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Sacramento
and
San Joaquin
River Basins

Comprehensive Study

TECHNICAL STUDIES

APPENDIX D

HYDRAULIC TECHNICAL DOCUMENTATION

THE RECLAMATION BOARD
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Sacramento District

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APPENDIX D

HYDRAULIC TECHNICAL DOCUMENTATION
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CHAPTER I

INTRODUCTION

GENERAL

In response to extensive flooding and damages experienced in 1997, the United States Congress authorized the U.S. Army Corps of Engineers, Sacramento District (Corps) to provide a comprehensive analysis of the Sacramento and San Joaquin River Basin flood management systems and to develop comprehensive plans for flood management. The Corps and the State Reclamation Board of California conducted this Comprehensive Study to improve flood management and integrate ecosystem restoration in the Sacramento and San Joaquin River Basins.

The authorization for the Comprehensive Study directed the development of hydrologic and hydraulic models for both river basins that will allow basin-wide, systematic evaluation. These models incorporate historic rainfall-runoff, reservoir operations, and flow along the major river systems to effectively evaluate the hydraulic performance of the flood management systems. The models can be used to assess the performance of the current systems or modified systems under a wide range of hydrologic conditions.

PURPOSE OF DOCUMENTATION

This report documents the work conducted for the Sacramento and San Joaquin River Basins Comprehensive Study to develop hydraulic computer models, establish existing hydraulic conditions and floodplains, and use the hydraulic tools developed to evaluate various concept and detailed evaluations. The main product components of this effort include:

- Description of the hydraulic analysis methodology
- Development of the models (UNET and FLO-2D) for the Sacramento River and San Joaquin River Basins
- Illustration of existing conditions based on model results
- Conclusions drawn from this effort and future model applications
- Development of abridged hydrologic models (HEC-HMS) for initial plan formulation
- Analysis of three concept evaluations using the hydraulic modeling tools
- Analysis of three detailed evaluations using the hydraulic modeling tools

A primary purpose of the concept and detailed evaluations was to improve the understanding of how potential modifications could affect the system and to familiarize the Study Team in the use of the various hydrologic, hydraulic, and economic tools available. These concepts are not alternative plans. However, lessons learned in the process of formulating the concept evaluations will be invaluable in the development and evaluation of alternative future plans.

STUDY AREA

The study area encompasses the watersheds of the two major river systems of California's Central Valley, the Sacramento River in the north and the San Joaquin River in the south. These river systems comprise a combined drainage area of over 43,000 square miles, an area nearly as large as the state of Florida. The study area is illustrated in Plate 1. The problem identification area consists of the channels and floodplains of the main river reaches and the lower reaches of the major tributaries of the Sacramento and San Joaquin Rivers, roughly equivalent to the 500-year floodplain of the two rivers and their tributaries.

Due to its climate and geography, flooding is a frequent and natural event in the Central Valley. Historically, the Sacramento River Basin has been subject to floods that result from winter and spring rainfall as well as rainfall combined with snowmelt. The San Joaquin River Basin has been subject to floods that result from both rainfall that occurs during the late fall and winter months, and unseasonable and rapid melting of the winter snowpack during the spring and early summer months.

The Mokelumne, Cosumnes, and Calaveras Rivers are currently not included in the study area. These rivers are not part of the model development or data collection efforts discussed herein. These watercourses drain directly to the Delta and are hydraulically separable from the Sacramento and San Joaquin River systems. Because the Comprehensive Study has investigated flooding and ecosystem related problems associated with the Sacramento and San Joaquin Rivers, the Mokelumne, Calaveras, and Cosumnes rivers are not a focus of this Comprehensive Study.

CHAPTER II

DESCRIPTIVE HYDRAULICS

The following chapter describes the hydraulic analysis methodology, including the development of the UNET and FLO-2D hydraulic models, the modeling approach, levee failure methodology, and the development of floodplains.

HYDRAULIC ANALYSIS METHODOLOGY

This section describes the methods used in developing computer models to simulate the hydraulics in the Sacramento and San Joaquin River Basins. These models will be used to identify current, baseline conditions and analyze the effects of various alternatives and measures.

Study Approach

For this study, two computer hydraulic models, UNET and FLO-2D, were utilized to represent the hydraulics in the Sacramento and San Joaquin River Basins. The steps taken to develop these models will be explained. In addition, detailed information about the strengths, applicability, and limitations of each of these analytical tools will be presented.

The level of detail for a study of this type is always limited by the availability of geometric and topographic data. The modeling effort is further constrained by limited or incomplete historical hydrologic data. Another possible limitation is the accuracy and applicability of the computer models used. While the models are continually being improved to better represent the river systems, no model is a perfect representation of actual riverine conditions. However, the models developed for this study are of sufficient detail to provide appropriate results for a systematic flood damage analysis of the two basins.

The models were developed to be comprehensive representations of the entire Sacramento and San Joaquin River Basins, capable of simulating the complex interaction of multiple stream systems and waterways. This approach differs from the traditional “piecemeal” approach in which individual rivers or reaches are examined out of context from the greater, more complex system to which they belong.

Floods Studied

For the hydraulic analysis, floods with 10-, 25-, 50-, 100-, 200-, and 500-year return frequency were explicitly modeled. In the Sacramento River basin, the 2-year return frequency was also modeled and was used to assist in the development of the stage versus frequency relationships. A hypothetical storm centering method was developed to position an n-year flood event at a particular location in the river system. For detailed information about the storm centering process, refer to the Hydrology Appendix. The storm centering method differs somewhat from the n-year design event used in traditional studies due to the extensive size of the system being examined in the Comprehensive Study.

Description of Hydraulic Models

Computer-based hydraulic models, such as UNET and FLO-2D, turn theoretical and empirical equations into useful analytical tools for simulating current, baseline conditions and analyzing alternative flood management scenarios. The two models are used jointly to simulate the channel and overbank hydraulics in the Sacramento and San Joaquin River systems. In-channel flows are simulated using UNET, and the FLO-2D model is used to simulate extensive flows in overbank and floodplain areas where they occur. The UNET model is strongly interfaced to the Data Storage System (DSS) developed by the Corps of Engineers, Hydrologic Engineering Center (HEC).

UNET Model Development

The computer model, UNET, developed by Dr. Robert Barkau, is designed to simulate unsteady flow through a full network of open channels, weirs, bypasses, and storage areas. For this study, use of the UNET model was limited primarily to the riverine channels. The August 1998 UNET Version 4.0 (with executable modifications included in April 2000 specifically for the Comprehensive Study) was used for this study. For more information about the capabilities of this model, refer to the August 1997 UNET User's Manual.

Purpose of Model - The purpose for using UNET in the Comprehensive Study is to provide a means for understanding and representing the channel hydraulics in the Sacramento and San Joaquin River systems. Two separate UNET models were developed - one for the Sacramento River system and one for the San Joaquin River system. The UNET models were constructed to allow modeling of both flood and low-flow conditions. The UNET models were used to determine river stage, velocity, and depth as well as breakout and return flows from overbank areas.

Procedures and Process - In general, model construction for both basins consisted of collecting and processing topographic data, developing river channel alignments, developing cross-sectional geometry from the topographic and hydrographic data, and constructing functional UNET models. The following procedure was used to develop the UNET model for the Comprehensive Study:

1. Assemble topographic data and tools;
2. Develop digital river alignments in Microstation and InRoads;
3. Extract cross sections along the river alignments using InRoads;
4. Develop an interim HEC-RAS model for graphical editing, attribute assignment, and bridge coding;
5. Export the data to UNET; and
6. Complete the UNET model by defining UNET connections, boundary conditions, etc.

At the outset of model construction, new alignments depicting the centerline of the low flow channel were developed for all of the modeled reaches. These alignments and the corresponding stationing do not necessarily agree with the historic centerline alignments and stationing (in terms of river miles) illustrated in the Corps' aerial atlas of the river systems and/or on the USGS quadrangle maps. Development and use of these new alignments was necessary given the following: 1) use of the new detailed topographic and hydrographic mapping for model construction, and 2) in many cases, the planform of the low flow channel has changed from previous configurations. It was important that the model have the best representation of the reach length between cross sections so that energy losses are accounted for correctly. In this document, all references to river stations refer to the new alignments developed for this study.

Extensive topographic data were collected for both the Sacramento and San Joaquin River Basins and processed electronically into digital terrain models (DTMs). Digital river channel alignments were developed manually in Microstation, based on topographic and hydrographic information. In-channel topography was obtained from bathymetric surveys and other existing information. Cross sections were extracted from the DTMs along the channel alignments using Microstation and InRoads. The raw cross sections were imported into HEC-RAS, a hydraulic model with graphical user interface features, for the purpose of editing cross section attributes and channel features as well as coding bridge geometries. The HEC-RAS model was then exported to UNET, where it was completed by adding bridges, boundary conditions, and model connectivity elements. Input and output from UNET are stored and post-processed in DSS, a database developed by HEC for time-series data.

Boundary Conditions - The four primary types of boundary conditions in UNET are interior, upstream, downstream, and internal. Interior boundary conditions define reach connections and ensure continuity of flow. Upstream boundary conditions are required for all reaches that are not connected to another reach at their upstream end. An upstream boundary condition is a flow hydrograph of discharge vs. time for a particular flood event. These hydrographs are supplied at the upstream end of each tributary or stream that has been modeled, and represent outflow hydrographs from the major controlling reservoirs or n-year flow hydrographs for unregulated streams. Regulated outflow hydrographs at controlling reservoirs were provided from HEC-5 simulations (refer to the Hydrology and Reservoir Simulation Appendices).

Downstream boundary conditions are required at the downstream end of all river systems not connected to another reach or river. Downstream boundary conditions consist of stage hydrographs and represent tailwater conditions such as tidal or estuary influences. Data from three tide gages were used in the Sacramento model, and data from four tide gages were used in the San Joaquin River Basin. Internal boundary conditions are coded in UNET to represent levee failures or storage interactions, spillways or weir overflow/diversion structures, bridge or culvert hydraulics, or pumped diversions.

Basic Assumptions and Limitations - It is important to note some of the basic capabilities, assumptions, and limitations inherent with the UNET models. UNET is used to simulate one-dimensional, fully unsteady flow. It is a fixed bed analysis and doesn’t account for sediment movement, scour, or deposition. The models assume no exchange with groundwater. The model is intended to adequately reproduce levee breaks and breaches and simulate channel hydraulics. The maximum spacing of cross sections in the UNET models (between 1/5- and 1/4-mile) also limits the application of these models to problems requiring more detail.

FLO-2D Model Development

In general, FLO-2D was used to model overbank hydraulics for this study. Out-of-bank flows were generated in UNET and passed to the corresponding grid elements in FLO-2D to delineate the floodplain. The October 1999 Version 99.1 is being used to conduct this effort. More information about FLO-2D can be found in the October 1998 FLO-2D User's Manual.

Purpose of Model - FLO-2D was used in this study to model overbank flows, which are comprised of flows that travel out of stream channels and across the topography of the floodplain. FLO-2D has the capability of modeling both one-dimensional channel flow and two-dimensional overbank flow. In the Sacramento River system, FLO-2D was run in overbank areas only, exclusive of the channels. Channel areas in the Sacramento River Basin are clearly defined; therefore, overbank flows occur less often. In the San Joaquin River Basin, channels are less well defined and have minimal capacity, making overbank flows more common. For this reason, the FLO-2D model included both the channel and overbanks for selected reaches of the San Joaquin River Basin.

Procedures and Process - Similar to the procedure for developing the UNET model, assembling topographic data was the first task in developing the FLO-2D models for the Sacramento and San Joaquin River Basins. One-dimensional flows are simulated in FLO-2D under a two-dimensional grid. A finite difference grid system was established in each basin, defining contiguous grid elements in the four compass directions. This process was performed using a digital terrain model (DTM) with Intergraph InRoads, in a computer aided design (CAD) environment.

Different topographic data were used in each basin. In the Sacramento River Basin, cross sectional data for channel areas were established from 2- and 5-foot topographic data. The FLO-2D grid in overbank areas was constructed from 10-meter and 30-meter United States Geological Survey (USGS) digital elevation models (DEMs). The FLO-2D models used grid elements representing areas of 1,000 and 2,000 feet on a side.

Overbank topography for the San Joaquin River Basin system was comprised primarily of 30-meter USGS DEM data. The two-dimensional grid was constructed completely from DEM data, with the 2-foot topography data used only for the one-dimensional channel cross-sections. Detailed channel topography was not integrated into the DEM. Each grid element in the San Joaquin River Basin FLO-2D model represents an area 2,000 feet on a side.

Water surface output from the FLO-2D model was exported to a CAD environment. Post-processing of the output in conjunction with basin topographic data was performed to generate and define floodplains.

Boundary Conditions - The types of boundary conditions in the FLO-2D computer model include inflow and outflow boundary nodes, tailwater conditions, and one-dimensional (1-D) channel inflow hydrographs and tailwater. Inflow boundary nodes are identified in the input file and inflow hydrographs are provided from the UNET model. Outflow boundary nodes are indicated in the input data along with the general direction of the outflow (among the eight possible directions). Tailwater conditions for the outflow nodes are based on normal depth, with the slope computed from adjacent node elevations.

The one-dimensional channels may have inflow hydrographs at the upstream end and tailwater at the downstream end. The inflow hydrographs come from either the UNET model or the synthetic hydrology. The outflow boundary conditions are based on either a rating curve or a stage hydrograph at the downstream end of the channel.

Basic Assumptions and Limitations - Several basic assumptions and limitations must be considered with the FLO-2D model. Two-dimensional flow simulation in FLO-2D is limited to the eight directions of the compass (north, northeast, east, southeast, and so forth). The model routes channel and overland flow using the full dynamic wave or the diffusive wave approximation to the momentum equation. The simulations performed represent a fixed bed analysis.

Grid sizes of about 2,000 feet were used throughout both basins. The only exception is in the Sutter Basin, where 1,000-foot grids were used to provide better resolution. Bridges, levees, streets, and other features were not specifically modeled in this application of FLO-2D; however, raised highways, levees, and other topographic features may be represented in the grid elements.

Contiguous and Commingling Overflows

The flows developed from these models have been termed 'contiguous and commingling overflows.' *Contiguous* refers to the continuity of flow from one end of the basin to the other. The flows are also described as *commingling* because of the storm centering process that was used to provide one composite floodplain by combining multiple storm centers. Refer to the Hydrology Appendix for more detail on the development of hypothetical hydrology and storm centering. Overlaying floodplains from each of the different storm centers results in a hypothetical, composite floodplain for the entire basin area. The composite floodplain accounts for contributions from storm loadings on each major tributary within the system. This concept is illustrated in Plate 2. It should be noted that the composite floodplain is not a real-world floodplain in that the probability of concurrent n-year frequency events throughout the entire basin is statistically unlikely.

Levee Breach Methodology

Approach - A levee failure methodology was devised to determine when simulated flows would cause levees to fail and a floodplain would be formed. A likely failure point (LFP) profile was developed for levees in the Sacramento and San Joaquin River Basins on a reach-by-reach basis. The LFP represents the approximate elevation at which there is a 50% probability of levee failure. Failure curves identifying the LFP distance from top of levee for various levee types in the Sacramento and San Joaquin River Basins are shown in Plates 3 and 4. The reaches where the failure curves apply are shown in Tables II-1 and II-2. The reaches distinguish changes in the geometry and/or soil-makeup of the levees.

The LFP was developed from available geotechnical data, extensive interviews with levee district personnel, and best engineering judgment. Information was gathered and analyzed by the Soil Design Section of the Corps and the Division of Engineering of the State of California, Department of Water Resources (DWR). The LFP approach represents a simplified analysis to yield generic conditional probability of failure vs. water surface elevation with respect to top of levee. The curves reflect a qualitative evaluation of the major geotechnical aspects of levee integrity. For more detail regarding the geotechnical aspects of the LFP analysis, refer to the section titled Geotechnical Studies located in the Technical Studies Report.

