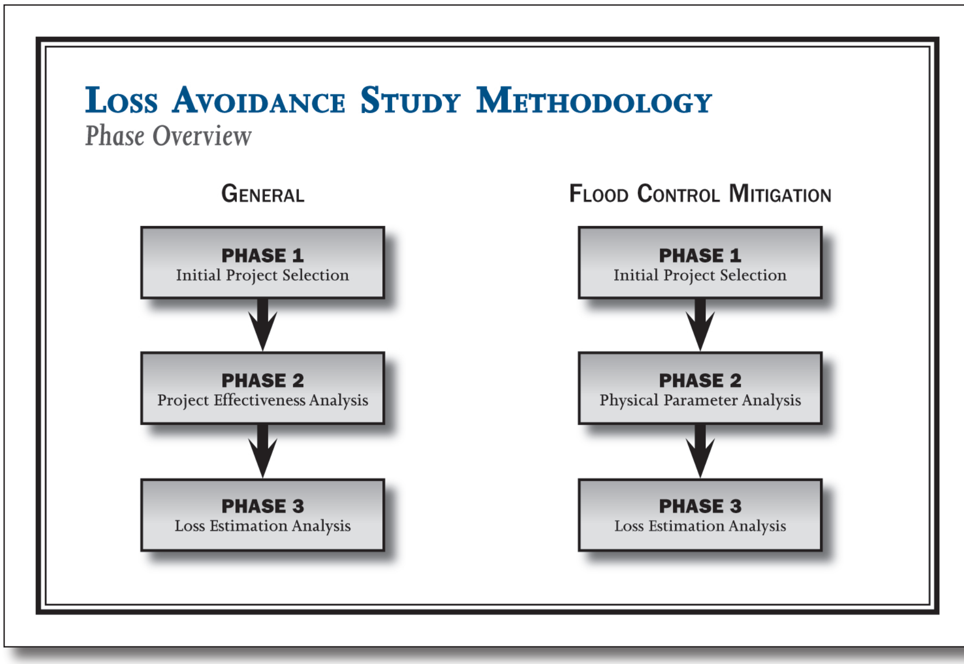
The Northern California flood control study uses the methodology that was introduced in the Southern California study. Figure 1.1 illustrates the phases of the general methodology for loss avoidance studies and the methodology specific to flood control projects. While Phase 1 and Phase 3 would be the same regardless of the type of mitigation project or type of disaster being evaluated, Phase 2 would vary depending upon the type of disaster and project. This study focuses on the methodology utilized when assessing flood control mitigation projects (FEMA, 2007).

Figure 1.2 provides a detailed illustration of the flood control mitigation project loss avoidance study methodology.

Phase 1 includes site selection and development of the initial project list. Projects are selected based on criteria determined by the sponsoring agency. The initial list of projects is screened, and projects are prioritized based on the availability of data required for completion of all phases of the analysis. Projects with adequate data advance to Phase 2 of the study.

Two distinct analyses comprise Phase 2: Storm Event Analysis and Flow Parameter Analysis. A storm event analysis is performed to determine if a post-construction precipitation event severe enough to have the potential to cause damage if the project had not been constructed (the MP_A condition) has occurred. A flow parameter analysis is performed to determine the extent, depth, and duration of flooding. Based on hydrologic, hydraulic, and topographic data, a flood boundary analysis is performed to delineate the limits of inundation that would have occurred. If the limits of inundation determined for the MP_A scenario indicate damage would have

Figure 1.1



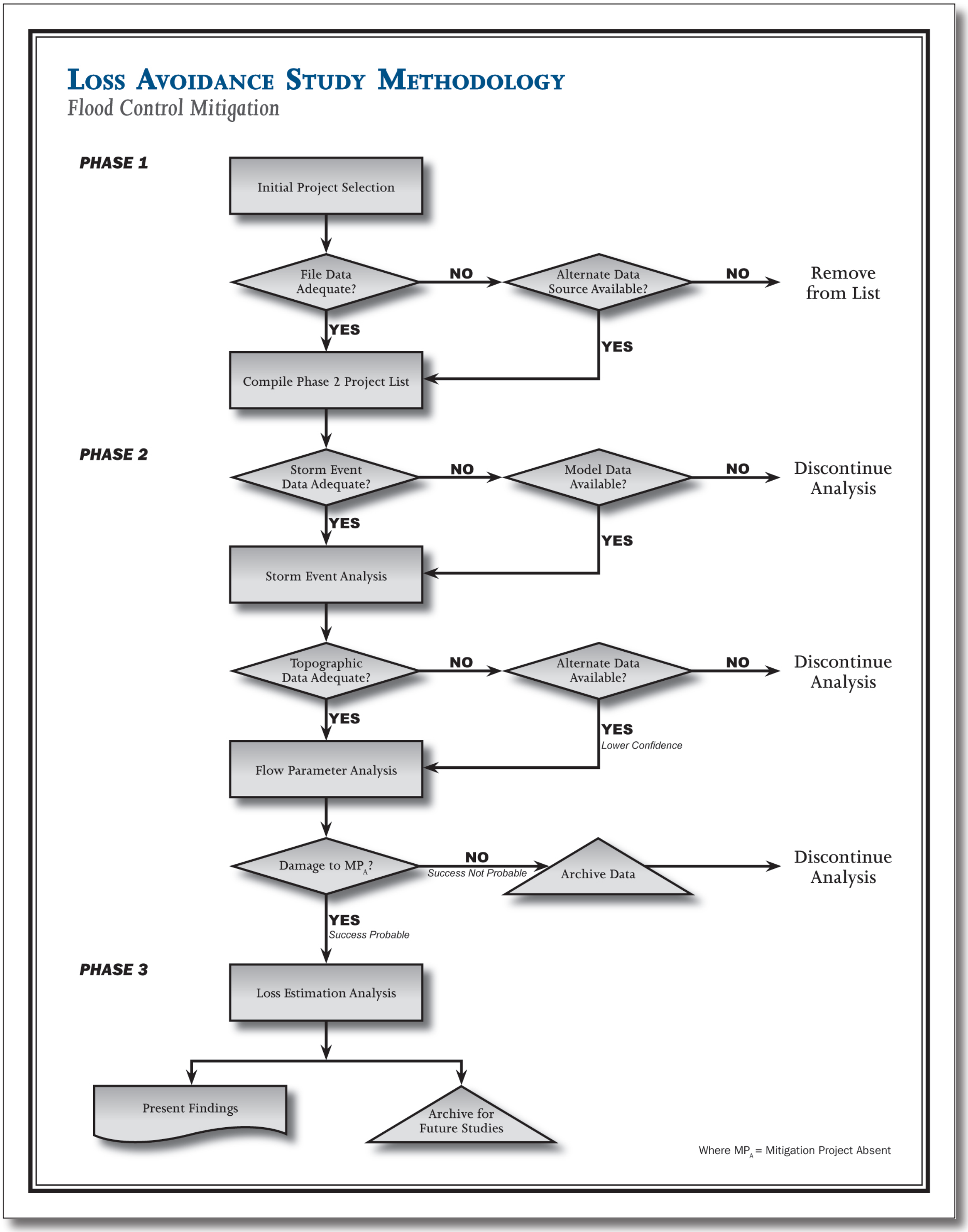
Source: FEMA, 2007

occurred if the project had not been implemented, the project advances to Phase 3 for a Loss Estimation Analysis.

Two steps comprise Phase 3. First, damages are calculated for the MP_A and MP_C conditions. Once the MP_A and MP_C damages are estimated, the difference between the two scenarios is calculated to determine the losses avoided. Second, the Return on Investment (ROI) is calculated by comparing the losses avoided to the project investment.

The three phases of the loss avoidance study and the results of the Northern California flood control study are discussed in greater detail in Sections Two, Three, and Four and in *Loss Avoidance Study: Northern California Flood Control Mitigation — Part Two: Detailed Methodology.*

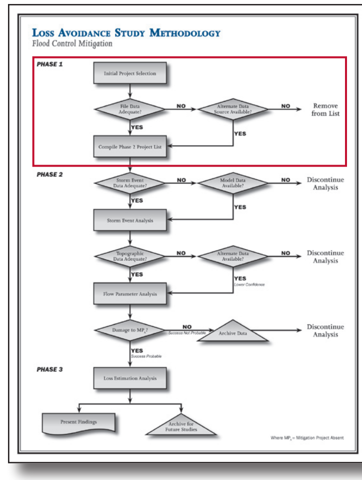
Figure 1.2



Source: FEMA, 2007

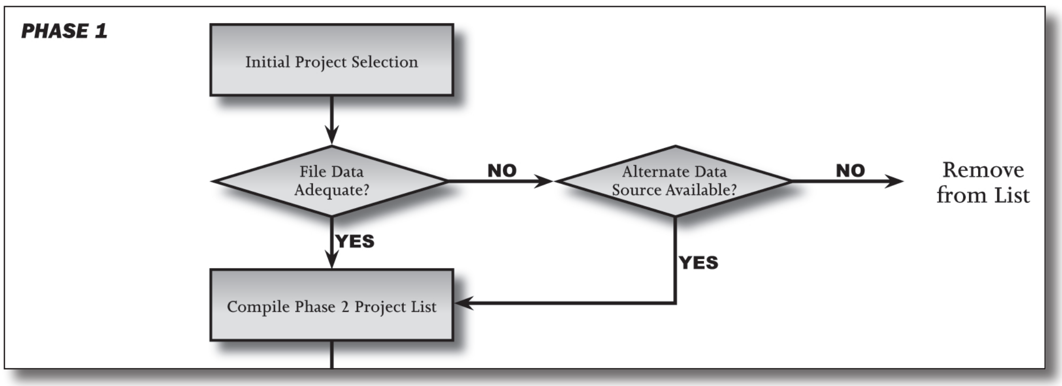
Section Two:

Phase 1 - Initial Project Selection



This section contains a discussion of Phase 1 - Initial Project Selection for any loss avoidance study, as well as details about the selection of projects for the Northern California flood control study. Figure 2.1 illustrates the process for Phase 1. As shown in Figure 2.1, an initial list of candidate mitigation projects is selected, data are collected for analysis of the projects. The projects are then screened based on the availability of the data that are required for Phase 2, and a list of projects advancing to Phase 2 is compiled.

Figure 2.1



Source: FEMA, 2007

2.1 Initial Project Selection

The Initial Project Selection is based on specific criteria defined for a particular loss avoidance study; as discussed in the Southern California study, these criteria may include but are not limited to:

- **Area of Interest** - The area of interest is the geographic boundary of a study. It can be a reach of a particular river or channel, a single community or watershed, a region such as Northern or Southern California, any jurisdictional boundary (city, county, state, special district, etc.), or any other area, but it must be defined by the agency sponsoring the loss avoidance study.
- **Hazard Type** - Projects in a loss avoidance study can be selected based on the type of hazard they are mitigating (riverine or coastal flood, seismic, wildfire, etc.).
- **Project Type** - The type of project (flood control projects, seismic retrofit of a building, vegetation maintenance for wildfire mitigation, etc.) is a parameter for a loss avoidance study.
- **Project Baseline** - Projects may be selected based on the date of completion. This may be selected as a parameter in order to include a particular storm event in the study. Older projects

have likely experienced a greater number of events and may have prevented more losses.

In loss avoidance studies, projects should be removed from the initial project list if specific, necessary data are not available, cannot be easily replicated, or if flood conditions cannot be easily modeled using acceptable methods. Each project on the initial project list should be evaluated for the data requirements of that particular study and the availability of that data.

2.2 Northern California Flood Control Study - Phase 1 Summary

FEMA Region IX and the (California) Governor's Office of Emergency Services (OES) initiated the Northern California flood control study after the severe storm events that occurred in Northern California during December 2005, January 2006, and April 2006. Presidential Disaster Declarations 1628-DR-CA and 1646-DR-CA resulted from these storms. Northern California was previously impacted by severe storms and flooding in 1995 (1044-DR-CA and 1046-DR-CA), 1997 (1155-DR-CA), and 1998 (1203-DR-CA). Officials noticed a dramatic decrease in damages during the 2005 and 2006 events when compared with the events that occurred during the late 1990s. They believed the decrease in damages in Northern California during the later events was the result of the implementation of flood control mitigation projects following the flood events of the 1990s.

FEMA Region IX and OES worked together to develop a project list for the loss avoidance study based on the following parameters:

- **Area of Interest** - The area of interest was the Northern California counties included in disaster declarations 1628-DR-CA and 1646-DR-CA.
- **Hazard Type** - The hazard type was flood or multi-hazard (including flood).
- **Project Type** - The type of project was structural flood control.
- **Project Baseline** - Projects selected must have been completed by April 2006, the most recent flood-related Presidential Disaster Declaration.

Table 2.1 lists the projects included on the initial project list, and Figure 2.2 illustrates the project locations. The initial project list included 20 projects; 2 of these projects (1044-0035 and 1046-1017) were constructed at the same location and were analyzed as 1 project in the study. The projects were located in Amador, Butte, Contra Costa, El Dorado, Lake, Mendocino, Napa, Placer, Sacramento, San Mateo, Sonoma, and Yuba Counties. The projects included in the initial project list received funding through HMGP under disasters 1008-DR-CA, 1044-DR-CA, 1046-DR-CA, 1155-DR-CA, and 1203-DR-CA.

Following the initial project list development, the Loss Avoidance Team (LAT) reviewed the HMGP project files and compiled the data. All of the data necessary for the completion of the loss avoidance study were not included in the HMGP project files. In early 2007, the LAT initiated a data collection process by contacting all selected county and city governments and lead agencies for the selected projects, and conducted initial site visits. The LAT used these sources to collect hydrologic, hydraulic, and topographic data and engineering drawings, to the extent these data were available. Data collected by the LAT were organized with the loss avoidance project files for all 20 projects.

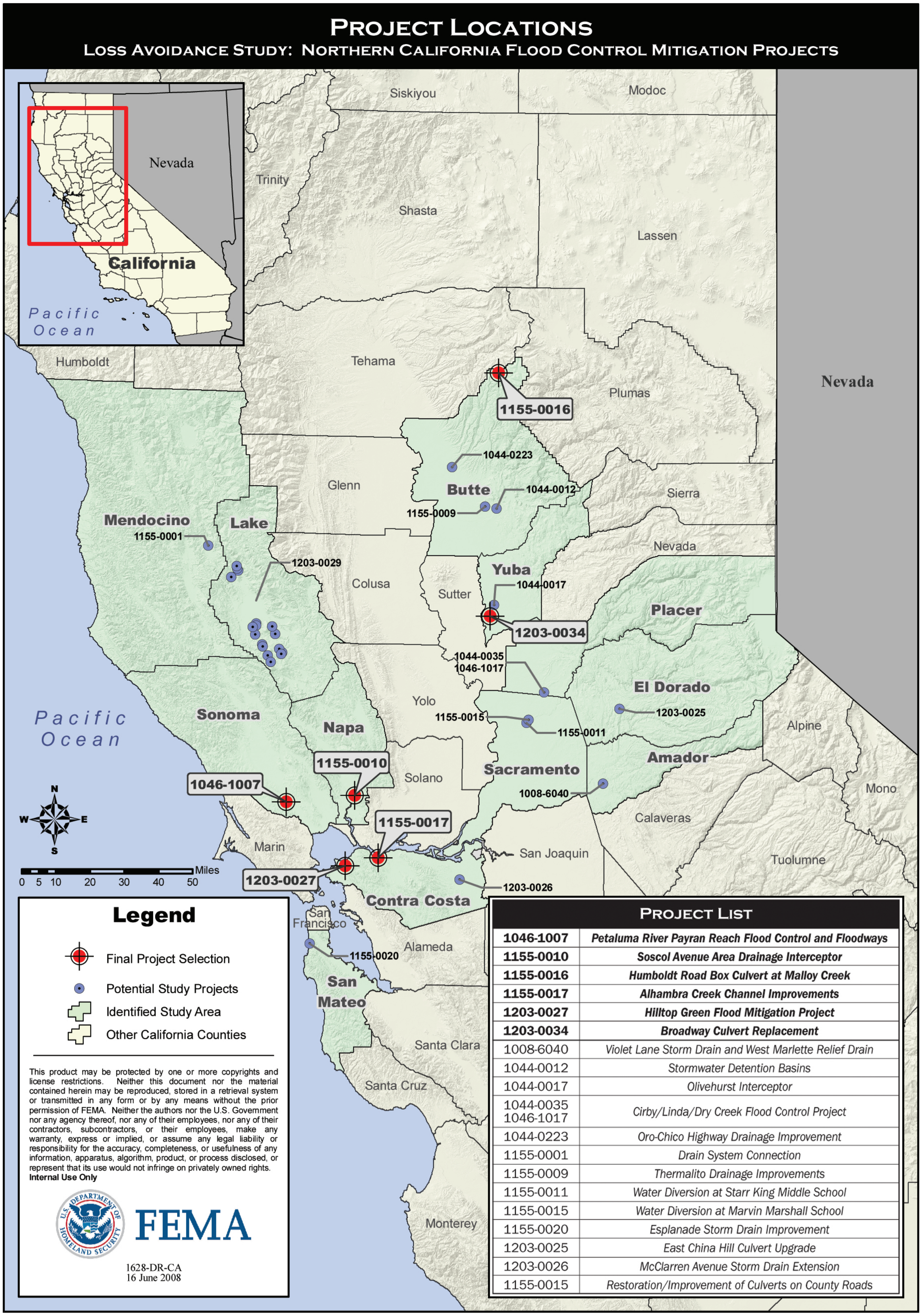
The scope of work for this loss avoidance study required the identification of six to eight projects in Northern California that could proceed through all three phases of the loss avoidance study. Figure 2.3 chronicles the progress of all 20 projects through all three phases of the Northern California flood control study.