TABLE II-1

APPLICATION OF LEVEE PERFORMANCE CURVES IN THE SACRAMENTO RIVER BASIN

Reach		**River Miles**	**Levees?**	**Selected P(f) Model**	
No.	**Description**			Left Bank	Right Bank
1	**Shasta Dam to Red Bluff**	315-245	No		
2	**Red Bluff to Chico Landing**	245-194			
	Sacramento River				
	Red Bluff to Elder Creek	245-230.5	No		
	Elder Creek to Deer Creek	230.5-220	No		
	Deer Creek to Chico Landing	220-194	No		
	Tributaries				
	Elder Creek		Yes	C2	C2
	Deer Creek		Yes	C2	C2
3	**Chico Landing to Colusa**	194-146			
	Sacramento River				
	Chico Landing to head of east levee	194-176	Partial		S3
	East levee head to Moultan Weir	176-158.5	Yes	S2	S2
	Moultan Weir to Colusa Weir	158.5-146	Yes	S2	S2
	Tributaries				
	Mud Creek		Yes	C1	C1
	Butte Creek		No	C1	C1
	Cherokee Canal		Yes	S3	S3
4	**Colusa to Verona**	146-80			
	Sacramento River				
	Colusa Weir to Butte Slough	146-138	Yes	S3	S4
	Butte Slough to Tisdale Bypass	138-119	Yes	S3	S4
	Tisdale Weir to Knights Landing	119-90	Yes	S3	S3
	Knights Landing to Verona	90-80	Yes	S2	S3
	Tributaries				
	Colusa Basin Drainage Canal				
	Tisdale Bypass			S3	S3
	Sutter Bypass				
	Butte Slough to Wadsworth Canal		Yes	C3	C3
	Wadsworth Canal to Tisdale Bypass		Yes	C2	C2
	Tisdale Bypass to Feather River		Yes	C2	C2
	Feather River to Verona		Yes	S3	C2
	Feather River				
	Oroville to mouth of Yuba River		Yes	S2	S2
	Mouth of Yuba River to Bear River		Yes	S2	S2
	Bear River to Yolo Bypass		Yes	S2	
	Tributaries				
	Yuba River	5-0	Yes	S2	S2
	Bear River	5-0	Yes	S2	S2
5	**Verona to Steamboat Slough**	80-32.3			
	Sacramento River				
	Verona to Sacramento Weir	80-63	Yes	S2	S4
	Sacramento Weir to American River	63-60	Yes	S2	S2
	American River to Elk Slough	60-42	Yes	S2	S2

Reach		**River Miles**	**Levees?**	**Selected P(f) Model**	
No.	**Description**			Left Bank	Right Bank
	Elk Slough to Sutter Slough	42-34	Yes	S3	S3
	Head of Sutter Slough to Steamboat Slough	34-32.3	Yes	10-yr	10-yr
	Tributaries				
	Natomas Cross Canal		Yes	C2	C3
	American River		Yes	S3	S2
	Yolo Bypass				
	Verona to Knights Landing Ridge Cut		Yes	S4	S3
	Knights Landing Ridge Cut to Cache Creek		Yes	S3	S3
	Cache Creek to Sacramento Weir		Yes	C3	C3
	Sacramento Weir to Putah Creek		Yes	C3	C3
	Putah Creek to Miner Slough		Yes	C3	C3
	Miner Slough to Cache Slough		Yes	C3	C3
	Cache Slough to mouth of Old River			C3	C3
	Tributaries				
	Knights Landing Ridge Cut	6-0	Yes	S3	S3
	Cache Creek		Yes	S3	S3
	Willow Slough	7-0	Yes	C3	C3
	Putah Creek	7-2	Yes	C3	C3
	Miner Slough	2-0	Yes	S4	S4
	Cache Slough	5-0	Yes	S4	S4
6	**Sacramento River Steamboat Slough to Collinsville**	32.3-0			
	Sacramento River				
	Steamboat Slough to head of Georgiana Slough	32.3-26.5	Yes	10-yr	10-yr
	Georgiana Slough to Cache Slough (junction point)	26.5-14	Yes	10-yr	10-yr
	Cache Slough to 3 Mile Slough	14-9		10-yr	
	3 Mile Slough to Collinsville	9-0		10-yr	
	Tributaries				
	Elk Slough	9-0	Yes	S3	S3
	3 Mile Slough		Yes	10-yr	10-yr
	Steamboat Slough	6.5-0	Yes	10-yr	10-yr
	Sutter Slough				
	Steamboat Slough to Miner Slough	2.5-0	Yes	10-yr	10-yr
	Miner Slough to Sacramento River	7-2.5	Yes	10-yr	10-yr
	Georgiana Slough	10-0	Yes	10-yr	10-yr

Notes:
Levee geotechnical probability of failure curves, P(f), are representative of the levee's past performance, existing condition (where known), foundation and levee soil characteristics, and engineering judgment within each reach. For example, a SJ1 curve in the San Joaquin Basin reflects a better performing levee than a SJ3 curve. The curves do not necessarily reflect the probability of failure based on levee height. A low sand levee may have a history of poor performance and as such could have a 50% failure at or near the toe of the levee. Likewise, a highly engineered clay levee may have a curve with a 50% failure at or near the top of the levee.

Lower Sacramento River and Delta Distributaries – A different methodology was used to develop levee failure elevations for the lower Sacramento River and its Delta distributaries. Rather than using LFP elevations based on Geotechnical data, levee failures in the lower Sacramento River were based on the elevation of the 10-year tide and flood combination. This methodology was used because Delta levees endure atypical conditions and perform differently than other levees in the river system. This is primarily due to their continuous exposure to water on the riverside of the levees, acting similar to dams. Additional issues associated with Delta levees include tidal fluctuation, wave run-up, poor foundation conditions (organic soils) and poor levee materials (sand).

TABLE II-2

APPLICATION OF LEVEE PERFORMANCE CURVES IN THE SAN JOAQUIN RIVER BASIN

Reach			**River Miles**	**Length (miles)**	**Selected P(f) Model**
Area	**Description**	**Watercourse**			
A	Mendota Dam to Friant Dam	San Joaquin River	205-286	63	SJ1
	San Joaquin River to James Road	Fresno Slough		12	SJ1
	Fresno Slough to James Road	James Bypass		2	SJ1
B	Sand Slough Control Structure to Mendota Dam	San Joaquin River		37	SJ2
	Connector Channel from San Joaquin to Bypass	Eastside Bypass		32	SJ2
	San Joaquin River to Road 18	Fresno River		6	SJ2
	San Joaquin River to Route 152	Berenda Slough		11	SJ2
	San Joaquin River to Route 152	Ash Slough		6	SJ2
C	Merced River to Sand Slough Control Structure	San Joaquin River		50	SJ2
	Mariposa Bypass to Connector Channel from San Joaquin River	Eastside Bypass		10	SJ2
	San Joaquin River to Eastside Bypass	Mariposa Bypass		4	SJ2
	Bear Creek to Eastside Bypass	Deep Slough		6	SJ2
	San Joaquin River to Eastside Canal	Bear Creek		7	SJ2
D	Stanislaus River to Merced River	San Joaquin River	75-118	43	SJ3
	San Joaquin River to McConnel State Park	Merced River		23	SJ2
	San Joaquin River to AT&SF Railroad	Tuolumne River		22	SJ3
	Tuolumne River to River Mile 2	Dry Creek		2	SJ3
	San Joaquin River to downstream of Treatment Plant	Stanislaus River		13	SJ3
E	Deep Ship Channel to Stanislaus River	San Joaquin River	40-75	35	SJ3
	Old River to San Joaquin River	Paradise Cut		7	SJ3
	Tracy Boulevard to San Joaquin River	Old River		11	SJ3
	Grant Line Canal to Old River	Doughty Cut		1	SJ3
	Tracy Boulevard to Doughty Cut	Grant Line Canal		1	SJ3
	Victoria Canal to Old River	Middle River		12	SJ3

See notes for Table II-1 regarding P(f) levee curves. San Joaquin River Basin levee failure curves are shown in Plate 4.

Based on engineering judgment, existing levee conditions, and history of levee performance, it was determined that the Delta levee failure elevation profile more closely corresponds to the 10-year water surface profile. The 10-year water surface profile was obtained from stage versus frequency curves for a number of tide gages located along the Sacramento River and major distributaries. A list of the tide gages is provided in Table II-3. The curves are presented in a Corps of Engineers' office report dated February 1992 titled "Sacramento-San Joaquin Delta, California, Special Study, Hydrology".

The tide gage data consists of the recorded annual peak stages for the period of record, therefore the statistical elevations provided by the stage-frequency curves account for the combination of tide and river flows (i.e., the combined probability). Because tide gages were not available in every Delta reach, use of the 10-year water surface failure profile was limited to the model reaches shown in Table II-4. Failure elevation for the remaining Delta watercourses uses the Geotechnical-based levee failure methodology described previously.

TABLE II-III

TIDE GAGES USED TO DEVELOP LOWER SACRAMENTO RIVER LEVEE FAILURE PROFILES

Gage No.	Location	Watercourse	River Mile	10-yr Water Surface Elevation (ft)
2	Collinsville	Sacramento River	0	5.9
3	SAC R @ 3 Mi Slough	Sacramento River	9.23	6.7
4	Rio Vista @ Hwy 12	Sacramento River	12.87	6.9
5	Walnut Grove	Sacramento River	26.7	12.6
6	Snodgrass Slough	Sacramento River	37.1	18.3
7	I Street	Sacramento River	59.84	29.3
9	Georgiana Sl. at Mokelumne R.	Georgiana Slough	0.15	6.4
11	Three Mile Slough at SJ River	Three Mile Slough	0.27	5.8

Note: 10-year water surface elevations reference the national Geodetic Vertical Datum of 1929 (NGVD29)

TABLE II-IV

APPLICATION OF 10-YEAR WATER SURFACE LEVEE FAILURE METHOD

Watercourse	Extent	UNET Model Reaches
Sacramento River	Collinsville to Sutter Slough	90, 93, 95, 97, 99, and 101
Three Mile Slough	Entire Length	98
Georgiana Slough	Entire Length	94
Sutter Slough	Entire Length	86 and 89
Steamboat Slough	Entire Length	91 and 92

Failure Modeling - Levee failure was simulated in UNET when the water surface elevation reached the LFP for a given levee. Levee failure is simulated by UNET as a levee breach. This failure method was adopted for UNET because levees tend to fail before they overtop, and flood-fight efforts and intentional breaching often prevent catastrophic failures of long sections of levee. Flow through a levee breach is then routed into floodplain storage areas by UNET. UNET supports two types of levee failure procedures: simple levee failure (SF record) and embankment failure (EF record). Both types of levee failure methods were utilized in this study.

The simple failure procedure, identified by the SF record, uses a simple spillway concept whereby the volume of available storage multiplied by a linear routing factor gives flow through the breach. This simple method, often used in cases where the details of a breach are unknown, does not simulate the erosion of material from the breach, but assumes a maximum breach length. This method acknowledges that flow into the storage area is proportional to available storage; thus, flow is greatest at the onset of the breach and decreases as the available floodplain storage decreases.

The detailed embankment failure method, identified by the EF record, simulates an enlarging breach corresponding to either a piping or embankment failure. The breach starts when a failure elevation is exceeded, and is assumed to enlarge at a linear rate. Flow through a piping breach is given by an orifice equation, with failure occurring when the pipe breaks through the top of the levee. Flow through an overtopping breach is given by a weir equation.

Assumptions – Table II-5 lists the levee breach assumptions used in the Sacramento and San Joaquin River UNET models.

Levee Stability Data - Refer to the Geotechnical discussion in the main document for details regarding levee stability in the Sacramento and San Joaquin River Basins.

TABLE II-5

UNET MODEL LEVEE BREACH ASSUMPTIONS

Assumption Type	Sacramento River	San Joaquin River
Breach Length	Not specified (SF cards used)	Generally 200 feet, but SF cards used for selected breaks
Breach Side Slopes	Not specified (SF cards used)	Vertical sideslopes
Coefficients	Linear Routing – 0.025 to account for rate of flow through levee breach into overbank area	Linear Routing – 0.025 to account for rate of flow through levee breach into overbank area
Time for Breach to Occur	10 hours	Usually 5 hours

QUALIFICATION OF BASE CONDITION RESULTS

The base condition results are plotted as n-year floodplains, but it must be emphasized that they are not FEMA floodplains, nor are they intended to replace or supersede existing FEMA maps. The intended use of the models and model output data is to evaluate the performance of the current and modified flood management systems under a range of hydrologic conditions. There are many limitations due to the level of detail of this work.

CHAPTER III

HYDRAULIC ANALYSIS

This chapter describes information and procedures specific to the hydraulic analyses performed in the Sacramento and San Joaquin River Basins.

SACRAMENTO RIVER BASIN

The Sacramento River Basin covers approximately 26,300 square miles at Rio Vista, and is approximately 240 miles long and up to 150 miles wide. The Sierra Nevada bounds the basin on the east, the Coastal Range on the west, the Cascade and Trinity Mountains on the north, and the Sacramento-San Joaquin Delta on the south. A detailed map of the Sacramento River Basin is shown in Plate 5. The cities of Sacramento, Yuba City, Marysville, Chico, Colusa, Red Bluff, and Redding are in the Sacramento River Basin.

Major tributaries to the Sacramento River include the Feather, Yuba, and American Rivers, which enter from the east. Numerous smaller streams flow into the Sacramento River from both sides of the valley.

The Sacramento River Flood Control Project (SRFCP) in the Sacramento Valley consists of a series of levees and bypasses, placed to protect preferred areas and take advantage of several natural overflow basins. The SRFCP system includes levees along the Sacramento River south of Ord Ferry; levees along the lower portion of the Feather, Bear, and Yuba Rivers; and levees along the American River. The system benefits from three natural basins: Butte, Sutter, and Yolo. These basins run parallel to the Sacramento River and receive excess flows from the Sacramento, Feather, and American Rivers via natural overflow channels and constructed weirs. During floods, the three basins form one continuous waterway connecting the Butte, Sutter, and Yolo Basins. This interconnection poses unique challenges to the hydraulic modeling efforts.

Study Area and Model Extent

The Sacramento River system was subdivided into various study reaches. The specific watercourses that have been included in the UNET model are illustrated in Plate 6 and listed in Table III-1. Table III-1 details the upstream and downstream extent of each UNET model reach and notes where model boundary conditions (identified with the acronym BC) were applied. The extent of the FLO-2D modeling in the basin is also illustrated in Plate 6. Generally, the UNET models for the Sacramento River Basin extend farther upstream than the available topography. In these cases, portions of previously developed UNET or HEC-2 models were added to the UNET model developed specifically for this study.

TABLE III-1

UNET MODEL REACHES IN THE SACRAMENTO RIVER BASIN

Reach Name	UNET Reach No.	No. of Cross Sections	Upstream River Mile	Downstream River Mile	Upstream Boundary	Downstream Boundary
Butte Creek	1	83	32.50	12.00	BC	4,5
Angel Slough	2	19	25.50	20.50	BC	3,4
Little Chico Creek	3	37	9.25	0.25	BC	2,4
Angel Slough	4	81	20.14	0.25	2,3	1,5
Butte Creek	5	16	11.75	7.75	1,4	6,7
Cherokee Canal	6	48	12.25	0.50	BC	5,7
Butte Creek	7	15	7.25	3.75	5,6	8,9
Moulton Weir Overflow	8	37	9.13	0.25	BC	7,9
Butte Creek	9	2	3.42	3.25	7,8	10,11
Colusa Bypass	10	11	2.76	0.25	BC	9,11
Butte Creek	11	11	2.75	0.25	9,10	12,13
Butte Slough	12	3	0.78	0.50	BC	11,13
Butte Slough - Sutter Bypass	13	56	94.45	84.31	11,12	16,17
East Intercept Canal	14	17	3.17	0.19	BC	15,16
West Intercept Canal	15	7	1.12	0.00	BC	14,16
Wadsworth Canal	16	24	4.29	0.00	14,15	13,17
Sutter Bypass	17	33	84.14	78.16	13,16	19,20
Sacramento River	18	566	215.50	80.38	BC	19
Tisdale Bypass	19	22	3.95	0.04	18	17,20
Sutter Bypass	20	104	77.98	58.81	17,19	BC
Feather River	21	75	59.00	30.40	BC	22,23
Jack Slough	22	22	5.18	0.14	BC	21,23
Feather River	23	8	29.25	27.40	21,22	24,25
Yuba River	24	83	22.00	0.27	BC	23,25
Feather River	25	22	27.29	12.90	23,24	34,35
Bear River	26	8	11.10	5.50	BC	27,28
Dry Creek	27	7	5.00	0.85	BC	26,28
Bear River	28	4	5.40	3.62	26,27	31,32
UP Intercept	29	6	4.85	2.17	BC	30,31
Best Slough	30	2	0.60	0.10	BC	29,31
UP Intercept	31	3	2.16	0.01	29,30	28,32
Bear River	32	4	3.50	2.81	28,31	33,34
Yankee Slough	33	7	6.00	0.60	BC	32,34
Bear River	34	13	2.80	0.18	32,33	25,35
Feather River	35	59	12.00	0.13	25,34	36
Sacramento River	36	4	80.00	79.33	BC	53
Coon Creek - East Side Canal	37	3	0.63	0.00	BC	38,39
Channel South of Coon Creek	38	5	0.50	0.00	BC	37,39
East Side Canal	39	2	1.00	0.00	37,38	40,41
Bunkham Slough	40	4	1.03	0.00	BC	39,41
East Side Canal	41	2	0.57	0.00	39,40	42,43
Markham Ravine	42	3	0.52	0.00	BC	41,43
East Side Canal	43	3	1.00	0.00	41,42	44,45
Auburn Ravine	44	5	1.66	0.00	BC	43,45
East Side Canal	45	3	1.00	0.00	43,44	46,47
King Slough	46	4	1.00	0.00	BC	45,47
East Side Canal	47	3	0.80	0.00	45,46	52,53
Curry Creek-Pleasant Grove Cnl	48	5	0.86	0.00	BC	49,50
Pleasant Grove Creek	49	2	0.76	0.00	BC	48,50