Table 2.1

Initial Project List

County	Disaster and Project Number	Project Name
Amador	1008-6040	Violet Lane Storm Drain and West Marlette Relief Drain
Butte	1044-0012	Stormwater Detention Basins
	1044-0223	Oro-Chico Highway Drainage Improvement
	1155-0009	Thermalito Drainage Improvements
	1155-0016	Humboldt Road Box Culvert at Malloy Creek
Contra Costa	1155-0017	Alhambra Creek Channel Improvements
	1203-0026	McClarren Avenue Storm Drain Extension
	1203-0027	Hilltop Green Flood Mitigation Project
El Dorado	1203-0025	East China Hill Culvert Upgrade
Lake	1203-0029	Restoration/Improvement of Culverts on County Roads
Mendocino	1155-0001	Drain System Connection
Napa	1155-0010	Soscol Avenue Drainage Interceptor
Placer	1044-0035 1046-1017	Cirby/Linda/Dry Creek Flood Control Project
Sacramento	1155-0011	Water Diversion at Starr King Middle School
	1155-0015	Water Diversion at Marvin Marshall School
San Mateo	1155-0020	Esplanade Storm Drain Improvement
Sonoma	1046-1007	Petaluma River Payran Reach Flood Control and Floodways
Yuba	1044-0017	Olivehurst Interceptor
	1203-0034	Broadway Culvert Replacement

Figure 2.2



PROJECT LIST	
1046-1007	***Petaluma River Payran Reach Flood Control and Floodways***
1155-0010	***Soscol Avenue Area Drainage Interceptor***
1155-0016	***Humboldt Road Box Culvert at Malloy Creek***
1155-0017	***Alhambra Creek Channel Improvements***
1203-0027	***Hilltop Green Flood Mitigation Project***
1203-0034	***Broadway Culvert Replacement***
1008-6040	*Violet Lane Storm Drain and West Marlette Relief Drain*
1044-0012	*Stormwater Detention Basins*
1044-0017	*Olivehurst Interceptor*
1044-0035 1046-1017	*Cirby/Linda/Dry Creek Flood Control Project*
1044-0223	*Oro-Chico Highway Drainage Improvement*
1155-0001	*Drain System Connection*
1155-0009	*Thermalito Drainage Improvements*
1155-0011	*Water Diversion at Starr King Middle School*
1155-0015	*Water Diversion at Marvin Marshall School*
1155-0020	*Esplanade Storm Drain Improvement*
1203-0025	*East China Hill Culvert Upgrade*
1203-0026	*McClarren Avenue Storm Drain Extension*
1155-0015	*Restoration/Improvement of Culverts on County Roads*

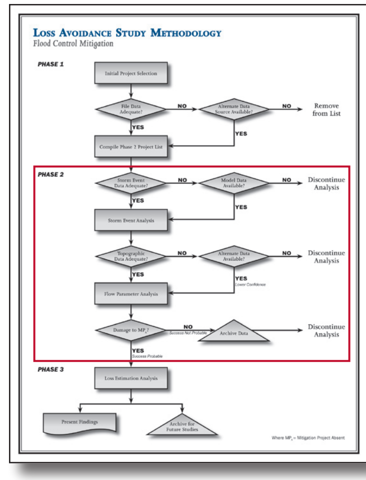
Table 2.2

Final Project Screening

County	Disaster and Project Number	Project Name	Phase 1	Phase 2				Phase 3
				Storm Event Analysis	Flow Parameter Analysis			
					Hydrologic Analysis	Hydraulic Analysis	Flood Boundary Analysis	
Amador	1008-6040	Violet Lane Storm Drain and West Marlette Relief Drain						
Butte	1044-0012	Stormwater Detention Basins						
	1044-0223	Oro-Chico Highway Drainage Improvement						
	1155-0009	Thermalito Drainage Improvements						
	1155-0016	Humboldt Road Box Culvert at Malloy Creek						
Contra Costa	1155-0017	Alhambra Creek Channel Improvements						
	1203-0026	McClarren Avenue Storm Drain Extension						
	1203-0027	Hilltop Green Flood Mitigation Project						
El Dorado	1203-0025	East China Hill Culvert Upgrade						
Lake	1203-0029	Restoration/Improvement of Culverts on County Roads						
Mendocino	1155-0001	Drain System Connection						
Napa	1155-0010	Soscol Avenue Drainage Interceptor						
Placer	1044-0035 1046-1017	Cirby/Linda/Dry Creek Flood Control Project						
Sacramento	1155-0011	Water Diversion at Starr King Middle School						
	1155-0015	Water Diversion at Marvin Marshall School						
San Mateo	1155-0020	Esplanade Storm Drain Improvement						
Sonoma	1046-1007	Petaluma River Payran Reach Flood Control and Floodways						
Yuba	1044-0017	Olivehurst Interceptor						
	1203-0034	Broadway Culvert Replacement						

Section Three

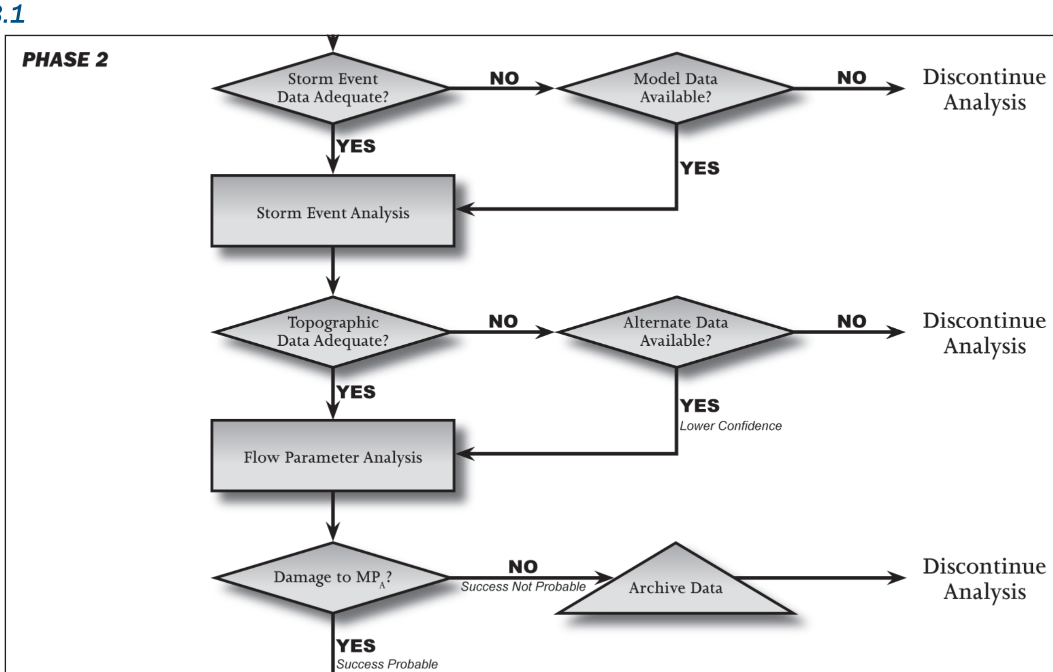
Phase 2 - Physical Parameter Analysis



This section contains a discussion of Phase 2 of the loss avoidance study methodology-the Physical Parameter Analysis. As with Phase 1, projects with inadequate data may be eliminated from the study during Phase 2. The Phase 2 analysis conducted for the Northern California flood control study followed the methodology first presented in the Southern California study (FEMA, 2007), which is illustrated in Figure 3.1. During Phase 2, the following analyses are conducted:

1. **Storm Event Analysis** - This analysis is conducted to identify storm events that could have caused damage in the MP_A scenario.
2. **Flow Parameter Analysis** - This analysis includes:
   - **Hydrologic Analysis** to determine the storm event runoff/ flow.
   - **Hydraulic Analysis** to determine how runoff moved through the project area, and what water surface elevations (WSEs) resulted from the storm event.
   - **Flood Boundary Analysis** to determine the flood inundation area, which is used to determine the flood depth at the project location.

Figure 3.1



Source: FEMA, 2007

3.1 Storm Event Analysis

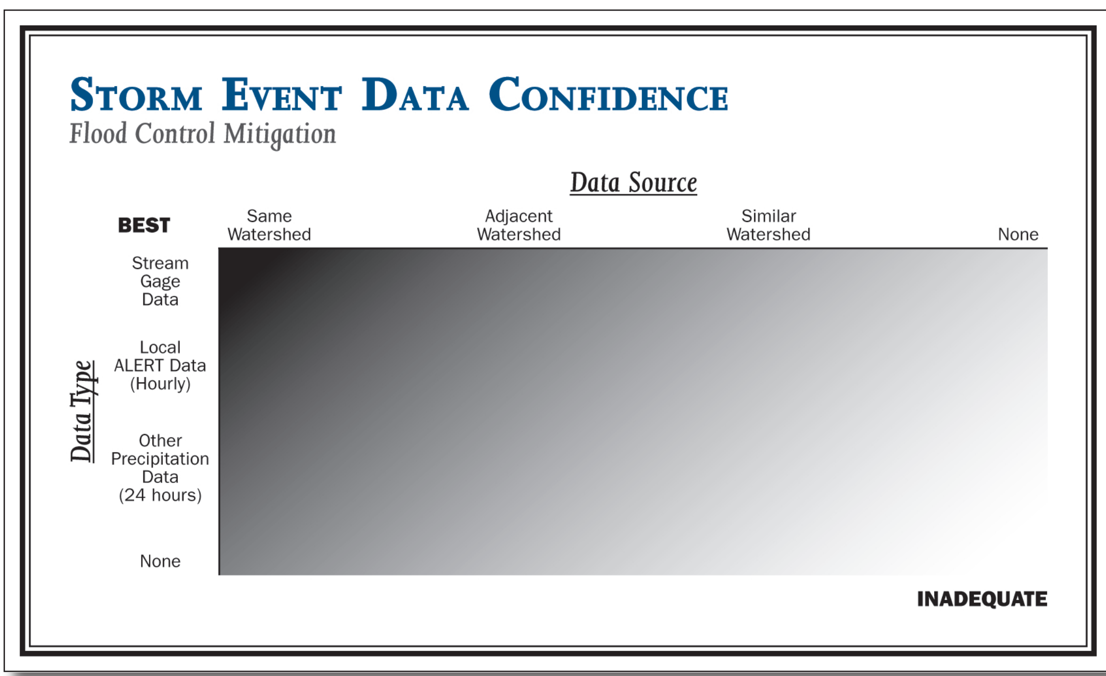
> **Storm Event Analysis Data Sources**
>
> *For loss avoidance studies, local, regional, state, and federal weather and conservation agencies are the primary source for data.*
>
> *State and Federal Agencies That Operate Gage Networks Include:*
>
> - Local or regional agencies
> - State departments of water resources
> - National Weather Service (NWS), National Climatic Data Center (NCDC)
> - U.S. Geological Survey (USGS)
> - U.S. Army Corps of Engineers (USACE)
> - U.S. Forest Service (USFS)

A loss avoidance study for any flood-related project is dependent upon the occurrence of a storm event severe enough to have caused damage in the MP_A scenario (FEMA, 2007). For some projects, more than one storm event may have occurred during the project's lifetime that could have caused damages, or did cause damages, in the project area.

Storm event data may be available in the form of stream gage data, precipitation gage data, or both. Stream gages provide flow or stage for a particular channel, whereas precipitation gages provide rainfall at a particular point. The best data for storm event analysis is stream gage data for the specific channel being studied. If a stream gage is not located on the studied channel, then a precipitation gage must be used. A precipitation gage within the watershed of the project area would be preferable; precipitation gages in adjacent watersheds can be used in a loss avoidance study but would not provide the most accurate results. This concept is illustrated in Figure 3.2.

When the storm event data are organized, the candidate events are ranked by severity. Based on the severity of the events that have occurred since project completion, a determination can be made as to the likelihood of MP_A scenario damage. If data are inadequate or no post-construction storm event with the potential to have caused MP_A damage has occurred, analysis should be discontinued for that project.

Figure 3.2



Source: FEMA, 2007

3.1.1 Northern California Flood Control Study - Storm Event Analysis

In the case of the Northern California flood control study, recent storm events at the project sites were analyzed to determine whether damage would have occurred in the study area had the project not been implemented. Projects were removed from the list if it was determined that no event was found to have been severe enough to cause damage in the MP_A scenario.

The following sources were used to collect storm event data:

- California Data Exchange Center (CDEC), maintained by the California Department of Water Resources (DWR) and the National Weather Service (NWS)
- U.S. Geological Survey (USGS), and
- Hydrology studies performed by county or city engineers.

Only a few of the projects had stream gage data for the reach of interest. The runoff for all the other project sites was estimated from precipitation data during the hydrologic analysis.

Unlike the Southern California study, during the Northern California flood control study, the storm event analysis was completed almost concurrently with Phase 1. This was due to the quality and availability of gage data in Northern California. DWR maintains an extensive database for the State of California which includes precipitation gage data, river stage data, and flow data. Gage data were readily available and were collected from the DWR CDEC Web site. The quality and availability of gage data obtained for Northern California may not be found in other areas of the United States, so it is not expected that all projects on a loss avoidance study initial project list will undergo the storm event analysis. Rather, the storm event analysis is more likely to occur after the initial project list has been screened.

One project was removed from the Phase 2 project list due to the size and complexity of the project area.

- 1203-0029 Restoration/ Improvement of Culverts on County Roads

This project involved many culverts and a project area of many square miles in Lake County. Continued analysis was not feasible.

Five projects were removed from the Phase 2 project list due to the very low likelihood of MP_C storm events causing damage in the MP_A scenario.

- 1008-6040 Violet Lane Storm Drain and West Marlette Relief Drain
- 1044-0012 Stormwater Detention Basins
- 1044-0017 Olivehurst Interceptor
- 1155-0009 Thermalito Drainage Improvements
- 1203-0025 East China Hill Culvert Upgrade

3.2 Flow Parameter Analysis

The flow parameter analysis consists of three separate analyses: a hydrologic analysis, a hydraulic analysis, and a flood boundary analysis. These three analyses help to determine how the project area was impacted by the storm events of interest identified during the storm event analysis.

3.2.1 Hydrologic Analysis

A hydrologic analysis is required when only precipitation gages are available in the study area. It uses precipitation data to estimate the amount of runoff from a given storm event for different locations in a project area. Once the amounts of precipitation from the peak events are identified from the storm event analysis, a hydrologic analysis can be performed. The resulting runoff estimate can then be used in conjunction with a hydraulic analysis to determine flood depths (FEMA, 2008).

The process of data collection is determined by the results of the storm event analysis, specifically by the type of gage data used. If stream gage data are available, they may be used to calculate peak runoff directly. If stream gage data are not available, then a hydrologic model may use precipitation data to determine peak runoff. For some projects, it may be possible to obtain existing hydrologic models. When these models are available, they can be modified to simulate the event of interest. Models should represent both the MP_A and MP_C scenarios.

The difficulty of modifying a model for a given project is highly dependent upon the model. In some cases, conducting a new hydrologic analysis may be less time consuming, even when existing models are available. If a new hydrologic analysis must be conducted, method selection should be matched to the available data and standard practices. In addition to conducting a hydrologic analysis using gage station data; regional regression equations, rational method calculations, and numerical models may be used. Information about FEMA-acceptable hydrologic models can be found on FEMA's Web site, www.fema.gov, within the National Flood Insurance Program (NFIP) flood mapping guidance (FEMA, 2003).

For studies confined to a limited reach of a single flooding source, a hydrologic analysis may only be needed for a single upstream watershed. For larger, multi-reach projects, hydrologic analyses of multiple watersheds may be required. If the required data and models are not available, or cannot be developed, then the project or event is removed from further consideration in the study (FEMA, 2008).