Reach Name	UNET Reach No.	No. of Cross Sections	Upstream River Mile	Downstream River Mile	Upstream Boundary	Downstream Boundary
Pleasant Grove Canal	50	5	1.48	0.00	48,49	51,52
Pierce Roberts Drain	51	3	0.83	0.00	BC	50,52
Pleasant Grove Canal	52	5	0.68	0.00	50,51	47,53
Natomas Cross Canal	53	17	5.242	0.041	47,52	36,54
Sacramento River	54	86	79.21	61.00	36,53	55,56
Natomas East Main Drain	55	110	15.052	0.12	BC	54,56
Sacramento River	56	3	60.89	60.60	54,55	57,58
American River	57	159	22.00	0.12	BC	56,58
Sacramento River	58	124	60.40	34.28	56,57	86,90
Yolo Bypass	59	15	57.15	54.52	BC	60,61
Knights Landing Ridge Cut	60	33	6.01	0.00	BC	59,61
Yolo Bypass	61	15	54.33	51.62	59,60	62,63
Cache Creek	62	28	8.08	0.00	BC	61,63
Yolo Bypass	63	28	51.43	45.02	61,62	64,65
Sacramento Bypass	64	10	1.68	0.00	BC	63,65
Yolo Bypass	65	7	44.65	43.49	63,64	66,67
Willow Slough	66	45	8.15	0.00	BC	65,67
Yolo Bypass	67	31	43.36	39.33	65,66	68,69
Putah Creek	68	21	3.79	0.01	BC	67,69
Yolo Bypass	69	53	39.19	29.04	67,68	70,73
Toe Drain	70	8	28.85	27.54	69,73	71,72
Liberty Cut-Toe Drain Connect	71	8	28.00	25.84	70,72	74,75
Toe Drain	72	23	8.04	23.23	70,71	75,76
Yolo Bypass	73	41	28.85	21.36	69,70	85,88
Liberty Cut-Shag Sl Connector	74	7	26.81	24.98	71,75	77,78
Liberty Cut	75	17	26.22	23.23	71,74	72,76
Prospect Slough	76	19	23.04	19.68	72,75	84,85
Shag Slough	77	13	25.46	23.21	BC	74,78
Shag Slough	78	19	23.02	19.31	74,77	81,82
Haas Slough	79	10	2.25	0.09	BC	80,81
Cache Slough	80	5	25.00	24.00	BC	79,81
Cache Slough	81	10	23.74	21.50	79,80	78,82
Cache Slough	82	8	21.36	19.88	78,81	83,84
Lindsey Slough	83	24	25.50	19.90	BC	82,84
Cache Slough	84	3	19.71	19.32	82,83	76,85
Cache Slough	85	1	18.77	18.77	76,84	87,88
Sutter Slough	86	20	28.50	24.48	58,90	87,89
Miner Slough	87	34	26.06	18.87	86,89	85,88
Cache Slough	88	14	18.48	15.21	85,87	92,96
Sutter Slough	89	10	24.18	21.98	86,87	91,92
Sacramento River	90	12	34.17	32.70	58,86	91,93
Steamboat Slough	91	21	26.265	22.12	90,93	89,92
Steamboat Slough	92	28	21.87	15.12	89,91	88,96
Sacramento River	93	30	32.59	26.75	90,91	94,95
Georgiana Slough	94	60	12.36	0.09	93,95	BC
Sacramento River	95	53	26.50	14.62	93,94	96,97
Cache Slough	96	2	14.95	14.71	88,92	95,97
Sacramento River	97	24	14.25	9.50	95,96	98,99
Three Mile Slough	98	18	3.34	0.099	97,99,100	BC
Sacramento River	99	7	8.75	7.25	97,98,100	100,101
Horseshoe Bend	100	13	2.85	0.10	97,98,99	99,101
Sacramento River	101	26	7.00	0.84	99,100	BC

Index Points

Index points in the Sacramento River Basin are shown in Plate 7. Also shown in Plate 7 are the economic impact areas, used in conjunction with output from the hydraulic models to develop economic impacts. Plate 8 shows the hydrologic-hydraulic handoff points. The handoff points are locations where output from the hydrologic analysis was passed to the hydraulic models. Output at the index and handoff points may also be passed on to other analyses being performed for this study, such as economics or ecosystem function.

Base Data

The following section describes various elements of the UNET and FLO-2D models developed in the Sacramento River Basin, including the inflow and tailwater hydrographs that form the upstream and downstream boundary conditions, topographic and hydrographic data, and modeled structures affecting flow.

Inflow Hydrographs

Inflow hydrographs have been constructed from available hydrologic data for the Sacramento River Basin. The inflow hydrographs are described in detail and illustrated in the Hydrology Appendix; refer to that document for more information. There are almost 40 handoff points between the hydrology and hydraulics analyses, representing hydrograph input into the UNET model. Some of the hydrographs are from the hydrologic analysis, but others were developed from previous studies and other hydrologic analyses. Seven floods were modeled in the hydraulic analysis portion of this study: the 2-year, 10-year, 25-year, 50-year, 100-year, 200-year, and 500-year frequency floods.

Tailwater/Stage Hydrographs

Tailwater hydrographs are included at three locations in the Sacramento River Basin: Sacramento River at Collinsville, and the downstream ends of Three-Mile and Georgiana Sloughs. These stage vs. time hydrographs represent downstream boundary conditions in the UNET model, and are shown in Plate 9. The tailwater hydrographs were developed from information gathered at tide gages during the 1997 flood event. Conditions during the 1997 event are thought to represent conservative tailwater conditions.

Topographic and Hydrographic Data

Topography is an essential component of the hydraulic modeling effort, as it forms the geometric input to the UNET program. At the outset of this study, mapping for the Sacramento River system was readily available for model development. Topographic data consist of Level 2 USGS 30-meter DEM’s, with 10-meter DEM’s used where available, and surveying performed in the riverine channel areas. A map indicating the extent of topographic data used within the Sacramento River Basin is illustrated in Plate 10.

Extent - In general, mapping is comprised of linear riverine reaches that include the main river channel, the levees, and the overbanks for a distance of approximately 300 feet landward of the levees. Recent mapping efforts include collection of detailed topographic and hydrographic surveys of the Feather, Bear, and Yuba Rivers. Mapping data for the Feather River Basin is complete but has not been included in the models.

Survey data for the Sacramento River Basin consist primarily of 2-foot contour mapping (with limited 5-foot topography). Data collection was conducted to produce topographic mapping above and below the waterline to provide accuracy suitable for development of 2-foot contours along most of the watercourses. However, along the most northern reach of the Sacramento River and throughout most of the Butte Basin overbanks, the survey was conducted with an accuracy suitable to produce 2-foot contours below the waterline and 5-foot contours above the waterline. The mapping is accurate vertically to one-half the contour interval.

Sources - Most of the topographic data were collected in 1997, with the exception of the 5-foot topography data for Butte Basin, which were collected in 1995. Cross sections were extracted from 1997 photogrammetry performed on the Sutter Bypass, Yolo Bypass, Tisdale Bypass, Wadsworth Canal, and along a few other small tributaries. Data for the Feather River, Putah Creek, and Cache Creek were taken from older studies.

The hydrographic and topographic data were developed for use in MicroStation and InRoads. The topographic data are presented as three-dimensional contour files and the planimetric data are presented in separate three-dimensional design files. Along each reach of the surveyed watercourses, full digital terrain models (DTM's) were developed for the hydrography and topography. The DTM's were produced to be used within the InRoads environment. Level 2 DEM's, which are relatively smooth compared to Level 1, were used to satisfy GIS requirements. Along the Yolo, Sutter, Tisdale, and Sacramento Bypasses, the survey data consist of HEC-2 formatted cross-sections, which are based on photogrammetry suitable to produce 2-foot contours.

Channel Profiles and Representative Cross-Sections

Summary plots of channel profiles in the Sacramento River system are provided in Plates 11 through 14. The channel profiles included in this appendix include left and right bank elevations, and bottom of channel elevation. Additional profiles for left and right landside elevation and levee as-built (constructed) elevation were also developed for this study. The profiles were derived from topographic DTM's, the interim HEC-RAS model, and extensive searches through levee as-built drawings. Representative cross sections at the index points and several other key locations in the Sacramento River Basin are included as Plates 15 through 18. The cross sections illustrate the level of detail obtained from study topography and captured in the UNET model.

Structures Affecting Flow

Levees - A map showing the extent of levees in the Sacramento River system is provided in Plate 19. Levees in this basin are 20 to 30 feet high with 3 to 5 feet of freeboard. They are generally set back from the natural riverbank to accommodate flood flows. Bank protection, most often in the form of rock riprap, is discontinuous along much of the lower Sacramento River. Information about the integrity of the levees in the Sacramento River system was obtained from previous studies, including the Federal Emergency Action Team (FEAT) report of 1997 and others.

Bridges **-** The bridges that were identified in the Sacramento River Basin during this study are included in Table III-2. Some bridges within the basin were not included in the modeling effort because they do not significantly affect the hydraulics of the system. Information regarding bridge geometry, size, and other parameters included in the UNET model was obtained from bridge as-built drawings and field investigations. Bridges were not included in the model if sufficient data were not available.

There are two methods for modeling bridge hydraulics in UNET: the 'normal' and 'special' procedures. The *normal* bridge procedure simply subtracts the area of the embankments and bridge structure from the total cross sectional area. The decrease in cross sectional area and the increase in wetted perimeter combine to reduce conveyance through the bridge. The cross section of the bridge structure and the embankments is specified in UNET for the normal bridge method by the BT card. The normal method is most commonly used for perched bridges, where embankments are low and generally submerged, or where information about the bridge is not readily available.

The second method, the *special* bridge procedure, utilizes a family of free and submerged rating curves to simulate bridge hydraulics. The rating curves for the special bridge method consider the three types of hydraulic conditions that could occur at the bridge: free or low flow (when flow is below the bridge deck and only constricted by the piers), pressure flow (when the bridge deck is submerged and the bridge acts as a pressurized conduit or orifice), and weir flow (when flow is overtopping the bridge deck). The free and submerged rating curves are computed for the bridge-weir system for a range of headwater and tailwater elevations.

Bypasses **-** The following bypasses were included in the UNET model of the Sacramento Basin: Sutter Bypass, Tisdale Bypass, Sacramento Bypass, and Yolo Bypass.

Diversion/Impoundment Structures **-** Dams are generally not included in the model, with the exception of a few small impoundment structures (such as Daguerre Point on the Yuba River). The Moulton and Colusa Weirs, which transfer water into the Sutter Bypass, and the Fremont and Sacramento Weirs, which transfer water to the Yolo Bypass, were also modeled. No fish ladders were modeled.

Operating Rules - Diversion and impoundment structures were treated as hydraulic entities for modeling purposes. For example, the Colusa Weir was modeled as an uncontrolled lateral spillway 1,736 feet wide with a weir coefficient of 2.5 that sends water into the Colusa Bypass. The weir is set to begin spilling at elevation 58.89. The other weirs in the system are modeled similarly.

The Sacramento Weir was modeled as a controlled lateral spillway. All 48 gates on the weir were modeled in groups of 8. Each group of 8 gates is 300 feet wide and is explicitly named so that it can be referenced in boundary conditions for time series of gate openings.

Daguerre Point Dam was modeled as an inline spillway with a crest elevation of 125.3 and a length of 575 feet. Other small impoundment and diversion structures were modeled similarly.

TABLE III-2

BRIDGE/STRUCTURE INVENTORY IN THE SACRAMENTO RIVER BASIN

Watercourse	Roadway / Location	River Mile
Sacramento River	State Route 12	12.5
Sacramento River	State Route 160 (Isleton)	18.5
Sacramento River	Sacramento River Bridge at Walnut Grove	26.75
Sacramento River	State Route 160 (Paintersville)	33.5
Sacramento River	Sacramento River Bridge at Freeport	46
Sacramento River	Pioneer Memorial Bridge	58.5
Sacramento River	Tower Bridge	59
Sacramento River	I Street Drawbridge	59.5
Sacramento River	Interstate Route 80	62.5
Sacramento River	Interstate 5	70.5
Sacramento River	State Route 113	89.75
Sacramento River	State Route 20	134
Sacramento River	River Road near Colusa	143.5
Sacramento River	State Route 162	168.5
Sacramento River	Ord Ferry Road	184.25
Sacramento River	Gianella Bridge/State Route 32	199.5
Sacramento River	Gardiner Ferry Road/Woodson Bridge	218.5
Steamboat Slough	Howard Landing Ferry	20.5
Steamboat Slough	State Route 160	26
Sutter Slough	State Route 160	28.5
Georgiana Slough	Tyler Island Bridge	4.5
Georgiana Slough	Southern Pacific Railroad	5.75
Georgiana Slough	Andrus Island Road	12
Miner Slough	Jefferson Blvd. / Route 84	6
American River	Jibboom Street Bridge	0.2
American River	American River Bridge (Interstate 5)	0.3
American River	State Route 160 (double)	2
American River	Bike Bridge near River Mile 2.2	2.2
American River	Western Pacific Railroad	2.3
American River	Southern Pacific Railroad	3.8
American River	Interstate 80	4
American River	H Street Bridge	6.5
American River	Guy A West Bridge	7
American River	State Route 16 (Howe Avenue)	7.8
American River	Watt Avenue	9
American River	Bike Bridge at Goethe Park	14.6
American River	private unknown road	20
American River	Sunrise Boulevard	20.2
American River	Bridge Street	20.5
American River	Hazel Avenue	22.8
American River	Nimbus Dam	23
Natomas East Main Drain	American River Bridge (Interstate 5)	0.4
Feather River	Garden Highway / Highway 99	9
Feather River	Northern Pacific Railroad	28.5

Watercourse	Roadway / Location	River Mile
Feather River	5th Street	28.6
Feather River	10th Street	29
Feather River	Southern Pacific Railroad	30.5
Feather River	Oroville-Gridley Highway	50.8
Feather River	State Route 162	64.5
Feather River	State Route 70	
Bear River	State Route 70	3
Bear River	Western Pacific Railroad (parallel State Route 70)	3.5
Bear River	40 Mile Road / Pleasant Grove Road	
Bear River	State Route 65 near Wheatland	11
Yuba River	Western Pacific Railroad (downstream of State Route 70)	0.4
Yuba River	State Highway 65/70	0.5
Yuba River	Northern Pacific Railroad	1
Yuba River	Simpson Lane	1.7
Yuba River	Daguerre Dam	11
Yolo Bypass	Cache Slough	4
Yolo Bypass	unknown	7
Yolo Bypass	Old Railroad Grade	17.9
Yolo Bypass	Yolo Causeway (I-80)	25
Yolo Bypass	Southern Pacific Railroad	25.3
Yolo Bypass	Interstate Route 5 (double)	32.4
Yolo Bypass	State Route 16 / Main Street	32.6
Yolo Bypass	Sacramento Northern Railroad (trestle)	32.6
Yolo Bypass	Fremont Weir	39
Knights Landing Ridge	State Route 45	
Sacramento Bypass	Tule Canal	0
Sacramento Bypass	Sacramento Weir	1.9
Sutter Bypass	Sacramento Slough	1
Sutter Bypass	Nelson Slough	9
Sutter Bypass	State Route 113 / Sutter Causeway	14.5
Sutter Bypass	Kirkville Road (to Sacramento Avenue)	
Sutter Bypass	Sacramento Avenue (to Kirkville Road)	
Sutter Bypass	Gilsizer Slough	17.8
Sutter Bypass	Hughes Road (east and west bridges)	23.5
Sutter Bypass	Franklin Road	28.5
Sutter Bypass	Colusa Road / State Route 20	30.5
Sutter Bypass	Sacramento Northern Railroad	30.7
Sutter Bypass	Long Bridge	30.9
Sutter Bypass	West Channel Bridge	
Butte Slough	Mawson Bridge (Lower Pass Road)	6.7
Colusa Bypass	Colusa Weir / River Road	1
Tisdale Bypass	Southern Pacific Railroad	2.1
Tisdale Bypass	Reclamation Road	2.2
Tisdale Bypass	Tisdale Weir and Bridge	4.3
Three Mile Slough	State Route 160	0.1
Lindsey Slough	Local Road	0.8

Model Calibration

Sources of Data

Calibration data included high-water marks collected by the Corps of Engineers and others, and gage flow/stage data for the 1995, 1997, and other floods. Stage data were collected from official stream gages and from gages at weirs, pump stations, and other diversion structures.

Quality and Limitations of Data

The accuracy and quality of the hydraulic modeling results are limited by the availability of data used in the calibration. Data from 33 gages were available for the 1997 flood in the Sacramento River Basin.

UNET Calibration

The UNET model of the Sacramento River Basin was calibrated to the 1997 flood. Inflow hydrographs to the model were created using 1997 flood gage information from major tributaries and flood control structures. Model result hydrographs were compared to gage records and peak stage data where available. The UNET model parameters for Manning’s n, weir coefficients, and levee breaches were then adjusted as needed in an iterative procedure to modify the model results to more closely match the calibration data.

FLO-2D Calibration

The calibration of the FLO-2D model of the Sacramento River Basin was mostly accomplished using the 1997 flood; however, additional calibration was done using comparisons to the 1937 flood in the Colusa Basin. The main basis for comparison of the model with actual events was the areal extent of flooding and experience from recent large floods that caused levee breaches and flooding.

Calibration Results

The results of the model calibration verify the accuracy and usefulness of the model for hydraulic analyses. Observed vs. computed hydrographs are shown for key locations in the Sacramento River Basin in Plates 20 through 23. The model calibration task produced results that were more accurate for stage than for flow.

Sedimentation

Geomorphologic analyses addressing sedimentation and channel mechanics were not performed specifically for this study. The UNET model developed for the Sacramento River Basin does not simulate sediment transport or movement in the basin.

UNET/FLO-2D Model Results

UNET and FLO-2D were jointly used to model the hydraulic conditions in the Sacramento River Basin. The results of the modeling simulations of existing conditions are discussed in this section. Flow, stage, and frequency relationships calculated by the model are reported at the index points.

Flood Flow Routing

The models were used to predict routing for the seven n-year floods. The flood flows are based on the hypothetical storm centering method described previously.

Floodplain Delineations

Composite floodplains were developed for the 10-, 50-, 100-, 200-, and 500-year floods in the Sacramento River Basin. The floodplains are shown in Plate 24. These floodplains include the effects of operations at headwaters reservoirs located upstream of the major flood control reservoirs. As stated earlier, the composite floodplains developed for the purpose of this study are not traditional design-event floodplains, but represent combined floodplains from n-year storm centerings at each of the index points in the basin. It is important to note that these are not FEMA floodplain maps, nor are they intended to replace or supersede existing FEMA maps.

Stage Versus Frequency Relationships

Without-project condition stage versus frequency curves for the watercourses were developed at 62 index points corresponding to the 62 damage areas in the Sacramento River basin (see Plate 7 for locations). These rating curves were used in the HEC-FDA without-project analysis to define base conditions and are shown in Attachment D.1 located at the end of this appendix. Extreme care must be exercised when using data from these rating curves given the levee failure and numerous other assumptions used in the basin-wide hydraulic modeling effort. These curves represent only one of many possible stage versus frequency relationships.

SAN JOAQUIN RIVER BASIN

The San Joaquin River Basin covers approximately 13,500 square miles at Vernalis, extending about 120 miles from the northern to southern boundaries. The total watershed area is over 16,700 square miles. This includes drainage from the Central Sierra rivers and streams and the central Delta islands. The basin lies between the crests of the Sierra Nevada on the east and the Coastal Range on the west, and extends from the northern boundary of the Tulare Lake basin near Fresno to the confluence with the Sacramento River in the Sacramento-San Joaquin Delta. The San Joaquin River Basin is illustrated in Plate 25. The cities of Stockton, Modesto, Fresno, Merced, and Firebaugh are located in the San Joaquin River Basin.

Major tributaries to the San Joaquin River include the Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolumne, and Merced Rivers. These streams, in combination with the San

Joaquin River, contribute the major portion of the surface inflow to the basin. Minor streams on the east side of the valley include the Fresno and Chowchilla Rivers, and Burns, Bear, Owens, and Mariposa Creeks. Panoche, Little Panoche, Los Banos, San Luis, Orestimba, and Del Puerto Creeks comprise the minor streams on the west side. The west side streams contribute very little runoff. Numerous other small foothill channels carry water only during intense storms.

The San Joaquin River Basin and the Tulare Lake Basin are hydrologically connected through the Kings River. During high runoff periods, the James Bypass, a distributary channel of the Kings River, discharges water into the San Joaquin River near Mendota. In addition, floodwater is diverted to the San Joaquin River from Big Dry Creek Reservoir near Fresno. Flows from the rivers and creeks are significantly reduced by storage, diversions, and channel seepage losses as they cross the valley floor so that only a portion of the water at the foothill line reaches the San Joaquin River. The historic channel of the San Joaquin River carries little water during the summer months.

Flood control facilities in the San Joaquin River Basin consist of a complicated, interconnected series of natural, semi-modified, and constructed channels, with and without levees. In addition, a number of canals have been constructed throughout the valley with the primary function of water supply, but these canals may also be used for diverting and/or controlling flood runoff. Along the east side of the valley, multipurpose reservoirs are located primarily in the foothills and provide various levels of flood protection.

The flood management system includes levees along the lower portions of Ash and Berenda sloughs; Bear Creek; Fresno, Stanislaus, and Calaveras Rivers; and various leveed sections along the San Joaquin River. Major bypass systems in the San Joaquin River system include the Chowchilla, Eastside, and Mariposa Bypasses, which intercept and divert water from the San Joaquin River and many of its tributaries. The capacity of the San Joaquin River generally decreases moving downstream between Friant Dam and the Mariposa Bypass.

The Mokelumne, Cosumnes, and Calaveras Rivers are not included in the hydraulic modeling or data collection efforts for this study. These watercourses drain directly to the Delta and are treated separately from the Sacramento and San Joaquin River systems. Other major studies or projects are ongoing for both the Cosumnes and Calaveras Rivers.

Study Area and Model Extent

The San Joaquin River system was subdivided into various study reaches. The specific watercourses that have been included in the UNET model are illustrated in Plate 26 and listed in Table III-3. The extent of the FLO-2D modeling in the basin is also shown in Plate 26.

Index Points

Index points in the San Joaquin River Basin are shown in Plate 27. Also shown in Plate 27 are the economic impact areas, used in conjunction with output from the hydraulic models to develop economic impacts. The hydrologic-hydraulic handoff points for the San Joaquin River Basin are shown in Plate 28. The handoff points are locations where output from the hydrologic analysis was passed to the hydraulic models. Output at the index and handoff

TABLE III-3

UNET MODEL REACHES IN THE SAN JOAQUIN RIVER BASIN

Reach Name	UNET Reach No.	No. of Cross Sections	Upstream River Mile	Downstream River Mile	Upstream Boundary	Downstream Boundary
Sacramento River	1	264	264.20	202.96	BC	3
Fresno Slough	2	112	112.12	0.10	BC	3
San Joaquin River	3	161	202.94	166.44	1, 2	4, 12
San Joaquin River	4	77	166.38	145.87	3	15
Eastside Bypass	5	51	32.33	15.93	BC	7
Fresno River	6	58	8.36	0.19	BC	7
Eastside Bypass	7	13	15.85	13.92	5, 6	9
Berenda Slough	8	126	12.13	0.16	BC	9
Eastside Bypass	9	15	13.59	10.75	7, 8	11
Ash Slough	10	60	6.65	0.07	BC	11
Eastside Bypass	11	38	10.48	0.13	9, 10	13
SJR Connector Channel	12	8	10.53	0.11	3	13
Eastside Bypass	13	55	15.62	5.25	11, 12	29
Mariposa Bypass	14	18	4.23	0.52	BC	15
San Joaquin River	15	36	145.42	133.91	4, 14	10
Bear Creek	16	32	8.01	4.25	BC	17
Bear Creek/Deep Slough	17	28	4.02	0.07	29, 16	18
San Joaquin River	18	63	133.80	115.97	15, 17	20
Merced River	19	61	20.27	1.25	BC	20
San Joaquin River	20	119	115.97	81.49	18, 19	24
Tuolumne River	21	45	23.84	16.89	BC	23
Dry Creek	22	36	2.03	0.30	BC	23
Tuolumne River	23	82	16.73	0.87	21, 22	24
San Joaquin River	24	26	81.83	72.64	20, 23	26
Stanilaus River	25	36	13.94	0.58	BC	26
San Joaquin River	26	88	72.49	53.29	24, 25	30, 31
Eastside Bypass Spill	27	28	13.39	0.72	SA 3	SA 4
Owens Creek	28	20	0.97	0.12	BC	29
Deep Slough	29	24	5.12	0.42	13, 28	17
San Joaquin River	30	91	53.24	39.68	26	BC
Old River	31	18	135.51	131.45	26	32, 33
Middle River	32	88	28.32	15.92	31	BC
Old River	33	18	31.38	28.04	31	34, 36, 38
Grant Line Canal	34	10	27.93	26.07	33	BC
Paradise Cut	35	67	7.32	0.03	BC	37
Old River	36	3	31.87	34.51	33	37
Old River	37	2	31.43	31.33	35, 36	39
Crocker Cut	38	3	0.35	0.04	33	39
Old River	39	2	31.24	31.11	37, 38	40, 41
Old River	40	10	31.20	29.88	39	42
Old River Central Cut	41	6	1.24	0.01	39	42
Old River	42	8	29.80	28.98	40, 41	43, 44
Old River	43	2	28.93	28.82	42	45
Old River Oxbow Channel	44	3	0.39	0.02	42	45
Old River	45	2	28.78	28.68	43, 44	BC

Note: The acronym "BC" refers to a model boundary condition. The acronym "SA" refers to a storage area.

points may also be passed on to other analyses being performed for this study, such as economics or ecosystem function.

Base Data

The following section describes various elements of the UNET and FLO-2D models developed in the San Joaquin River Basin, including the inflow and tailwater hydrographs that form the upstream and downstream boundary conditions, topographic and hydrographic data, and modeled structures affecting flow.

Inflow Hydrographs

Inflow hydrographs for the San Joaquin River system have been constructed from available hydrologic data. The inflow hydrographs are described in detail and illustrated in the Hydrology Appendix; refer to that document for more information. There are 17 handoff points between the hydrology and hydraulics analyses, representing hydrograph input into the UNET model. All of the hydrographs are from the hydrologic analysis (refer to the Hydrology Appendix for more information). Six floods were modeled in the hydraulic analysis portion of this study: the 10-year, 25-year, 50-year, 100-year, 200-year, and 500-year frequency floods.

Tailwater Rating Curves

Although the UNET model is capable of using stage hydrographs to emulate a varying tailwater condition (e.g., tides), a series of tailwater rating curves was developed for the downstream boundary condition. This approach simplified the overall analysis and eliminated the dilemma associated with determining the appropriate contemporaneous conditions between riverine flows and tidal activity.

The tailwater rating curves are used at four locations in the San Joaquin River UNET model: 1) Grant Line Canal at Tracy Road, 2) Middle River at Highway 4, 3) Old River at Tracy Road, and 4) the San Joaquin River at the Stockton Deep Water Channel. These stage versus discharge rating curves represent the downstream boundary conditions in the UNET model and are shown in Plate 29. The rating curves were developed from tide gage data, which were generally located at the downstream model boundaries, listed above. The one exception to this was that data from two gages were used to establish the proper rating curve for the San Joaquin River as it enters the Stockton Deep Water Channel (approximately RM 39.68). The tide gages used for this location are located on the San Joaquin River at Burns Cutoff and at Brandt Bridge.

The rating curves were developed as follows. Stage versus frequency curves were obtained from a hydrology report prepared in support of the Sacramento-San Joaquin Delta Special Study (Hydrology, Sacramento-San Joaquin Delta, California, Special Study, US Army Corps of Engineers Office Report, February 1992) to establish n-year stages for the 10-, 50-, 100-, 200-, and 500-year events. These peak stages were assumed to correspond to the n-year peak discharge/tide combination. Preliminary discharges were assumed for the n-year stages to form stage versus discharge rating curves at each of the downstream boundaries. Using a trial and error approach and by running the UNET model for each of the n-year frequencies for the Vernalis storm centering, the assumed discharges were adjusted until a stable solution was found for the stage versus discharge rating curves. Thus, the points shown on the rating curves in Plate 29 represent the correct stage versus frequency relationships at each location. The rating curve for the San Joaquin River at the Stockton Deep Water Channel was developed by using a length-weighted average of the rating curves developed for the San Joaquin River at Burns Cutoff and at Brandt Bridge.

Topographic and Hydrographic Data

Hydrographic and photogrammetric surveys of the San Joaquin River Basin were conducted in 1998 and 2000. The survey area consists primarily of the mainstem of the San Joaquin River and includes reaches of the major tributaries, distributary sloughs, and the Eastside/Chowchilla Bypass. The data were collected for use as the geometry for development of basin-wide hydraulic modeling. A map showing the extent of topographic data in the San Joaquin River Basin is included as Plate 30.

Extent - Data were collected to produce 2-foot contour interval topographic mapping above and below the waterline along the watercourses. The mapping is accurate vertically to one-half the contour interval.

Sources – At the outset of this study, the only source of topographic data covering the entire study area that was available during model development was the USGS digitized 7.5 minute quadrangle maps. The topography shown on these maps was developed between about 1955 and 1962, making it approximately 40 years out of date. In a few cases, small-unconnected segments of mapping were also identified throughout the San Joaquin River system. This mapping was previously collected at various times for various purposes and was not considered a worthwhile source of data. Therefore, given the lack of detailed, up-to-date mapping, an extensive amount of topographic and hydrographic data was collected on the San Joaquin River system to support the hydraulic modeling efforts.

Above the waterline, topography was developed using standard photogrammetric mapping techniques with flight elevations above the mean terrain of 5,000 feet for the 2-foot contour mapping. In addition, hydrographic survey data were collected along river cross sections. The riverine survey data were collected in the summer of 1998 and an extensive photogrammetric survey of the overbanks was conducted in 2000. Cross sections from previous FEMA mapping efforts for the Tuolumne River and Dry Creek, in the vicinity of Modesto, were also used for this study.

In addition to the mapping collected by the Corps, the Bureau of Reclamation obtained a hydrographic and topographic survey of the San Joaquin River between Gravelly Ford (River Mile 230) and Friant Dam (River Mile 267) during the summer of 1998. This survey supports 2-foot contours and was used for the development of the UNET model between Friant Dam and Gravelly Ford.

Subsidence - Land subsidence is a significant factor in the southern part of the San Joaquin Valley. Since the topography for the FLO-2D models was based on approximately 40-year old DEM data, a means of estimating the subsidence that had occurred over this time period needed to be devised.

The effect of land subsidence was accounted for by first calculating subsidence rates based on data that were readily available, and then by adjusting the elevation data based on these rates. The information came from surveys performed as part of this study, a recent survey of control points along the southern portion of the Delta Mendota Canal, and reports written by the State of California and the USGS that documented past subsidence studies. Subsidence rates developed for the San Joaquin River Flood Control Project and vicinity were based on both survey data and historical subsidence documented to have occurred between the 1920s and 1966. The subsidence rate information can only be considered approximate because of the age of the data on which it is based and the limited amount of solid survey data.

The results of this effort are shown in Plate 31. The subsidence rates illustrated in the Plate were used to manually adjust the DEM data from which the geometry for the FLO-2D models was extracted. First, a 40-year subsidence surface was developed which estimates the subsidence that has occurred between 1958 and 1998 within the area being modeled. This surface was then subtracted from the DEM surface. This information was used to represent the ground surface when terrain data was required for areas outside of the area surveyed for this project.

It should be noted that the detailed (2-foot contour) mapping from 1998 for this part of the valley was based on control points which had not been adjusted by the NGS for some time. Therefore, in order to confirm the vertical accuracy of the mapping, the Sacramento District conducted a subsidence survey in 2000 which utilized stable control points located on either side of the valley. A maximum vertical difference of about 2 feet was found to exist between the control points near Mendota and the “true” elevations from the 2000 survey. At the time of this writing, the affected topographic mapping is being adjusted to reflect the “true” elevations in the southern part of the San Joaquin Valley. After the mapping has been adjusted, new cross sections will be extracted from the adjusted digital terrain models (DTM’s). These new cross sections will then be substituted into the UNET model.

Channel Profiles and Representative Cross-Sections

Summary plots of channel profiles in the San Joaquin River system are provided in Plates 32 through 36. The channel profiles included in this appendix include left and right bank elevations, and bottom of channel elevation. Additional profiles for left and right landside elevation and levee as-built (constructed) elevation were also developed for this study. The profiles were derived from topographic DTM’s, the interim HEC-RAS model, and extensive searches through levee as-built drawings. Representative cross sections at the index points and several other key locations in the San Joaquin River Basin are included as Plates 37 through 40. The cross sections illustrate the level of detail obtained from study topography and captured in the UNET model.

Structures Affecting Flow

Levees – The extent of levees in the San Joaquin River system is shown in Plate 41. Levees in this basin are generally between 6 and 8 feet high, which is smaller than those in the Sacramento System. This is largely because the levees in the San Joaquin River Basin were designed for spring snowmelt floods with a lower return frequency than the levees in the Sacramento River Basin, which were designed for larger winter runoff. Levees are present along scattered reaches of the San Joaquin River, starting near Gravelly Ford on the upper San Joaquin River and becoming more continuous along the lower reaches of the river.

Bridges - The bridges that were identified in the San Joaquin River Basin during this study are included in Table III-4. Some bridges within the basin were not included in the modeling effort because they do not significantly affect the hydraulics of the system.