3.2.1.1 Northern California Flood Control Study - Hydrologic Analysis

Most of the Northern California flood control study projects did not have adequate hydrologic data. Most hydrologic data provided in the project files were hardcopy reproductions of drainage master plans and other drainage studies. For the majority of the projects, hydrologic calculations or digital input and output files of hydrologic models were not provided; therefore, many projects were eliminated at this stage of the analysis. A hydrologic analysis was conducted only for the seven projects with sufficient data.

Hydrologic Analysis Data Sources

Mitigation Project Data:

- HMGP Project Files
- FEMA Databases
- Construction Drawings and Specifications
- GIS Data (Aerial Photography and Political Boundary Mapping)

Hydrologic Modeling Data:

- HMGP Project Files
- Pre- and Post-Construction Hydrology Design and Model Reports
- Local Drainage Plans
- NOAA Design Storm Maps
- FEMA Data (FIRM, DFIRM, FIS, LOMC)
- GIS Data (Streams, Rivers, Watersheds, Land Cover, and Soils)

Six projects were removed from the Phase 2 project list due to lack of the data required to perform a hydrologic analysis.

- 1044-0223 Oro-Chico Highway Drainage Improvement
- 1155-0001 Drain System Connection
- 1155-0011 Water Diversion at Starr King Middle School
- 1155-0015 Water Diversion at Marvin Marshall School
- 1155-0020 Esplanade Storm Drain Improvement
- 1203-0026 McClarren Avenue Storm Drain Extension

3.2.2 Hydraulic Analysis

Hydraulic analyses are used to estimate WSEs at a series of cross-sections to determine how a particular project performs during the peak flow of the event(s) of interest. A hydraulic analysis is required for both the MP_A and MP_C scenarios because channel configurations and other conditions may have changed as a result of the mitigation project.

Extensive topographic data are required to represent the elevation profile in the project area. Topographic data are available from a variety of sources, such as government agencies, engineering or surveying consultants, and third-party vendors. The best topographic data available should be used to improve the accuracy of the hydraulic analysis. Data with 1- to 4-foot contour intervals are considered the best data available for the hydraulic analysis. Confidence in the data drastically decreases if the contour intervals are greater than 10 feet, as illustrated in Figure 3.3.

Hydraulic Analysis Data Sources

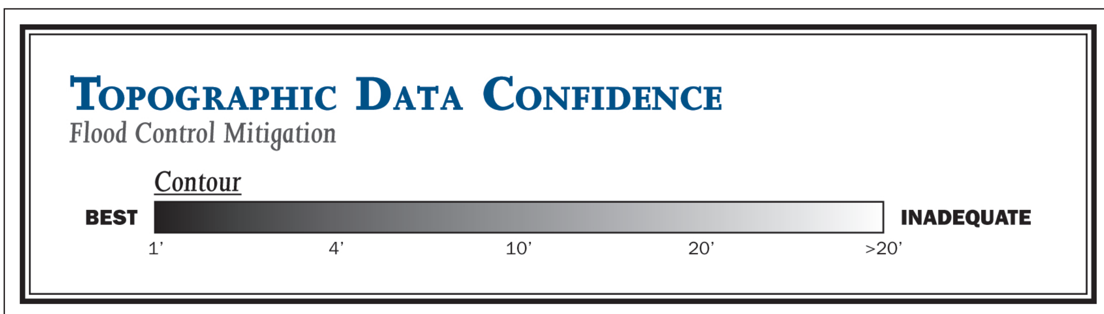
Topographic Data:

- Digital Elevation Data (Contours, LIDAR, and TIN)
- NOAA IfSAR Data
- USGS Topographic Mapping
- Paper Drawing Contours

Hydraulic Modeling Data:

- HMGP Project Files
- Pre- and Post-Construction Hydrology Design and Model Reports
- Local Drainage Plans
- NOAA Design Storm Maps
- FEMA Data (FIRM, DFIRM, FIS, LOMC)
- GIS Data (Streams, Rivers, Watersheds, Land Cover, and Soils

Figure 3.3



Source: FEMA, 2007

Most analysis methods require project cross-section elevation data. Cross-sections are commonly placed at locations along a channel where flow conditions may change (e.g., before and after a bend in the channel or a change in channel roughness, the location of a hydraulic structure such as a dam, culvert, or bridge). Other data required for successful completion of the hydraulic analysis include peak flow, boundary conditions (at the upstream and downstream extents of the study area), and model runtime settings.

For some projects, it may be possible to obtain existing hydraulic models. When these models are available, they can be modified to simulate the event of interest. In some cases, only portions of the original model may be applicable for use in the loss avoidance study. For many projects, a new hydraulic analysis is required for the MP_A and MP_C scenarios, either because an existing model is not available, specific data are not available, or the difficulties associated with modifying an existing hydraulic model are too great. If a new hydraulic analysis must be conducted, the method selected should be matched to the data available and standard practices. Additional information on FEMA acceptable hydraulic models can be found within the NFIP guidance on FEMA's Web site, www.fema.gov. If data or models are inadequate, unavailable, or unusable or the analysis indicates that the peak flow of the event of interest was not likely to have caused damage in the MP_A scenario, analysis should be discontinued for that project or event (FEMA, 2003).

3.2.2.1 Northern California Flood Control Study - Hydraulic Analysis

Hydraulic data collected for most of the Northern California flood control study projects included design drawings, as-built drawings, flood studies, and flood maps. Some projects had topographic data and numerical modeling files available for modification. Most hydraulic data provided in the project files were hardcopy reproductions of drawings, drainage master plans, and other drainage studies. Hydraulic calculations or digital input and output files of hydraulic models were not provided for most projects. The LAT obtained topographic data from local government Web sites, USGS, and third-party vendors, as appropriate. Hydraulic models were modified when available and appropriate; however, for most projects, a new hydraulic analysis was required.

One project was removed from the Phase 2 project list due to lack of a damaging event.

- 1044-0035 / 1046-1017 Cirby/Linda/Dry Creek Flood Control Project

3.2.3 Flood Boundary Analysis

The final step of Phase 2 is to delineate the floodplain and associated flood depth to determine whether there would have been impacted structures, facilities, and property during the event(s) of interest for both the MP_A and MP_C scenarios.

Some projects may have observed flood boundary data. These data may consist of aerial photographs and surveys taken during an actual flood event and may be used for the MP_C scenario to estimate losses during the actual event. These data may also be used to validate or verify the hydraulic analysis conducted in the previous step of the loss avoidance study.

Most of the data required for the flood boundary analysis are generated by the hydrologic and hydraulic analyses. The flood boundary analysis will likely require the hydraulic modeling results and existing floodplain modeling data (if available). A hydraulic analysis may only require topographic data for the channel of interest. A flood boundary analysis requires requires additional topographic data inclusive of the potential floodplain and the location and elevation data for assets within the floodplain.

Flood Boundary Analysis Data Sources

Topographic Data:

- Digital Elevation Data (Contours, LIDAR, and TIN)
- NOAA IfSAR Data
- USGS Topographic Mapping
- Paper Drawing Contours

Flood Boundary Analysis Data:

- HMGP Project Files
- FEMA Data (FIRM, DFIRM, FIS, LOMC)
- GIS Data (Streams, Rivers, Watersheds, Land Cover, and Soils)

If the data are inadequate or unavailable, analysis of that project or event should be discontinued. Likewise, candidate projects or events should be eliminated if the flood boundary analysis indicates that there would have been no out-of-bank flooding in the MP_A scenario.

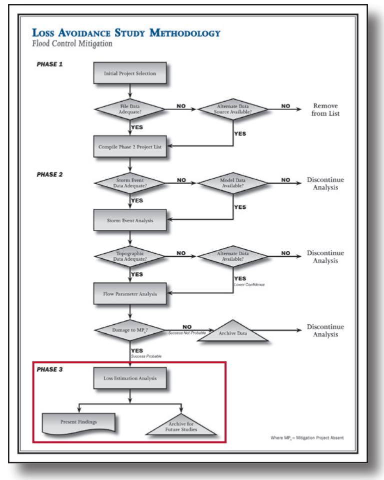
3.2.3.1 Northern California Flood Control Study - Flood Boundary Analysis

The flood boundary analyses for the six remaining projects indicated that there would have been damages for the modeled scenarios. The analysis indicated that these projects would have sustained damage in the MP_A scenario. Table 3.3 summarizes the project analysis for all six remaining projects.