TABLE III-4

BRIDGE/STRUCTURE INVENTORY IN THE SAN JOAQUIN RIVER BASIN

Watercourse	Roadway / Location	River Mile
San Joaquin River	Rough and Ready Railroad	39.95
San Joaquin River	West Charter Way/Route 4	40.05
San Joaquin River	Santa Fe Railroad	41.40
San Joaquin River	Garwood Bridge	42.15
San Joaquin River	Howard Road Bridge	46.15
San Joaquin River	Southern Pacific Railroad	56.20
San Joaquin River	Manthey Road Bridge	56.22
San Joaquin River	Highway 120	56.23
San Joaquin River	Highway 5 (South Bound)	56.25
San Joaquin River	Highway 5 (North Bound)	56.25
San Joaquin River	Western Pacific Railroad	56.80
San Joaquin River	Durham Ferry Road/Airport Way	69.80
San Joaquin River	Highway 132/Maze Blvd.	74.90
San Joaquin River	Grayson Road	87.10
San Joaquin River	Las Palmas Avenue (West Main St?)	96.20
San Joaquin River	Crows Landing Road/Layered Slough	104.67
San Joaquin River	Hills Ferry Road	115.90
San Joaquin River	Highway 140	123.30
San Joaquin River	Highway 165	131.00
San Joaquin River	Erreca Road/Turner Island Road	155.15
Pick Anderson Bypass	Erreca Road/Turner Island Road	
San Joaquin River	West Washington Road	168.00
Bypass Connector Channel	Washington Road	167.40
San Joaquin River	Diversion Structure	167.50
San Joaquin River	Highway 152 (Westbound)	172.00
San Joaquin River	Highway 152 (Eastbound)	172.00
San Joaquin River	7.5 Avenue	193.20
San Joaquin River	Mendota Dam	202.60
San Joaquin River	Upper Eastside Bypass Diversion Structure	213.95
San Joaquin River	Skaggs Bridge (Highway 145)	232.00
San Joaquin River	Access Bridge	238.60
San Joaquin River	Highway 99	243.30
San Joaquin River	Southern Pacific Railroad	243.32
San Joaquin River	Topeka/Sante Fe Railroad	245.21
San Joaquin River	Gravel Pit Bridge	250.10
San Joaquin River	Abandoned Bridge	250.20
San Joaquin River	Lanes Bridge (Highway 41 Southbound)	252.40
San Joaquin River	Lanes Bridge (Highway 41 Northbound)	252.40

Watercourse	Roadway / Location	River Mile
San Joaquin River	Highway 41 Frontage Road	252.45
San Joaquin River	Ledger Island Bridge	259.20
San Joaquin River	North Fork Road Bridge	263.70
Old River	Tracy Blvd.	26.95
Old River	Farm Access Bridge	30.00
Paradise Cut	Paradise Road Bridge	2.90
Paradise Cut	Farm Access Bridge	4.08
Paradise Cut	Southern Pacific Railroad	5.40
Paradise Cut	Manthey Road Bridge	6.05
Paradise Cut	Highway 5 (Southbound)	6.06
Paradise Cut	Highway 5 (Northbound)	6.08
Paradise Cut	Highway 205	6.15
Paradise Cut	Union Pacific Railroad	6.75
Grant Line Canal	Tracy Blvd.	27.95
Middle River	Middle River Bridge/Highway 4	16.10
Middle River	Tracy Blvd.	18.10
Middle River	Howard Road Bridge	23.20
Middle River	Undine Road	26.90
Tuolumne River	Shiloh Bridge	3.60
Tuolumne River	Carpenter Road	12.90
Merced River	River Road/Stevinson Bridge	1.10
Merced River	Historic Bridge	1.15
Merced River	Highway 165/Milliken Bridge	12.00
Merced River	Highway 99	20.95
Merced River	Southern Pacific Railroad	20.97
Bear Creek	Bear Creek Patrol Bridge	1.00
Bear Creek	Harney Access Bridge	3.90
Bear Creek	Eastside Canal Patrol Road	7.95
Deep Slough	Green House Road/Dickinson Ferry	3.80
Deep Slough	Bifurcation Structure	6.65
Mariposa Bypass	Diversion Structure	0.85
Mariposa Bypass	Bifurcation Structure	4.20
Lower Eastside Bypass	Eastside Bypass at Mariposa Bypass	6.40
Lower Eastside Bypass	Mayfield Access Bridge	1.00
Lower Eastside Bypass	Sandy Mush Bridge	2.20
Lower Eastside Bypass	Control Structure	3.00
Lower Eastside Bypass	Chamberlain Road Access Bridge	5.70
Upper Eastside Bypass	West Washington Bridge	1.30
Upper Eastside Bypass	Highway 152 Bridge (Eastbound)	5.00
Upper Eastside Bypass	Highway 152 Bridge (Westbound)	5.00
Upper Eastside Bypass	Avenue 21	6.70
Upper Eastside Bypass	Road 4	8.90
Upper Eastside Bypass	Avenue 18.5	11.60
Upper Eastside Bypass	Triangle T	13.10
Upper Eastside Bypass	Road 9	15.80
Upper Eastside Bypass	Dam	15.85
Upper Eastside Bypass	Dam	16.25

Watercourse	Roadway / Location	River Mile
Upper Eastside Bypass	Avenue 14	18.70
Upper Eastside Bypass	Madera Road Bridge	24.50
Upper Eastside Bypass	Firebaugh Fresno Road	26.00
Upper Eastside Bypass	Chowchilla Bypass Diversion Structure	32.25
Ash Slough	Grade Control/Diversion Structure	0.20
Ash Slough	Grade Control/Diversion Structure	0.50
Ash Slough	Grade Control/Diversion Structure	0.90
Ash Slough	Grade Control/Diversion Structure	1.30
Ash Slough	Avenue 21	2.30
Ash Slough	Road 8	3.50
Ash Slough	Check Structure/Road	4.50
Ash Slough	Ashview Lateral Road	4.95
Ash Slough	Highway 152 (Eastbound)	6.30
Ash Slough	Highway 152 (West bound)	6.30
Berenda Slough	Road 9 Bridge	1.55
Berenda Slough	Avenue 18	5.00
Berenda Slough	Diversion Structure	5.05
Berenda Slough	Avenue 18.5	5.50
Berenda Slough	Road 13	6.55
Berenda Slough	Avenue 19.5	7.35
Berenda Slough	Avenue 20	7.95
Berenda Slough	Avenue 20.5	8.50
Berenda Slough	Road 14	8.75
Berenda Slough	Avenue 21	9.50
Berenda Slough	Avenue 21.5	10.15
Berenda Slough	Avenue 22	10.70
Berenda Slough	Abandoned Diversion Structure	10.85
Berenda Slough	Avenue 22.5	11.30
Berenda Slough	Highway 152 (Westbound)	12.00
Berenda Slough	Highway 152 (Eastbound)	12.00
Fresno River	Access Road	3.29
Fresno River	Road 16	7.30
Fresno River	Diversion Structure	7.30
Fresno Slough	Private Road	0.20
Fresno Slough	Southern Pacific Railroad	4.60
Fresno Slough	Whites Bridge/Highway 180	4.80
Fresno Slough	California Avenue	6.55
Fresno Slough	Southern Pacific Railroad	12.45
Fresno Slough	James Road	14.00
James Bypass	Southern Pacific Railroad	0.80
James Bypass	James Road	2.60

Information regarding bridge geometry, size, and other parameters included in the UNET model was obtained from bridge as-built drawings and field investigations.

Bypasses - The Chowchilla Canal Bypass and the Eastside Bypass are both represented in the UNET model. During high flow, these facilities generally carry the majority of the flow in the San Joaquin Valley, with a greater flow capacity than the mainstem of the San Joaquin River. The bypasses also intercept flow from various eastside streams, including the Fresno, Chowchilla, and Bear Rivers. The Eastside Bypass is hydraulically connected to the San Joaquin River by the Mariposa Bypass, which runs east to west. Both bypasses have levees.

Diversion/Impoundment Structures – The major dams are not included in the model; however, several of the smaller impoundment/diversion structures are explicitly included in the UNET model. These include the Mendota Dam, the Chowchilla/Eastside Bypass bifurcation structure, and the control structures located at the head of Deep Slough and the Mariposa Bypass. Fish ladders were not included in the model.

> **Operating Rules** - Diversion and impoundment structures were treated as hydraulic entities for modeling purposes. The bifurcation structure from the San Joaquin River to the Eastside/Chowchilla Bypass was modeled to control the upstream water surface in the San Joaquin River to an elevation of 172.5 feet using a rating table that divides the flows between the San Joaquin River and the Eastside/Chowchilla Bypass. The model also assumes that 12,500 cfs is the largest flow that will reach the bifurcation structure because higher flows would cause upstream levee breaches.
>
> The bifurcation structure from the Eastside/Chowchilla Bypass to the Mariposa Bypass and Deep Slough is modeled in the same manner, with the upstream pool elevation being held to an elevation of 97.0 feet (NGVD 1929) and flows being divided between the Mariposa Bypass and Deep Slough. Flows in excess of 30,000 cfs are assumed to overtop the control structure and surrounding levees.

The San Joaquin River Control Structure is modeled as a 100-cfs diversion to the old San Joaquin River Channel. Stages greater than 113.0 feet elevation (NGVD 1929) are assumed to overtop the embankment and travel down the abandoned river channel.

Model Calibration

Sources of Data

Several sources of data were used to calibrate the model for the San Joaquin River system. These sources included historical hydrological data, high water marks collected by the Corps of Engineers and others, and gage readings from official stream gages and from gages at weirs and other diversion structures.

Quality and Limitations of Data

The accuracy and quality of the hydraulic modeling results are limited by the availability of data for the San Joaquin River system. Data from several gages were available for the 1995 and 1997 floods in the San Joaquin River Basin.

UNET Calibration

Calibration of the San Joaquin River Basin UNET model was focused on the 1995 flood, and in some cases, the data from the 1997 flood was used. Model result hydrographs were compared to gage records and peak stage data where available. The UNET model parameters for Manning's n, weir coefficients, and levee breaches were then adjusted as needed in an iterative procedure to modify the model results to more closely match the calibration data. The model calibration task produced results that were more accurate for stage than for flow.

FLO-2D Calibration

The calibration of the FLO-2D model of the San Joaquin River Basin mostly focused on the 1997 flood, but calibration also included comparisons to the 1938, 1952, 1955, and 1958 floods. The main basis for comparison of model output with actual flooding was the areal extent of flooding along the river.

Results

The results of the model calibration verify the accuracy and usefulness of the model for hydraulic analyses. Observed vs. computed hydrographs are shown for key locations in the San Joaquin River Basin in Plates 42 through 45. The model calibration task produced results that were more accurate for stage than for flow.

Sedimentation

Geomorphologic analyses addressing sedimentation and channel mechanics were not performed specifically for this study. The UNET model developed for the San Joaquin River Basin does not simulate sediment transport or movement in the basin.

UNET/FLO-2D Model Results

UNET and FLO-2D were jointly used to model the hydraulic conditions in the San Joaquin River Basin. The results of the modeling simulations of existing conditions are discussed in this section. Flow, stage, and frequency relationships calculated by the model are reported at the index points.

Flood Flow Routing

Because the UNET computer model is an unsteady, dynamic flow model, it is used to route flood hydrographs through the San Joaquin River Basin. Inflow hydrographs, either historic or synthetic (see Hydrology Appendix for description of development of synthetic flood hydrographs) are used as upstream and internal boundary conditions for the model. The flood routing in UNET uses the finite difference form of the unsteady flow equations to compute the progression of flood waves through the system. It takes into account overbank storage, levee breaches, diversions to other basins, and other internal boundary conditions when computing the flood routing.

Floodplain Delineations

Composite floodplains were developed for the 10-, 50-, 100-, 200-, and 500-year floods in the San Joaquin Valley. The floodplains are shown in Plate 57. As stated earlier, the composite floodplains developed for the purpose of this study are not traditional design-event floodplains, but represent combined floodplains from n-year storm centerings at each of the index points in the basin. It is important to note that these are not FEMA floodplain maps, nor are they intended to replace or supercede existing FEMA maps.

Stage Versus Frequency Relationships

Without-project condition stage versus frequency curves for the watercourses were developed at 42 index points corresponding to the 42 damage areas in the San Joaquin River basin (see Plate 22 for locations). These rating curves were used in the HEC-FDA without-project analysis to define base conditions and are shown in Attachment D.2 located at the end of this appendix. Extreme care must be exercised when using data from these rating curves given the levee failure and numerous other assumptions used in the basin-wide hydraulic modeling effort. These curves represent only one of many possible stage versus frequency relationships.

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CHAPTER IV

CONCEPT EVALUATIONS

Chapters IV and V describe the application of hydraulic modeling tools for the formulation and development of system-wide modifications to the flood management system. Included in this chapter is a description of the modeling approaches used to evaluate the initial concepts.

The concepts described in this chapter are not alternative plans. Instead, the development and refinement of these initial formulation concepts serves multiple purposes: refining the process of developing and evaluating master plans, familiarizing the Comprehensive Study Team in the use of the various hydrologic and hydraulic tools available, and developing important information about the hydraulic performance of a range of flood damage reduction and ecosystem restoration measures.

Concept evaluations were conducted to see how the system would respond to various types of modifications. Each concept explored a different goal and combination of features to achieve that goal. Each concept represents one potential way to attain the goal specified; there are countless different combinations of features that could potentially be explored to attain the same goal. The nature of modeling necessitates that details about features - such as locations, sizings, and operations - be assumed. Because of this, the output from the models is similarly detailed. However, for this level of study, it is the general representation of potential effects that is important, and not the specific details.

MODELING APPROACH

An iterative approach using a combination of hydrologic and hydraulic models was used to develop and evaluate the concepts. The original modeling approach proposed for the Comprehensive Study would have involved the use of multiple UNET runs to arrive at the desired combination of components. However, due to the length of time required to make multiple UNET runs, an alternate approach was developed and tested during the formulation of the concepts. This approach was revised and refined numerous times during the formulation process.

In order to determine project performance, output from the UNET analyses, in the form of stage versus frequency curves at selected index points, was passed on to an HEC-FDA model. The specific process used to develop input for the FDA analysis is more fully discussed in the Technical Studies Report.

Performance Objectives

The purpose of a performance objective is to provide a means of measuring success. Performance objectives provide targets that guide the formulation process toward a desired outcome and provide a threshold for accomplishment. Performance objectives must be in-line with the overall goals of the Comprehensive Study to provide flood damage reduction and ecosystem restoration. Performance objectives may be hydraulic in nature, such as establishing flow objectives, or may address other factors such as land use, the environment, or socio-political goals.

Specific performance objectives for the concepts are described in detail later in this chapter. In general, the performance objectives for Concept 1 are focused on restoring the function and reliability of the existing flood control system. The performance objectives for Concept 2 are focused on attaining consistent levels of flood protection for agricultural and urban areas, while the performance objectives for Concept 3 are focused on improving the health and vigor of the natural stream systems.

One performance objective common to all concepts is that flows entering the Sacramento - San Joaquin Delta (Delta) do not increase as a result of with-project improvements. In the Sacramento River Basin, a 50-year event flow of 485,000 cfs at the latitude of Sacramento was determined to represent existing conditions entering the Delta. In the San Joaquin River basin, a 50-year event flow of 200,000 cfs at Vernalis was determined to represent existing conditions. Whenever possible, all concepts also avoided impacts to major physical infrastructure such as interstate highways, railroads, major pumping facilities, heavy industrial areas, and municipal facilities.

Concept Components

Each concept has a dominant theme that guides the selection of components or measures to meet specific performance objectives. Concept components can be organized into three categories: conveyance, storage, and floodplain management. Conveyance components include levee realignment and reconstruction, construction of new floodways or bypasses, strengthening existing levees, and raising levees. Storage components include measures such as re-operation of existing reservoirs to increase flood control space, re-operation of reservoirs to meet new objective releases, construction of new upstream storage, and development of storage within the floodplain, also called transitory floodplain storage. Floodplain management measures include moving at-risk development out of flood-prone areas, floodproofing structures within the floodplain, and institutional measures to modify land use general plans and discourage inappropriate development in floodplains. Some of these components are not hydraulic in nature, such as floodplain management measures, and were not incorporated into the modeling effort. Table IV-1 provides a qualitative comparison of the extent of each type of measure that would be included in the concepts.

As indicated by Table IV-1, Concept 1 focuses on rehabilitation and improvement of existing flood control facilities in favor of the construction of new facilities. Concept 2 stresses the use of upstream flood storage, in both existing and new facilities, to meet flood damage reduction goals in the lower watersheds. Concept 3 focuses on meeting study goals primarily through the use of levee realignments, reservoir re-operation and floodplain storage components that provide maximum ecosystem benefits.

TABLE IV-1

COMPONENTS USE IN INITIAL CONCEPTS

Component	**Concept 1 - Restore System Conveyance**	**Concept 2 - Level of Performance**	**Concept 3 – River Functions**
Conveyance:			
Strengthen existing conveyance system	High	Moderate	Moderate
Enlarge conveyance system	Low	Low	High
Storage:			
Increase foothill storage and flow regulation	Moderate	High	Low
Increase floodplain storage	Moderate	Low	High
Floodplain Management	Moderate	Low	High
New Habitat	Moderate	Moderate	High

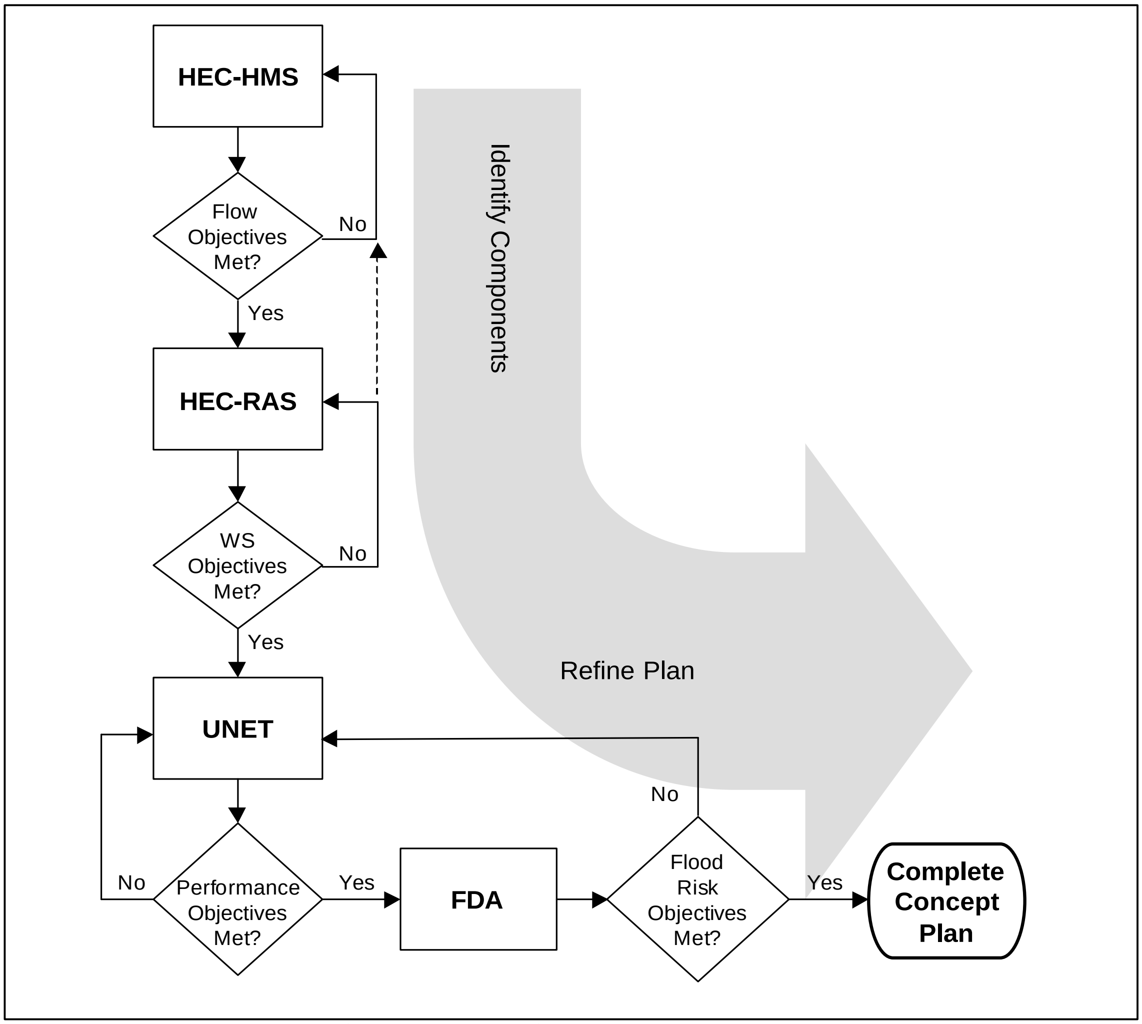
Formulation Approach

The basic formulation approach used for the concepts consists of identifying themes and performance objectives that would drive the selection of flood damage reduction and ecosystem restoration components for each concept. Components are sized and refined using an iterative modeling approach, beginning with the use of a simple, abbreviated hydraulic model and concluding with detailed modeling using UNET. The formulation approach uses the abbreviated hydraulic models to quickly arrive at the general combination and sizing of components that would meet the established performance objectives. The concept is then fine-tuned using the detailed, and more time-intensive, hydraulic models described in Chapters II and III of this document. The exception to this approach is in the Sacramento River Basin, where a more detailed HEC-HMS model was used in lieu of the UNET model to refine the concepts.

Concept Refinement

Basic concepts were initially outlined using information about the existing river systems then modeled using an abbreviated HEC-HMS model. Modifications were made to concept components until all performance objectives were met to the greatest extent possible. Modifications included changes to the general channel geometry, weir or bypass operations, and the addition of storage components. Refined HEC-HMS results for each concept were then passed to HEC-RAS, as needed, to verify water surface elevations and account for backwater conditions. Further refinements were made to the concepts if water surfaces in HEC-RAS indicated that the objectives had not been met. Figure IV-1 shows the iterative process used to develop the concepts.

FIGURE IV-1 CONCEPT MODELING PROCESS



Note: The abbreviation "WS" refers to "water surface". FDA is the Corps Flood Damage Assessment model.

UNET Verification

The UNET model was used to simulate the various concepts in the San Joaquin River Basin after initial refinement using the HEC-HMS and HEC-RAS models. The UNET models for the concepts were modified to reflect channel geometry changes and other components developed in the abridged HEC-HMS model. Revised cross sections from the intermediate HEC-RAS models were used as the basis for the revised UNET channel geometry. A different approach was used in the Sacramento River Basin, where more detailed HEC-HMS models were developed and used in lieu of the UNET model. The UNET models provide a more detailed simulation of the basins and could be used in subsequent alternative modeling.

HEC-HMS / HEC-RAS SIMULATION PROCESS

The purpose of the HEC-HMS model is to simply and quickly estimate the coincidence and attenuation of river flows at index points under various frequency storm events based on potential changes in channel geometry and reservoir storage. In the Sacramento River Basin, output flow information from the HEC-HMS model was used as input to the HEC-RAS models to identify influences on river stages. In this iterative process, the HEC-RAS models are modified to reflect channel geometry changes represented in HEC-HMS. Results from the HEC-RAS models are then used to estimate any additional changes in channel geometry and off-stream storage required to meet the concept's performance objectives. The goal is to iterate between the HEC-HMS and HEC-RAS models until there is an indication of channel geometry throughout the river system that would convey various frequency river flows to the Delta without decreasing the existing level of protection for any given reach. After the primary system components are identified in HEC-HMS, they can be modeled and refined, if necessary, in the UNET model. In the San Joaquin River Basin, no iterations were performed in HEC-RAS and model results were passed directly from HEC-HMS to UNET.

Development of HEC-HMS Models

The Hydrologic Modeling System (HEC-HMS) simulates precipitation-runoff and routing processes, and is the successor to the HEC-1 program. HEC-HMS represents physical watersheds as a network of connected elements, which may include sub-basins, stream reaches, junctions, reservoirs, diversions, sources, and sinks. The program is capable of open-channel routing using a variety of hydrologic routing methods. For the purpose of this study, channels with overbank areas were modeled with the Muskingum-Cunge method and an 8-point cross section. Flow routing is performed from upstream to downstream and does not include the effects of backwater. Previously developed 30-day regulated and unregulated streamflow hydrographs were used as program input; consequently, the precipitation and rainfall-runoff simulation elements of HEC-HMS were not required for this application.

HEC-HMS Input Data Development

The Sacramento River Basin HEC-HMS model includes channel geometry data for the Sacramento River from Woodson Bridge (Vina) to Sutter Slough; Feather River from Oroville to the Sacramento confluence; lower reaches of the Yuba and Bear Rivers; the Sutter Bypass; and the Yolo Bypass from Fremont Weir to Liberty Island. The Sacramento River and its distributary system downstream of Sutter Slough (entering the Delta) was not modeled because this area is highly influenced by tide cycles (backwater) which HEC-HMS is not capable of simulating. The model includes the eight primary diversion weirs along the Sacramento River (M&T, 3B's, Goose Lake, Moulton Weir, Colusa Weir, Tisdale Weir, Freemont Weir, and Sacramento Weir). The Sacramento River Basin model also accounts for the routing of flows through the Butte Basin. A schematic of the Sacramento River Basin HEC-HMS model is included as Plate 47. Two versions of the Sacramento River Basin HEC-HMS model were developed: one that contains all flow within the main channels, and a second that uses diversions to approximate levee failures and flow leaving the channel.

The San Joaquin River Basin HEC-HMS model includes channel geometry data for the San Joaquin River from Friant Dam to Vernalis; Chowchilla and Eastside Bypasses; and lower reaches of the Fresno, Bear, Merced, Tuolumne, and Stanislaus river systems. The San Joaquin River downstream of Vernalis was not modeled because this area is highly influenced by tide cycles (backwater). The San Joaquin River bifurcation structures at the Chowchilla Bypass and the Mariposa Bypass were also represented in the HEC-HMS model. A schematic of the San Joaquin River Basin HEC-HMS model is included as Plate 48.

Channel Geometry - Channel geometry is represented in HEC-HMS in the form of eight-point cross sections (one data point for each left and right levee, overbank, bank, and bottom of channel). The HEC-HMS cross sections represent average channel geometry along a river reach. This is in contrast to the cross sections used in the UNET and HEC-RAS models, which represent actual topography at a given location. Each HEC-HMS cross section represents about five miles of river, the length of the reach being adjusted as necessary to accommodate incoming tributaries, stream junctions, or significant changes in channel geometry. An example eight point cross section is shown in Figure IV-2.

A spreadsheet tool was created to facilitate the development of the representative HEC-HMS cross sections. The spreadsheet uses output from HEC-RAS in the form of channel width, area, and Manning’s n parameters at each HEC-RAS cross section. Average geometric parameters are calculated from the HEC-RAS cross section data within each HEC-HMS reach. A graphical eight-point cross section is then defined that approximates the average HEC-RAS parameters.

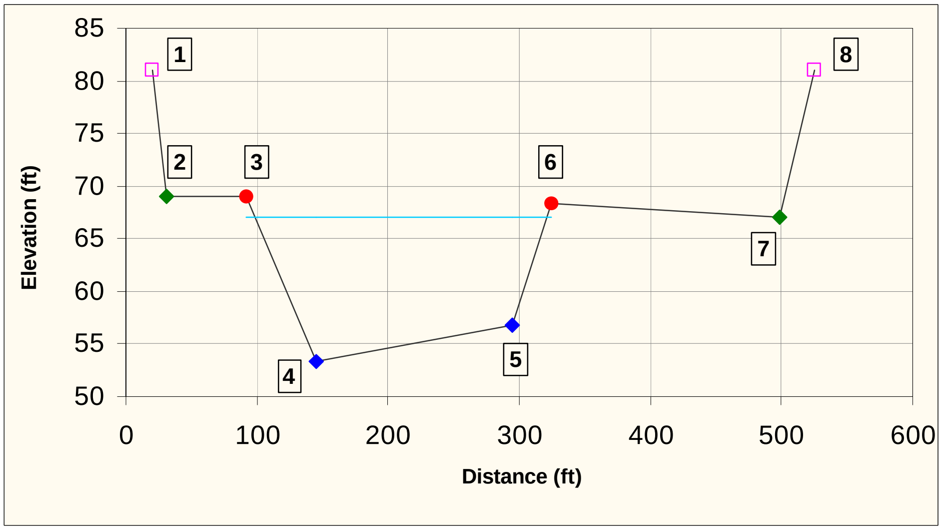
Weir Operation - Weir simulations in HEC-HMS are based on flow alone, which differs from the stage-based input data used by UNET. Weir operation parameters for HEC-HMS require a relationship between flow in the main river and flow over the weir. Descriptive properties of the weirs (e.g. length, weir coefficient) were obtained from UNET input files and the weirs were then simulated in HEC-RAS. Output from HEC-RAS was then used to develop the necessary flow-based weir operation curves for HEC-HMS. The weir diversion tables in HEC-HMS were modified, if necessary, during the model verification process to more closely simulate existing weir operations.

In the Sacramento River basin, the following weirs were included in the HEC-HMS model: M&T, 3B’s and Goose Lake overflows to the Butte Basin, Moulton Weir, Colusa Weir, Tisdale Weir, Freemont Weir, and the Sacramento Weir. There were no weirs modeled in the San Joaquin River basin.

Connections and Bypasses - All major bypasses and confluences were modeled in the HEC-HMS models. In the Sacramento River basin these elements included the Sutter Bypass, Tisdale Bypass, Yolo Bypass, and Sacramento Bypass. In the San Joaquin River basin these elements included the Chowchilla Bypass and bifurcation structure, Mariposa Bypass, and Eastside Bypass. The flow split at the Chowchilla Bypass bifurcation was modeled using existing information from the UNET model.

Levee Breach Simulation – A method was developed to generally approximate levee breach conditions in the HEC-HMS model. As described in Chapter III, UNET compares the calculated water surface elevation with an assigned likely failure point (LFP) elevation to trigger a levee breach. Unlike UNET, HEC-HMS does not calculate water surface elevation.

FIGURE IV-2 EIGHT-POINT HEC-HMS CROSS SECTION



The cross section shown above is typical of the 8-point cross sections in the HEC-HMS models. Points 1 and 8 represent top of levee elevations, 2 and 7 define overbank areas, 3 and 6 represent top of bank, and 4 and 5 define channel geometry.

Therefore, levee breaches in HEC-HMS must be described in terms of flow using diversion tables. In order to accomplish this, a spreadsheet was developed using reach capacity calculations (previously performed using HEC-RAS) to develop flows corresponding to the various LFP elevations. For each HEC-HMS reach, rating curves were developed to approximate each levee failure within the reach and account for water leaving the system through the breaches. Water leaving the main channels through levee breaches was not conserved or recycled back into downstream waterways in the HEC-HMS models. This assumption was adopted because return flows from levee breaches are not likely to have a significant impact on flood peaks. Levee breach assumptions were only used in the HEC-HMS model of the Sacramento River Basin.

Input Flow Data - Previously developed 30-day storm hydrographs were used as input data to the HEC-HMS models. The source of the hydrographs was either the base condition hydrology (which also acts as input to the UNET models) or from UNET simulations. The UNET infinite channel simulations assume no levee breaks, containing all flows within the channels and designated floodways. The UNET baseline simulations assume levee failures have occurred and that water can leave the channels and flow into overbank areas. Flow inputs to the Sacramento and San Joaquin HEC-HMS models are summarized in Tables IV-2 and IV-3, respectively.

HEC-HMS Model Verification

Results from the 50-year HEC-HMS models were compared against results from the 50-year UNET simulations. In the Sacramento River Basin, the comparison between HEC-HMS and UNET results was made both with- and without the levee breach diversions. The two

TABLE IV-2

SACRAMENTO RIVER BASIN HEC-HMS MODEL FLOW INPUTS

Flow Input	Source	Description
Sacramento River		
Vina / Woodson Bridge	UNET baseline	Simulated flow at Vina / Woodson Bridge
Big Chico Creek	Base hydrology	Regulated Big Chico flow u/s Sacramento R
Stony Creek	Base hydrology	Regulated Stony Creek flow u/s Sacramento R
Natomas Cross Canal	UNET baseline	Simulated Cross Canal flow u/s Sacramento R
American River	UNET baseline	Simulated American River flow at Sacramento
Butte Basin		
Little Chico Creek	UNET baseline	Simulated Little Chico Ck u/s Angel Slough
Feather River System		
Feather at Thermalito	Base hydrology	Regulated Feather River flow at Thermalito
Honcut Creek	Base hydrology	Regulated Honcut Creek flow u/s Feather River
Jack Slough	UNET baseline	Simulated Jack Slough flow u/s Feather River
Yuba at Englebright	Base hydrology	Regulated Yuba River flow at Englebright
Deer Creek	Base hydrology	Regulated Deer Creek flow u/s Yuba River
Bear River	Base hydrology	Regulated Bear River flow u/s of Dry Creek
Dry Creek	Base hydrology	Regulated Dry Creek flow u/s Bear River
Yankee Slough	UNET baseline	Simulated Yankee Sl flow u/s Bear River
UP Intercept / Best Slough	UNET baseline	Simulated UP Intercept & Best Slough flows
Sutter Bypass		
Cherokee Canal	UNET baseline	Simulated Cherokee Canal flow at Sutter Byp
Wadsworth Canal	UNET baseline	Simulated Wadsworth Canal flow at Sutter Byp
Yolo Bypass		
Knights Landing RC	UNET baseline	Simulated Knights Landing flow u/s Bypass
Cache Creek	Base hydrology	Regulated Cache Creek flow u/s Yolo Bypass
Putah Creek	Base hydrology	Regulated Putah Creek flow u/s Yolo Bypass

Notes: The acronyms "u/s" and "d/s" refer to upstream and downstream, respectively.

verification comparisons were made to account for conditions in which all flow was contained in the channels ("infinite channel"), and conditions in which flow was leaving the system through breaches triggered by the LFP. In the San Joaquin River Basin, the HEC-HMS model did not include any levee breach simulation and was therefore calibrated using UNET infinite channel output. Adjustments were made to the HEC-HMS models, as appropriate, until results were comparable to the UNET results. HEC-HMS adjustments included channel geometry changes, reach length adjustments, and weir or bifurcation modifications. A detailed HEC-HMS calibration was not performed because the models are intended to be used for refining concepts before simulation in the UNET models, not as stand-alone models. The results from the calibrated HEC-HMS models were used as a baseline for comparison with HEC-HMS simulations for each of the concepts. Flow adjustment factors, based on the percent difference between peak HEC-HMS flows and peak UNET flows, were used to scale HEC-HMS peak flows before passing them to the HEC-RAS models. The adjustment factors help reconcile differences in the HEC-HMS results that could not be remedied during the verification process.