Table 3.1

Project Analysis Summary

General Project Information				Phase 2 and Phase 3 Results	
Project Name	Community	County	Project Type	Phase 2 Physical Parameter Analysis	Phase 3 Loss Estimation Analysis
Petaluma River Payran Reach Flood Control and Floodways	Petaluma	Sonoma	Flood Control and Floodways	*Storm Event Analysis:* December 31, 2005, Event from California DWR and USGS data *Hydrologic Analysis:* Based on stream gage data within project reach *Hydraulic Analysis:* Modified using HEC-RAS model *Flood Boundary Analysis:* Mapping based on hydraulic model results and topographic data	*Primary Loss Categories:* Residential Structure Damage, Displacement and Disruption for Residents
Soscol Avenue Area Drainage Interceptor	Napa	Napa	Stormwater Management	*Storm Event Analysis:* December 31, 2005, Event from California DWR data *Hydrologic Analysis:* Based on precipitation gage data and Rational Method *Hydraulic Analysis:* New analysis based on topographic data and culvert calculations *Flood Boundary Analysis:* Mapping based on hydraulic model results and topographic data	*Primary Loss Categories:* Business Structure Damage, Business Interruption
Humboldt Road Box Culvert at Malloy Creek	Butte Meadows	Butte	Culvert Replacement	*Storm Event Analysis:* February 26, 2006, Event from California DWR data *Hydrologic Analysis:* Based on precipitation gage data and regional regression equation *Hydraulic Analysis:* New analysis based on topographic data and HY8 software *Flood Boundary Analysis:* Mapping based on hydraulic model results and topographic data	*Primary Loss Categories:* Road Damage, Road Closure, Emergency Management
Alhambra Creek Channel Improvements	Martinez	Contra Costa	Stormwater Management and Wetland Restoration	*Storm Event Analysis:* December 31, 2005, Event from California DWR and Contra Costa County data *Hydrologic Analysis:* Based on stream gage data within project reach *Hydraulic Analysis:* Modified using HEC-RAS model *Flood Boundary Analysis:* Mapping based on hydraulic model results and topographic data	*Primary Loss Categories:* Business Structure Damage, Emergency Management
Hilltop Green Flood Mitigation Project	Richmond	Contra Costa	Stormwater Management	*Storm Event Analysis:* December 31, 2005, Event from NOAA data *Hydrologic Analysis:* Based on precipitation gage data and Rational Method *Hydraulic Analysis:* New analysis based on topographic data *Flood Boundary Analysis:* Mapping based on hydraulic model results and topographic data	*Primary Loss Categories:* Infrastructure Damage, Emergency Management
Broadway Culvert Replacement	Olivehurst	Yuba	Culvert Replacement	*Storm Event Analysis:* December 31, 2005, Event from California DWR data *Hydrologic Analysis:* Based on precipitation gage data and regression equation *Hydraulic Analysis:* New analysis based on topographic data and HY8 software *Flood Boundary Analysis:* Mapping based on hydraulic model results and topographic data	*Primary Loss Categories:* Residential Structure Damage, Displacement and Disruption for Residents



Section Four:

Phase 3 - Loss Estimation Analysis

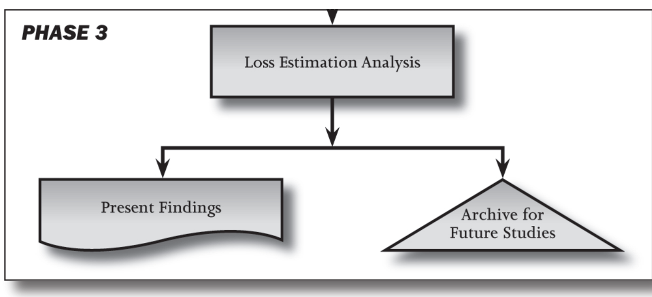
Phase 3 - Loss Estimation Analysis, the final phase of a loss avoidance study, is conducted to estimate the avoided losses based on the effectiveness of the mitigation project during the actual storm event(s) of interest. The Loss Estimation Analysis is accomplished by calculating the damage (in dollars) associated with the flood depths calculated in Phase 2. This section summarizes the process for Phase 3. It also provides details about the analysis specific to the Northern California flood control study.

Phase 3 includes two major tasks:

1. **Calculating losses avoided**
2. **Calculating a return on investment**

Phase 3 culminates in the presentation of the findings of the study. The data collected and analyses performed are also archived, so they can be used in the future. This concept is illustrated in Figure 4.1.

Figure 4.1



Source: FEMA, 2007

4.1 Calculating Losses Avoided

For Phase 3, the dollar value estimate of the damage that would have occurred had the mitigation project not been built (MP_A) and the damages that did occur after construction of the project (MP_C) must be determined.

During Phase 2, the following information must be determined for each project advancing to the Loss Estimation Analysis:

- The post-construction storm event(s) that either caused damages or would have caused damage in either the MP_C and MP_A scenarios respectively.
- The number and type of assets impacted by the storm event(s) being analyzed in both the MP_A and MP_C scenarios.

- The flood depth at each impacted asset, estimated from the flood boundary analyses.

The result of Phase 2 is a list of impacted assets and the depth of the flooding at each asset. Based on these depths, the losses/damages can be calculated for both the MP_A and MP_C scenarios. The losses avoided (in dollars) are calculated by subtracting the MP_C scenario damages from the MP_A scenario damages. Figure 4.2 illustrates the formula used to calculate losses avoided.

Figure 4.2

LOSS ESTIMATION ANALYSIS

$$MP_A - MP_C = LA$$

Where $\mathbf{MP_A}$ = Mitigation Project Absent
Where $\mathbf{MP_C}$ = Mitigation Project Completed
Where **LA** = Losses Avoided

Source: FEMA, 2007

When calculating losses, it is important to note that all of the losses should be calculated in present-day values. If historical losses are used as estimates, they should be adjusted to present-day values. Other values used in the calculations, such as the value of the structures and the project costs, should also be based on present-day values.

4.1.1 Loss Categories

After the flood boundary analysis has been completed and the impacted assets identified, the affected area must be evaluated for potential losses. Table 4.1 lists the loss categories for potential damages. Loss categories generally include physical damage, loss of function, and emergency management costs, each have multiple loss types.

4.1.1.1 Physical Damage

Physical damage includes impacts to structures (residential, commercial, industrial, and municipal); the contents and landscaping of those structures; roads, bridges, and infrastructure; the environment; and vehicles and equipment. The types of physical damage resulting from a given flood event will vary based on the land uses in the project area. When available, actual repair costs (or replacement costs if the structure was substantially damaged) should

Table 4.1

LOSS ESTIMATION CATEGORIES AND TYPES	
Loss Category	**Loss Types**
Physical Damage	Structure Contents Roads and Bridges Infrastructure Landscaping Environmental Impacts Vehicles/Equipment
Loss of Function	Displacement Expense Loss of Rental Income Loss of Business Income Lost Wages Disruption Time for Residents Loss of Public Services Economic Impact of Utility Loss Economic Impact of Road/Bridge Closure
Emergency Management	Debris Cleanup Governmental Expense

Source: FEMA, 2007

be used to estimate losses, if similar flood events have occurred in the past. Historical damage data may be obtained from building owners, homeowners' insurance claims, flood insurance claims, the NFIP's BureauNet database, Small Business Administration loan application databases, local contractors, and homeowner interviews. The Benefit-Cost Analysis (BCA) that was performed for the funding application of the mitigation project may also contain historical damage data. Additionally, for events in which there was a disaster declaration, FEMA may have provided grant funds under the Public Assistance (PA) Program for repairs to buildings owned by public entities and certain private non-profit organizations. Damage and repair information may be obtained from Project Worksheets (PWs) that FEMA prepared to document eligible costs under the PA Program. If this information is not available, then the losses must be estimated (FEMA, 2008).

Physical Damage Data Sources

- Depth-damage curves obtained from HAZUS-MH or USACE
- Insurance information
- HMGP or FMA project files and BCAs
- Public assistance program project worksheets for permanent repair work
- Historical flood damage information

4.1.1.2 Loss of Function

According to *What Is a Benefit?*, loss of function impacts are "the losses, costs and direct economic impacts that occur when physical damages are severe enough to interrupt the function of a building or other facility" (FEMA, 2001). Loss of function can vary significantly depending upon the building or facility damaged. For example,

Loss of Function Data Sources

- Factors used in HAZUS-MH for loss of function calculations
- FEMA BCA loss of function calculations
- Highway mapping and traffic counts
- Utility and infrastructure use information
- Historical flood damage information

flooding of a residential structure would prompt the owners to move to (displace to) another residence while floodwaters recede and repairs are made (displacement time), as well as cause disruption to the lives of those affected (disruption time). Loss of function related to flooding of a business or commercial facility could include lost business income, temporary relocation to another structure, and lost wages. There are also economic impacts caused by the loss of public services and infrastructure.