TABLE IV-3

SAN JOAQUIN RIVER BASIN HEC-HMS MODEL FLOW INPUTS

Flow Input	Source	Description
San Joaquin River		
Friant Dam	Base hydrology	Regulated San Joaquin River flow at Friant
Little Dry Creek	Base hydrology	Regulated Little Dry Ck flow at San Joaquin River
Fresno Slough	Base hydrology	Regulated Fresno Sl flow u/s San Joaquin River
Los Banos Creek	Base hydrology	Regulated Los Banos Ck flow at San Joaquin River
Merced River	Base hydrology	Regulated Merced River flow d/s New Exchequer
Orestimba Creek	Base hydrology	Regulated Orestima Creek flow at San Joaquin R.
Puerto Creek	Base hydrology	Regulated Puerto Creek flow at San Joaquin River
Tuolumne river	Base hydrology	Regulated Tuolumne River flow d/s Don Pedro
Dry Creek	Base hydrology	Regulated Dry Creek flow u/s of Tuolumne River
Stanislaus River	Base hydrology	Regulated Stanislaus River flow u/s San Joaquin R
Deep Slough / Eastside Bypass		
Fresno River	Base hydrology	Regulated Fresno River flow u/s Eastside Bypass
Berenda Slough	Base hydrology	Regulated Berenda Slough flow u/s Eastside Bypass
Ash Slough	Base hydrology	Regulated Ash Slough flow u/s Eastside Bypass
Mariposa Creek	Base hydrology	Regulated Mariposa Creek flow u/s Deep Slough
Owens Creek	Base hydrology	Regulated Owens Creek flow u/s Deep Slough
Bear Creek	Base Hydrology	Regulated Bear Creek flow u/s of Deep Slough

Notes: The acronyms "u/s" and "d/s" refer to upstream and downstream, respectively.

CONCEPT 1 – RESTORE SYSTEM CONVEYANCE

Local and regional stakeholders have an interest in restoring the flood management system to its advertised system conveyance capacity. This concept explored restoring this capacity while addressing hydraulic impacts. The goal of Concept 1 is to restore the advertised design capacity and function of the existing flood control system. This concept focuses on evaluating the existing levee systems and making improvements to achieve the flood channel flows that had been evaluated and published by the Department of Water Resources (DWR) in 1985. This concept does not seek to provide a specific level of protection to urban or agricultural areas, but would not decrease the existing level of protection provided by the flood control system. Concept 1 consists primarily of conveyance improvement components (levee strengthening and raising), with transitory floodplain storage employed as necessary to mitigate any downstream impacts of improving levee performance. The advertised design flow targets for Concept 1 are included in Tables IV-4 and IV-5 for the Sacramento and San Joaquin River basins, respectively.

TABLE IV-4

SACRAMENTO RIVER FLOOD CONTROL SYSTEM ADVERTISED CAPACITIES

Watercourse	**Advertised Design Flow Capacity (cfs)**[1]
Sacramento River	
Shasta to Red Bluff	100,000
Red Bluff to Ord Ferry	260,000
Ord Ferry to Moulton Weir	150,000
Moulton Weir to Colusa Weir	110,000
Colusa Weir to Colusa	65,000
Colusa to Tisdale Weir	66,000
Tisdale Weir to Fremont Weir	30,000
Fremont Weir to Sacramento Weir	107,000
Sacramento Weir to Sutter Slough	110,000
Sutter Slough to Rio Vista	90,000
Rio Vista to Collinsville	579,000
Feather River System	
Feather River: Oroville to Yuba River	210,000
Feather River: Yuba River to Bear River	300,000
Feather River: Bear River to Sutter Bypass	320,000
Yuba River	120,000
Bear River	40,000
Sutter Bypass	
Butte Basin to Wadsworth Canal	150,000
Wadsworth Canal to Tisdale Weir	155,000
Tisdale Weir to Feather River	180,000
Feather River to Fremont Weir	380,000
Yolo Bypass	
Fremont Weir to Cache Creek	343,000
Cache Creek to Sacramento Weir	362,000
Sacramento Weir to Putah Creek	480,000
Putah Creek to Cache Slough	500,000
American River	115,000

1. Source: Flood Channel Design Flows, Department of Water Resources, 1985

Performance Objectives

The performance objectives for Concept 1 are as follows:

- Restore channel capacities throughout the flood control system to that advertised by DWR.
- Do not decrease the current level of protection for urban and agricultural lands.
- Do not increase 50-year frequency flows to the Sacramento-San Joaquin Delta over existing conditions.

TABLE IV-5

SAN JOAQUIN RIVER FLOOD CONTROL SYSTEM ADVERTISED CAPACITIES

Watercourse	**Advertised Design Flow Capacity (cfs)[1]**
San Joaquin River	
Gravelly Ford to Bifurcation Structure	8,000
Bifurcation Structure to Mendota	2,500
Mendota to Connector Channel	4,500
Connector Channel to Mariposa Bypass	1,500
Mariposa Bypass to Eastside Bypass	10,000
Eastside Bypass to Merced River	26,000
Merced River to Tuolumne River	45,000
Tuolumne River to Stanislaus River	46,000
Stanislaus River to Paradise Cut	52,000
Paradise Cut to Stockton	37,000
Bypass System	
Chowchilla: Bifurcation Structure to Fresno River	5,500
Chowchilla: Fresno River to Berenda Slough	10,000
Chowchilla: Berenda Slough to Ash Slough	12,000
Eastside: Ash Slough to Chowchilla River	17,000
Eastside: Chowchilla River to Owens Creek	16,500
Eastside: Owens Creek to Bear Creek	13,500
Eastside: Bear Creek to San Joaquin River	18,500
San Joaquin Major Tributaries	
Fresno Slough	4,700
Fresno River	5,000
Berenda Slough	2,000
Ash Slough	5,000
Owens Creek	2,000
Bear Creek	7,000
Merced River	6,000
Tuolumne River	15,000
Stanislaus River	8,000

1. Source: Flood Channel Design Flows, Department of Water Resources, 1985

Modeling Process

The existing flood control levee systems were evaluated to identify areas where the system cannot convey the advertised design flow. The capacity of the modeled river channels was increased to advertised capacity, where necessary, by raising the LFP elevations. In the Sacramento Basin HEC-HMS, the levee breach diversions were modified such that the first breach diversion occurred above the advertised capacity. In UNET this was accomplished by modifying the break elevation on the SF or EF cards to elevations that would pass the advertised capacity as determined in the HEC-RAS models. In both models, reaches whose existing capacity met or exceeded the advertised capacity were not modified.

After the initial runs were made with the advertised capacities, the model results were used to determine if the level of protection had been reduced. Reductions in the level of protection resulted from increased flows sent downstream when upstream reaches that failed in the baseline conditions were improved to pass the advertised flow. Because one of the criteria set for Concept 1 was that level of protection could not be reduced, it was necessary to either improve the reaches where levels of protection declined, or provide upstream re-operation or transitory storage to reduce peak flows. This process was continued until all reaches carried at least the advertised capacity and were not subject to a reduction in level of protection.

Concept Components

Concept 1 relies most heavily on levee strengthening and re-operation or floodplain storage to achieve advertised capacities. The components are illustrated in Plates 49 and 50 for the Sacramento and San Joaquin River basins, respectively.

In the Sacramento River Basin, this concept anticipates strengthening or rehabilitating levees in their present alignment to safely convey the published design flows for the various reaches along the Sacramento River. The exception to this is a 25-mile reach between Colusa and the Tisdale Weir where an estimated 14 miles of levees would be realigned to improve reliability. Raising levees along this reach to contain the flow appears to be unrealistic because of the height required to contain the design flow in addition to flows from upstream modifications. Accordingly, levees would be realigned (straightened) to enlarge the effective flow area and increase levee reliability at design flows. Three transitory floodplain storage areas would be developed to remove some of the increased flow contained within the improved system. These would be located between the Sacramento River and the Sutter Bypass, north and south of the Tisdale Bypass (350,000 acre-feet), and in the “Elkhorn” area on the right bank of the Sacramento River just downstream of the Fremont Weir (25,000 acre-feet).

In the San Joaquin River Basin, this concept anticipates that levees upstream of the confluence with the Merced River would be strengthened in place as needed except for one mile of project levees along the lower reach of Bear Creek. The Bear Creek section would be realigned (straightened) to improve levee reliability. 100,000 acre-feet of new flood control storage would be established on the San Joaquin River upstream from Friant Dam. Four transitory floodplain storage areas would be established upstream of the Merced River, and two downstream of the Merced River. The total transitory floodplain storage in the system would be 66,000 acre-feet: 36,000 acre-feet upstream of the Merced River, 23,000 acre-feet along the Chowchilla / Eastside Bypass, and 7,000 acre-feet downstream from the Merced River. Downstream of the Merced River, a small reach of project levees would be realigned to improve reliability. 150,000 acre-feet of new flood control storage would be established on the upper Merced and Tuolumne Rivers.

Results and Conclusions

The following summarizes the hydraulic benefits of the concept:

- Improving the Sacramento River levees to their design conveyance capacity would decrease the chance of flooding in any given year from the present range of about 1 in 40 to 1 in 100, to a range of about 1 in 50 to 1 in 100.

- Improving the San Joaquin River levees to their design conveyance capacity would decrease the chance of flooding in any give year from the present range of about 1 in 10 to 1 in 50 to a range of about 1 in 50 to 1 in 80.

The formulation of Concept 1 identified numerous hydraulic characteristics of the Sacramento and San Joaquin River systems. These system insights include the following:

- The published flood channel design flows were developed over an extended period of time with varying objectives and criteria; they were not designed to provide any specific level of flood protection and their performance is inconsistent.
- In both the Sacramento and San Joaquin River basins, components to provide the design capacity and convey higher flows resulting from upstream modifications would result in increased flows into the Delta.
- Although large portions of the existing levee systems in both basins would require improvement under this concept, the San Joaquin River Basin would experience a much greater incremental flood benefit than the Sacramento River Basin.
- Additional flood control storage on the Upper San Joaquin (upstream from Friant Dam), Merced, and Tuolumne rivers was beneficial in reducing the amount of transitory floodplain storage required.

CONCEPT 2 – LEVEL OF PERFORMANCE

Concept 2 was created in order to begin to understand the reasonable extent of flood damage reduction possible. While this concept does not represent everything physically possible, it does explore how the system could be modified to provide consistent, and in most cases improved, levels of performance to various parts of the system area. This approach generally provided an improved level of performance for each general land use type. Concept 2 is focused on providing a consistent level of flood performance for agricultural and urban areas throughout the Sacramento and San Joaquin River basins. The primary goal of this concept is to provide agricultural areas with protection from a 50-year frequency storm event, major urban centers with 200-year flood protection, and small communities with 100-year flood protection. Achieving these levels of performance emphasizes changes or additions to upstream reservoir storage, when possible, rather than improving flood conveyance through the floodplain.

Performance Objectives

The performance objectives for Concept 2 are as follows:

- Provide 200-year flood protection for major urban areas.
- Provide 100-year flood protection for small communities.
- Provide 50-year flood protection for agricultural areas.
- Maximize the use of upstream storage to reduce flood flows.

- Whenever possible, preserve existing agricultural and urban lands by improving levees in-place rather than realigning them or creating new floodways.
- Avoid impacts to major physical infrastructure (interstate highways, water treatment plants, etc).
- Do not increase 50-year frequency flows to the Sacramento-San Joaquin Delta over existing conditions.

In the Sacramento River basin, major urban areas targeted for 200-year flood protection include Sacramento, West Sacramento, and Marysville-Yuba City. Small communities include Colusa, Knights Landing, Robbins, Grimes, Meridian, Hamilton City, Live Oak, and Gridley. In the San Joaquin River basin, the major urban areas targeted by the concept include Modesto, Fresno, Stockton, Lathrop, and Tracy. Small communities include Mendota, Firebaugh, Hills Ferry, Fremont Ford, Grayson, and Vernalis.

Modeling Process

Initial model simulations for Concept 2 evaluated the potential for new upstream storage to reduce valley flood flows. Numerous simulations were performed using the HEC-HMS models in the Sacramento and San Joaquin Basins to evaluate the potential flood impacts of increased flood storage at existing reservoirs and the construction of new reservoirs. The HEC-HMS models were also used to evaluate changes in the objective releases from various existing flood reservoirs. These initial HEC-HMS simulations indicated which storage locations had the greatest ability to reduce downstream flooding at key urban areas and small communities. These simulations also indicated that while some proposed flood storage facilities had significant local impacts they did not affect the system as a whole or improve flooding in downstream areas. For example, a proposed storage facility on the Yuba River was found to have local benefits along the Yuba River itself, but no significant impact in Sacramento or other downstream areas. New flood hydrographs were developed to reflect the revised hydrologic conditions with additional upstream flood storage.

After the most effective flood storage options had been evaluated and selected, the HEC-HMS models were used to estimate the need for additional transitory storage in the floodplain, identify channels that may require capacity improvements, and identify small communities that could most efficiently be protected with ring levees. Iteration with the HEC-RAS model provided additional detail regarding conveyance improvements. In the Sacramento River Basin, the final components were modeled using the detailed HEC-HMS (including levee failures) to assess the impacts of levee failures on downstream flows and estimate the level of performance provided. In the San Joaquin River Basin, UNET was used to model the components in detail, refine the concept, and estimate the level of performance provided.

Concept Components

As discussed previously, this concept focused on providing consistent levels of flood protection by increasing flood control storage in upstream watersheds, accompanied by some modifications in the flood conveyance system and transitory storage in the floodplains. Ring levees would be used to protect isolated small communities. This concept maximizes the use of existing facilities and minimizes the need for additional land acquisition and impacts to infrastructure and land use. The primary components of Concept 2 are illustrated in Plates 51 and 52 for the Sacramento Basin and San Joaquin Basin, respectively.

In the Sacramento River Basin, Concept 2 is comprised primarily of additional upstream storage on the Feather and American Rivers, new storage on Cottonwood Creek, modification of the Colusa, Moulton, and Tisdale weirs, and localized conveyance improvements. A transitory floodplain storage area in the Colusa Basin was considered for storing the large volume of floodwaters entering the river from unregulated tributaries between Shasta Dam and Ord Ferry. However, this area is undesirable hydraulically because there is no means of returning water to the Sacramento River after the flood event. Consequently, this concept would include 2 dry dams with a storage capacity of 150,000 acre-feet on Cottonwood Creek. Additional flood storage space is proposed at Folsom Dam (80,000 acre-feet) and Oroville Dam (200,000 acre-feet). In the Yolo Basin, 25,000 acre-feet of transitory floodplain storage would be required. About 20 miles of levee would be strengthened between Chico Landing and the Colusa Weir, 15 miles between Verona and Sutter Slough, and eight miles along the lower Feather River. About 34 miles of levee would be relocated along the Sacramento River and Tisdale Bypass to increase capacity by widening the floodway. The small communities of Grimes, Meridian, and Knights Landing would be protected with ring levees.

In the San Joaquin River Basin, Concept 2 is comprised of additional flood storage along the San Joaquin, Merced, and Tuolumne rivers, floodplain storage in the Sandy Mush area, and levee improvements along most of the San Joaquin River downstream of Mendota and along lower reaches of several tributaries. Upstream flood control storage in Millerton Lake/ Friant Dam would be increased by 100,000 acre-feet. Flood storage would also be increased at New Exchequer Dam (50,000 acre-feet) and New Don Pedro Dam (100,000 acre-feet) in combination with increases in objective releases from these reservoirs. Transitory floodplain storage areas totaling 49,500 acre-feet would be provided at Sandy Mush and West Bear Creek. Conveyance measures would include levee strengthening or raising along approximately 32 miles of the San Joaquin, and about 11 miles of backup levees near Paradise Cut. The small community of Firebaugh and the Modesto Wastewater Treatment Plant would be protected by ring levees. In addition, six highway bridges crossing Berenda Slough would be modified to convey higher flows.