Typically, methods for estimating loss of function involve calculating a time delay based on the percentage of damage to an asset, then calculating costs for this delay of function. More information can be obtained from *What Is a Benefit?*, the *Hazards-U.S. - Multihazard (HAZUS-MH) Technical Manual*, the U.S. Army Corps of Engineers (USACE), local agencies, and special districts.

4.1.1.3 Emergency Management

Emergency Management Data Sources

- Public assistance program project worksheets for emergency work
- Interviews with local public safety officials
- Historical flood damage information

Emergency management costs are those costs related to response and recovery activities conducted by government agencies as a result of a hazard event. These costs should be included in a loss avoidance study when they are known or can be estimated (FEMA, 2007).

If a flood control mitigation project under evaluation significantly reduces these emergency management costs, then the benefits of reduced emergency management costs should be counted. Many mitigation projects affect a small area, or are associated with single structures or a few scattered structures. There may be little difference between MP_A and MP_C emergency management costs.

When actual emergency management costs are known they should be used. These values are primarily obtained from historic damage records, such as PWs. They may also come from interviews with local emergency managers.

4.1.2 Northern California Flood Control Study - Calculating Losses Avoided

Each of the six projects analyzed in Phase 3 exhibited MP_A damages. Damages varied by project, but most projects evaluated would have sustained physical damage to structures, contents, and roadways, loss of function impacts, and emergency management costs. Two projects also sustained damages in the MP_C scenario due to the event of interest exceeding the MP_C capacity, or level of protection of the project. As expected, the MP_C damages for these two projects were much less than the MP_A scenario damages. The remaining four project sites did not experience a storm event that exceeded the MP_C damage threshold and did not sustain MP_C damages.

Table 4.2 displays the results of the Loss Estimation Analysis for all six projects. All damage estimates have been converted to 2008 dollars. At $44,170.317, the Petaluma River Payran Reach Flood Control and Floodways Project exhibited the greatest amount of losses avoided. The Humboldt Road Box Culvert at Malloy Creek Project exhibited the least amount of losses avoided at $67,924. The Petaluma River project exhibited such high losses avoided because the mitigation project protected nearly 600 flood-prone structures, whereas the Humboldt Road project did not protect any structures, it prevented the loss of function for 1 roadway. Physical damage was the most significant damage type for all projects in this study, representing over 80 percent of the total losses avoided.

4.2 Calculating Return On Investment

The final task in a loss avoidance study is to calculate the ROI. The methodology and results may vary depending upon the number of events being analyzed for each mitigation project and the level of damage sustained during each event. Figure 4.3 illustrates the general formula utilized in calculating the ROI.

Figure 4.3

Return on Mitigation Investment

$$\frac{\$\,LA}{\$\,PI} = \%\,ROI$$

Where **LA** = Losses Avoided
Where **PI** = Project Investment
Where **ROI** = Return on Investment

Source: FEMA, 2007

The numerator (LA) represents the total losses avoided for the mitigation project being evaluated. If the loss avoidance study is evaluating one event of interest, then the losses avoided and resulting ROI would represent one discrete event. If multiple events are being evaluated for each mitigation project, then the LA would represent the total losses avoided for all the storm events evaluated. Therefore, the ROI would represent the cumulative return on investment over several storm events.

The denominator (PI) represents the total project investment for the mitigation project being evaluated. The PI does not represent the federal investment alone, but rather the resource investment from all parties involved. The amount should represent the costs of

Table 4.2

Loss Estimation Analysis Results

General Project Information				Results by Loss Category						Losses Avoided Total
				MP_A Scenario Damages			MP_C Scenario Damages			
Project Name	Community	County	Project Type	Physical Damage Subtotal	Loss of Function Subtotal	Emergency Management Subtotal	Physical Damage Subtotal	Loss of Function Subtotal	Emergency Management Subtotal	
Petaluma River Payran Reach Flood Control and Floodways	Petaluma	Sonoma	Flood control and floodways	$38,171,451	$7,625,919	$175,261	$1,466,997	$306,111	$29,206	**$44,170,317**
Soscol Avenue Area Drainage Interceptor	Napa	Napa	Stormwater management	$1,060,411	$324,151	$13,570	$766,354	$230,060	$1,357	**$400,361**
Humboldt Road Box Culvert at Malloy Creek	Butte Meadows	Butte	Culvert replacement	$9,428	$50,762	$7,734	$0	$0	$0	**$67,924**
Alhambra Creek Channel Improvements	Martinez	Contra Costa	Stormwater management, wetland restoration	$280,104	$19,354	$170,586	$0	$0	$0	**$470,044**
Hilltop Green Flood Mitigation Project	Richmond	Contra Costa	Stormwater management	$132,891	$1,452	$58,366	$0	$0	$0	**$192,709**
Broadway Culvert Replacement	Olivehurst	Yuba	Culvert Replacement	$1,328,497	$233,289	$42,063	$0	$0	$0	**$1,603,849**
			Total	**$40,982,782**	**$8,254,927**	**$467,580**	**$2,233,351**	**$536,171**	**$30,563**	**$46,905,204**

All amounts rounded to the nearest dollar.

the project components being evaluated in the loss avoidance study, and should not include work conducted outside of the mitigation project scope of work. Additionally, the PI should be converted to present-day values for the ROI calculations.

4.2.1 Northern California Flood Control Study - Calculating Return on Investment

Table 4.3 displays a comparison of the losses avoided to the project investment for each project which was determined using the project files. The actual project investment may have come from several sources. The amount displayed in Table 4.3 reflects the combined investment from all sources.

For the 6 projects, ROI ranged from 26 percent to 1,154 percent. The ROI for each project reflects the losses avoided for one event of interest; therefore, the ROIs presented are expected to increase as additional storm events test the projects' effectiveness over their useful lives. For this study, an ROI of 100 percent or greater would indicate the project investment was fully recovered during the 1 event of interest.

The ROIs for each project should not be compared relative to one another; a project with a greater ROI is not necessarily more effective than a project with a lesser ROI. The ROI is a function of the losses avoided and the project investment. Projects are designed to meet specific needs. A relatively inexpensive project that protected a large number of assets, such as the Broadway Culvert Replacement project, would be expected to yield a greater ROI. The Broadway Culvert Replacement project included the replacement of an undersized (i.e., low MP_A capacity) culvert designed to alleviate flooding of a residential neighborhood with 40 structures. Losses avoided for this project were over $1.6 million, whereas the project cost was approximately $139,000. The Humboldt Road Box Culvert at Malloy Creek project was intended to prevent the loss of function for only one road. The losses avoided were nearly $68,000, and the project investment was approximately $257,000. Even though the ROI for the latter project was significantly less than the ROI for the former project, it should be considered no less effective.

The aggregate ROI for the 6 projects analyzed for the Northern California flood control study was 98 percent, using the combined losses avoided of $46,905,204 and a combined project investment of $48,028,996. This ROI only reflects the losses avoided for one event of interest for each project and will increase as additional storm events test each project's effectiveness.

Table 4.3

Return on Mitigation Investment

General Project Information			Results by Loss Category			Losses Avoided Total	Project Investment Adjusted for 2008 Dollars	Current ROI
Project Name	County	Date of Project Completion	Physical Damage Subtotal	Loss of Function Subtotal	Emergency Management Subtotal			
Petaluma River Payran Reach Flood Control and Floodways	Sonoma	**2004**	$36,704,454	$7,319,808	$146,055	**$44,170,317**	**$44,907,802**	**98.36%**
Soscol Avenue Area Drainage Interceptor	Napa	**10/28/1998**	$294,057	$94,091	$12,213	**$400,361**	**$766,914**	**52.20%**
Humboldt Road Box Culvert at Malloy Creek	Butte	**10/14/1998**	$9,428	$50,762	$7,734	**$67,924**	**$257,106**	**26.42%**
Alhambra Creek Channel Improvements	Contra Costa	**07/06/2001**	$280,104	$19,354	$170,586	**$470,044**	**$1,709,693**	**27.49%**
Hilltop Green Flood Mitigation Project	Contra Costa	**07/03/1999**	$132,891	$1,452	$58,366	**$192,709**	**$248,520**	**77.54%**
Broadway Culvert Replacement	Yuba	**09/29/1998**	$1,328,497	$233,289	$42,063	**$1,603,849**	**$138,961**	**1,154.17%**
		Total	**$38,749,431**	**$7,718,756**	**$437,017**	**$46,905,204**	**$48,028,996**	**97.66%**

All amounts rounded to the nearest dollar.

Section Five

Considerations and Recommended Practices

This section contains a summary of the special considerations and recommended practices of this study. Many of the considerations and recommended practices of the Southern California study are also contained in this report. The intent of providing this information is so that it may be used in future loss avoidance studies. The information is divided into two categories: 1.) data collection and availability and 2.) analysis methodology.

5.1 Data Collection and Availability

Multiple types of data are collected throughout a loss avoidance study. The availability and quality of the data can affect the accuracy of the study significantly. Sections 5.1.1 and 5.1.2 describe the data-related challenges that were encountered in the Northern California flood control study and provide recommendations for data collection in future loss avoidance studies.

5.1.1 Availability of Topographic Data

Obtaining digital topographic data of sufficiently quality was a significant challenge in this study. Topographic data are required for both the MP_A and MP_C scenario conditions of the channel and floodplain. The best topographic data have 4-foot or less contour intervals and are digital. None of the data that were available for any of the projects in the Northern California flood control study satisfied both of these requirements. Most subgrantees (local project sponsors) were able to provide hardcopy design drawings of the project area only (e.g., channel but no floodplain). A significant amount of time was spent locating, interpreting, digitizing, and compiling the data. Generally, those data were combined with data purchased from a vendor or from USGS Digital Elevation Model (DEM) using Geographic Information System (GIS) to create a topographic surface that included the channel, project area, and floodplain.

Topographic data are improving in quality and availability. Many counties have produced or are currently producing countywide airborne light detection and ranging systems (lidar) topographic data, and as this trend continues, the availability and quality of topographic data will improve.

5.1.2 Recommendations for Data Collection

The data-collection process and the importance of having a clear data-collection plan and priority list for data are discussed in great detail in both this study and the Southern California study. Most of the data collection occurs very early in the loss avoidance study process. It is difficult to know at this early stage which assets will be impacted by MP_A flooding because the scenario is theoretical. Although historical flooding and those impacted assets can be used to guide initial data collection, the MP_A-impacted assets are unknown until the flood boundary analysis has been completed, which occurs near the end of Phase 2.

It is recommended that loss avoidance analysts allow additional time for data collection after the flood boundary analysis has been completed. The additional data-collection period would be used to obtain asset information that may not have been collected during Phase 1 or the initial data-collection phase.

5.2 Analysis Methodology

In Sections 5.2.1 through 5.2.6, the ways in which the analysis methodology was modified from previous loss avoidance studies are discussed, and the challenges that were encountered in the Northern California flood control study are described.

5.2.1 Storm Event Analysis Timing

Northern California has many reservoirs, rivers, and channels, and much of the water system is highly regulated. DWR maintains an extensive network of gages throughout California, and gage data are readily available in most cases. The type of data provided by these gages includes precipitation, stage, and discharge. Records for most locations are provided through the online CDEC.

A search of the CDEC at the beginning of this study revealed applicable gages for all projects on the initial project list. The CDEC database also included historical readings for the entire recording period of most gages. CDEC data were downloaded and formatted as a spreadsheet to make it easier to identify the most severe storm events for each project. Storm events were compared to a project's MP_A capacity to determine whether the storms were severe enough to cause damage. If a potentially damaging storm event occurred, the project advanced to the next step.

Because gage data were readily available for this study, the storm event analysis for each project was conducted concurrently with Phase 1. When gage data are readily available, the storm event analysis may be executed early in project screening. Doing so decreases the time spent collecting data for these projects, because some projects may be eliminated due to lack of a potentially damaging event.

5.2.2 Hydraulic Modeling and Analysis

Loss avoidance studies rely heavily on existing data, particularly hydraulic modeling and analysis data. Data are most useful when provided in a widely used format such as Hydrologic Engineering Center - Riverine Analysis System (HEC-RAS), rather than in a proprietary or less used format. Using other formats can be expensive if the software must be purchased, and it may be difficult to interpret or modify the models. When data are in a proprietary or lesser-known format, it may be more efficient to recreate the hydraulic analysis than to spend a significant amount of time trying to organize and interpret an existing model or analysis.

5.2.3 Modeling the MP_C Scenario

The MP_C scenario represents an event that actually occurred, and historical data are therefore likely to be available to help determine the actual MP_C damages. However, sufficient data for any stage of the loss avoidance analysis can be difficult to obtain for a variety of reasons. All of the data needed to calculate MP_C damages may not be available or obtained during data collection. For example, damage survey reports (DSRs) or PWs may be obtained, but these sources do not provide information about damages to private property or loss of function. For this study, when MP_C damages were known to have occurred, a model for the MP_C scenario was developed. The model results were used to 'fill in the blanks' and estimate damages for which historical data were unavailable. The MP_C scenario model results were modified based on information in the project file obtained during data collection to better represent the event that occurred. This methodology differs from the Southern California study and other loss avoidance studies but was used for this study to more accurately reflect losses avoided and provide the opportunity to analyze additional damage types.

5.2.4 Determination of a Threshold Event

For both this study and the Southern California study (FEMA, 2007), the most severe storm event that occurred since a project was completed was analyzed, i.e., losses avoided were calculated only for one event of interest. To determine the losses avoided over a project's useful life, a threshold event must be determined. A threshold event is different from the design capacity of a project. The threshold event represents the storm event that would have exceeded the project's MP_A capacity and would have caused the first dollar of damage. The threshold event is a theoretical event and can be determined by hydraulic and flood boundary analyses. Determining the threshold event is an iterative process in which various flows are modeled until the event that has the potential to cause initial damage is identified. When the magnitude of the threshold event has been determined, that magnitude is used to identify actual storm events that would have resulted in flows through the project area equal to or greater than flows caused by the threshold event. Damages in the MP_A and MP_C scenarios should be calculated for all these events. The total losses avoided for a project would be the sum of the losses avoided for all damaging storm events.

Determination of a threshold event and total losses avoided requires a significant amount of time and hydrologic, hydraulic, topographic, and asset data of the highest quality. A flow parameter analysis must be performed for each storm event equalling or exceeding the threshold event, so the time required to analyze a project will vary significantly, depending upon the number of potentially damaging storm events that occurred. This type of analysis provides a more accurate assessment of losses avoided and ROI for the project. In addition, as future storm events occur in the project area, this type of analysis could streamline the calculation of new losses avoided.

Acronyms:

BCA
Benefit-Cost Analysis

CDEC
California Data Exchange Center

DEM
Digital Elevation Model

DFIRM
Digital Flood Insurance Rate Map

DSR
Damage Survey Report

DWR
California Department of Water Resources

FEMA
Federal Emergency Management Agency

FIRM
Flood Insurance Rate Map

FIS
Flood Insurance Study

FMA
Flood Mitigation Assistance

GIS
Geographic Information System

HAZUS-MH
Hazards U.S. - Multihazard

HEC-RAS
Hydrologic Engineering Center - River Analysis System

HMGP
Hazard Mitigation Grant Program

IfSAR
Interferometric Synthetic Aperture Radar

LA
Losses Avoided

LAT
Loss Avoidance Team

lidar
Airborne Light Detection and Ranging Systems

LOMC
Letter of Map Change

MP_A
Mitigation Project Absent

MP_C
Mitigation Project Complete

NCDC
National Climatic Data Center

NFIP
National Flood Insurance Program

NOAA
National Oceanic and Atmospheric Administration

NWS
National Weather Service

OES
(California) Governor's Office of Emergency Services

PA
Public Assistance

PDM
Pre-Disaster Mitigation

PI
Project Investment

PW
Project Worksheet

RFC
Repetitive Flood Claims

ROI
Return on Investment

SRL
Severe Repetitive Loss

TIN
Triangular Irregular Network

USACE
U.S. Army Corps of Engineers

USFS
U.S. Forest Service

USGS
U.S. Geological Survey

WSE
water surface elevation

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Resources

ArcMap - ESRI_BaseMap.mxd:
http://www.arcgisonline.esri.com/

California Census Data:
http://www.census.gov/census2000/states/ca.html

California Department of Water Resources. California Data Exchange Center:
http://cdec.water.ca.gov/

HEC-RAS:
http://www.hec.usace.army.mil/software/hec-ras/