Results and Conclusions

The following summarizes the hydraulic benefits of the concept:

- 200-year flood performance for Sacramento, West Sacramento, Yuba City / Marysville, Modesto, and the greater Stockton area
- 100-year flood performance for small communities including Colusa, Knights Landing, Meridian, Hamilton City, Mendota, and Firebaugh
- 50-year flood performance for agricultural areas
- Increased levee reliability in the Sacramento River basin due to reduced with-project flows and river stages

- Increased levee reliability in the San Joaquin River basin due to the reconstruction of levees along the San Joaquin River

The formulation of Concept 2 identified numerous hydraulic characteristics of the Sacramento and San Joaquin River systems. These system insights include the following:

- Upstream storage is an effective means of reducing flow volume in the Sacramento Valley, where the existing levee system is capable of carrying significant flood flows. However, upstream storage solves only half of the flood problem in the San Joaquin River Basin because levee systems there provide a much lower level of flood protection than those in the Sacramento River Basin.
- Changes in the operation of one reservoir may require changes in the operation of neighboring reservoirs. For example, if the objective release from Oroville is reduced, the objective release from Bullards Bar would also need to be reduced if a total reduction in flow at Marysville was the goal of the re-operation.
- The complex system of weirs in the Sacramento River Basin act as an “equalizer” in distributing flows. New upstream storage was effective within localized zones but often had little impact south of the Freemont Weir due to timing, storm centering effects, and weir operations. For example, new storage on the Yuba River benefited Yuba City / Marysville locally but had no impact downstream of the Feather River.
- Under existing flood conditions, flow out of the Tuolumne River system overwhelms flow in the San Joaquin River downstream of the Tuolumne confluence. Thus, storage or other actions on the Tuolumne have a significant impact on the lower San Joaquin River.
- The reach of the San Joaquin River south of Turner Island, commonly called the “sterile reach” due to the absence of year-round flow, is an effective means of reducing stress on the Eastside Bypass and Deep Slough during flood events. However, this reach can only convey an estimated 300 cfs and would require physical improvements to convey additional flow.

CONCEPT 3 – RESTORE RIVER FUNCTIONS

Concept 3 was created in order to begin to understand the extent of ecosystem restoration possible. While this concept does not represent everything physically possible, it does explore how the system could be modified to provide expansive increase in habitat and floodplain reconnection. The goal of Concept 3 is to re-establish the health and vigor of the natural stream systems throughout the Sacramento and San Joaquin River basins. This concept seeks to establish a self-sustaining floodway that would reduce flood damages and restore degraded physical and biological river functions and reduce operation and maintenance requirements. Concept 3 provides increased flood protection through the development of continuous, natural floodway corridors along the Sacramento and San Joaquin rivers. Concept 3 focuses on the interconnection between hydrologic and geomorphic processes, promoting components that allow the major rivers to engage in natural erosion and deposition processes between the levees.

Performance Objectives

The performance objectives for Concept 3 are as follows:

- Realign levees to permit natural riverine processes within a meander belt
- Reduce system maintenance requirements
- Restore habitat connectivity by establishing riparian corridors along the Sacramento and San Joaquin Rivers
- Where possible, capture cut-off oxbows and other hydrographic features within realigned levees
- Pass large flood events without major system failures
- Maintain or increase the existing level of flood protection for all land use types
- Avoid impacts to significant physical infrastructure (such as interstate highways, water treatment facilities, etc)
- Do not increase 50-year frequency flows to the Sacramento-San Joaquin Delta.

Levee realignments are intended to restore a riparian corridor along the major rivers and allow natural hydro-geologic processes of erosion and deposition to occur between levees. A constraint was put on all levee realignments that required new levees to be no more than 30 feet high. This constraint was particularly relevant along the Sacramento River, a perched system, where adjacent lands typically slope away from the existing levees. Wherever possible, levee realignments were restricted to only one side of the waterway to avoid significant levee reconstruction along both banks.

Reductions in system maintenance may be accomplished in a variety of ways: by reducing levee length; moving levees away from areas where foundation conditions are poor and significant seepage occurs; and developing a vegetation corridor capable of reducing flow velocity adjacent to levees, thereby reducing scour.

Although Concept 3 does not set a specific performance objective for the level of flood protection achieved, it seeks to pass large flood events without major system failures. In addition, the concept objective is to either maintain or improve upon the existing flood protection provided to all land uses and communities within the study area.

Modeling Process

Concept 3 is primarily comprised of levee realignments to develop continuous floodway corridors. The extent and width of the floodway corridors was first developed by examining topographic maps to identify the historic meander belt of the Sacramento and San Joaquin rivers and capture cut-off oxbow lakes and other valued habitat features. These initial floodways were considered the maximum in a range of possible corridor options. In order to determine the corridor width that maximized both environmental and flood damage reduction goals, three corridor widths were modeled in the HEC-HMS models, representing 1/3, 2/3 and full initial corridor widths. These initial model simulations provided insight as to the hydraulic performance of a range of floodway widths. These initial simulations, along with other environmental and flood damage reduction considerations, were used to determine the most appropriate corridor width along each reach of the major river systems.

Levee realignments would be designed to create floodways capable of passing large event flows without failure while lowering water surface elevations. While an objective of the floodways would be to restore natural river function, the realignments are not aimed at recapturing the entire width of the historic meander belt for the Sacramento and San Joaquin Rivers. Today, the Sacramento and San Joaquin Rivers are regulated by numerous reservoirs and flood control facilities and do not experience the same hydrologic conditions that were present historically. It is unlikely that the vast meanders seen on topographic maps today would ever be reproduced under the current geomorphic conditions and flow regimes. Therefore, the location and width of the floodways developed for Concept 3 were determined on a reach-by-reach basis and were influenced by numerous factors including:

1. The magnitude of flow anticipated for a given frequency storm event (system hydraulics);
2. The estimated flow that can be safely carried by the existing levees;
3. The reliability and past performance of existing levees (levees in poor condition or with known foundation problems were strong candidates for realignment);
4. The distance between existing levees in the reach (are levees immediately adjacent to the channel or set back from the river);
5. Hydrographic features of the river that create undesirable hydraulic conditions, such as levee scour occurring at sharp bends in the river;
6. The proximity of nearby communities that are prone to flooding and would benefit from lower water surface elevations;
7. The existence of flow constraints or ‘bottlenecks’;
8. The presence and quality of existing habitat between the levees; and,
9. The potential for successful habitat development, including the seasonal availability of water to support vegetation growth in the proposed floodway.

After the mainstem floodways were developed, additional components were added to the HEC-HMS simulations, as necessary, to meet the performance objectives. Additional components included other conveyance measures (such as levee strengthening), weir re-operation, and transitory storage in the floodplains. Iteration with the HEC-RAS model provided greater detail regarding the hydraulic carrying capacity of the widened floodways and was used to identify additional conveyance improvements.

Concept Components

As discussed previously, the measures included in this concept were selected to support the overall theme of the concept: to re-establish the health and vigor of the natural stream systems. The flood damage reduction benefits of Concept 3 are gained primarily through levee realignments that create wide floodways. The wider, more naturally functioning floodways would carry more flow at a lower stage than existing conditions with levees immediately adjacent to the river channel. Strengthening levees in-place was given a low priority in this concept because it provides little or no opportunity for habitat improvement or natural erosion-deposition processes. Flow reduction and attenuation would be accomplished through transitory floodplain storage. The flood damage reduction and ecosystem restoration components of Concept 2 are illustrated in Plates 53 and 54 for the Sacramento Basin and San Joaquin Basin, respectively.

In the Sacramento River Basin, Concept 3 is primarily comprised of levee realignment to create a continuous flood corridor along the Sacramento River between Knights Landing and Colusa, discontinuous levee realignments between Colusa and Ord Ferry to maintain corridor width, and levee improvement on the left bank of the lower Feather River downstream from the Sutter Bypass. Transitory floodplain storage would be developed between the Sacramento River and Sutter Bypass south of the Tisdale Bypass. The storage areas would be located adjacent to Sutter Slough (100,000 acre-feet) and in the "Elkhorn" area (50,000 acre-feet). There are no upstream storage components in this concept. Approximately 79 miles of project levees would be reconstructed on new alignments, and about 50 miles of project levees would be strengthened or raised.

In the San Joaquin River Basin, Concept 3 includes levee realignments to develop a continuous flood corridor along the San Joaquin River from Gravelly Ford to the Mariposa Bypass, and levee realignments between Bear Creek and the Merced River and downstream of the Tuolumne River. The concept includes an additional 50,000 acre-feet of flood control storage in Don Pedro Reservoir combined with an increase in the objective release from 9,000 cfs to 15,000 cfs. Also included is re-operation of the Eastside Bypass connector. Transitory floodplain storage totaling 145,500 acre-feet would be provided along Lone Willow Slough, east of the Chowchilla Bypass, near El Nido, Harmon Road, Sandy Mush, West Bear Creek, and Jennings Road areas.

Results and Conclusions

Concept 3 would provide the following hydraulic benefits:

- Reduced water surface elevations (stage) in areas with levee realignments
- Increased level of performance provided to various areas
- Improved levee reliability in reaches where levees would be realigned and moved away from poor foundation conditions
- Reduced levee maintenance requirements for realigned levees

The formulation of Concept 3 identified several hydraulic characteristics of the flood system. These system insights include the following:

- Levee realignments and the development of floodway corridors can significantly reduce river stage (locally) but has been shown to have little effect on flow attenuation in the HEC-HMS model simulations.
- Enlarging the floodway by constructing levees on a new alignment would reduce river stages. When levees are constructed to present standards with the same crown elevation as the replaced levees, the new levees would be able to safely contain even higher river stages. This combination results in substantial flood damage reduction.

- This concept would not provide flood damage reduction benefits from Shasta Dam to the beginning of project levees (near Ord Ferry) but would improve the performance of the remainder of the Sacramento system from about 1 in 50 chance in flooding to about 1 in 100 chance for any given year.
- This concept would reduce flood stages along the san Joaquin River from the upstream limit of the project levees to Paradise Cut, improving system performance from about 1 in 50 change of flooding to 1 in 100 chance of flooding in a given year.
- Realigning levees to allow river channel meander and migration would promote the establishment of riparian and other vegetation in the floodway corridor. This increase in vegetation represents a benefit in that flood flow velocity is reduced (reducing levee scour and erosion), but it also reduces the total flow capacity of the floodway. Hence, vegetation must also be taken into consideration when determining the required floodway width.
- The availability of water would play a key role in successful habitat development and ecosystem restoration efforts. For example, the hydrology and climate of the San Joaquin Basin may not support the wide variety of habitat that could be supported in the Sacramento Basin. The timing of flows throughout the year is also a significant factor.

CHAPTER V

DETAILED EVALUATIONS

INTRODUCTION

The information provided in this chapter describes detailed evaluations conducted for the Sacramento and San Joaquin River Basins Comprehensive Study. The purpose of these detailed evaluations is to provide flood damage reduction benefits and ecosystem restoration. Included in this chapter is a description of the modeling approaches used to develop the three detailed scenarios.

The three detailed evaluations are: Detailed Evaluation 1 – River Corridor Evaluation; Detailed Evaluation 2 – River Corridor Evaluation with Floodplain and Reservoir Storage; and Detailed Evaluation 3 – Levee Strengthening. Detailed Evaluation 1 focuses on restoring the river meander function through realignment of levees. Detailed Evaluation 2 includes the goal of Detailed Evaluation 1 and in addition focuses on reconnecting historic portions of the floodplain back into the river system. Detailed Evaluation 3 is focused on the use of upstream storage and reducing impacts to private land.

The detailed evaluations described in this chapter are not intended to represent final or comprehensive alternative plans. Instead, the development and refinement of these detailed evaluations serves to establish important information about the hydraulic performance of flood damage reduction and ecosystem restoration measures. The following discussion is restricted to the hydraulic modeling aspects of plan development.

MODELING TOOLS

The hydraulic modeling for this study was performed using the computer program UNET. UNET is a one-dimensional computer model that numerically simulates one-dimensional, unsteady flow in a complex network of open channels. The use of UNET alone in this effort differs from the approach presented in Chapter IV where an iterative approach using a combination of hydrologic and hydraulic models was described. The models described in Chapter IV were used to develop and evaluate the various concepts. Additionally, the 30-day flood hydrographs discussed in Chapter IV were used in modeling efforts presented in this chapter.

In order to determine project performance, output from the UNET analyses, in the form of stage versus frequency curves at selected index points, was passed on to an HEC-FDA model. The specific process used to develop input for the FDA analysis is more fully discussed in the Technical Studies Report.

MODELING OBJECTIVES

Objectives were set for each of the detailed evaluations. Some of the objectives pertain to all of the detailed evaluations while others pertain to only certain evaluations. A discussion of each objective is provided below.

- Provide Level of Performance – For consistency in this evaluation all of the detailed evaluations had a specific objective with regard to level of flood performance. The level of flood performance is 50 years for agricultural areas, 100 years for small communities, and 200 years for major urban areas. In the Sacramento River basin, major urban areas targeted for 200-year flood performance include Sacramento, West Sacramento, Marysville, and Yuba City. Small communities include Colusa, Knights Landing, Robbins, Grimes, Meridian, Hamilton City, Live Oak, and Gridley. In the San Joaquin River basin, major urban areas targeted for 200-year flood performance include Modesto, Fresno, Stockton, Lathrop, and Tracy. Small communities include Mendota, Firebaugh, Hills Ferry, Fremont Ford, Grayson, and Vernalis. In addition, if an area has an existing higher level of flood performance than the level described above, then that level would be maintained.
- Protect Infrastructure – All of the detailed evaluations, whenever possible, had an objective to avoid impacts to major physical infrastructure. These infrastructure includes features such as highways, railroads, major pumping facilities, heavy industrial areas, and municipal facilities.
- Realign Levees for Natural Riverine Processes Restoration and System Maintenance Reduction – Wherever possible, all of the detailed evaluations (unless otherwise noted) have the following objectives: 1) Detailed Evaluations 1 and 2 would allow natural riverine processes to occur within a meander belt; 2) levee realignments would allow the natural hydro-geologic processes of erosion and deposition to occur between levees and would restore a riparian corridor along the major rivers; 3) levee realignments are restricted to only one side of the waterway to avoid significant levee reconstruction along both banks; and 4) levee realignments are replaced to capture cut-off oxbows and other hydrographic features.

  Levee realignments would reduce system maintenance for a variety of reasons. Some of these reasons include reducing levee length, moving levees away from areas where foundation conditions are poor and significant seepage occurs, and developing a vegetation corridor capable of reducing flow velocity adjacent to levees, thereby reducing scour.
- Use of Storage to Reduce Flood Flows – Detailed Evaluations 2 and 3 have an objective to use storage to reduce flood flows. In the Sacramento River Basin, Detailed Evaluation 2 included only transitory floodplain storage. Detailed Evaluation 2 in the San Joaquin River included both transitory floodplain and foothill storage with Friant Dam re-operated at an objective flow increase of 8,000 cfs to 16,000 cfs and no additional flood storage. Detailed Evaluation 3 in both the Sacramento and San Joaquin Basins included both transitory floodplain and foothill storage. In the Sacramento River Basin, Oroville Dam was re-operated to add an additional 200,000 acre-feet of flood storage and reduce the 100-year objective release to 90,000. In the San Joaquin River Basin, Friant Dam

was re-operated with an objective flow increase of 4,000 cfs to 12,000 cfs and 50,000 acre feet of additional flood storage.

COMPONENTS OF THE DETAILED EVALUATIONS

Evaluation components can be organized into three categories: conveyance, storage, and floodplain management. Conveyance components include levee realignment and reconstruction, construction of new floodways or bypasses, strengthening existing levees, and raising levees. Storage components include measures such as re-operation of existing reservoirs to increase flood control space and/or to meet new objective releases, construction of new upstream storage, and development of controlled storage within the floodplain, referred to as transitory floodplain storage. Floodplain management measures include moving at-risk development out of flood-prone areas, floodproofing existing structures within the floodplain, and institutional measures to modify land use General Plans and discourage inappropriate development in floodplains. Some of these components, such as floodplain management measures, are not hydraulic in nature and were not incorporated into the modeling effort.

DESRIPTION OF DETAILED EVALUATIONS

Detailed Evaluation 1 - River Corridor

The objective of Detailed Evaluation 1 is to partially re-establish the natural stream system along the Sacramento and San Joaquin River mainstems. This evaluation established a self-sustaining floodway that would reduce flood damages, restore degraded physical and biological river functions, and reduce operation and maintenance requirements. Detailed Evaluation 1 provides increased flood performance through the development of a continuous, natural floodway corridor along the Sacramento and San Joaquin rivers. Detailed Evaluation 1 focuses on the interconnection between hydrologic and geomorphic processes, promoting the major rivers to engage in natural erosion and deposition processes between the levees.

For both the Sacramento and San Joaquin River systems, Detailed Evaluation 1 is primarily comprised of levee realignments to establish continuous floodway corridors. Topographic maps and aerial photographs were examined to determine the extent and width of the proposed floodway corridors. Topographic maps were used to identify historic meander belts and capture cut-off oxbow lakes and other valuable habitat features. Aerial photographs were used to identify planimetric features such as canals, roads, farmsteads, etc, that should be avoided by levee realignments when possible.

The levee realignments are designed to create a floodway capable of passing flows from large events without failure (50-years and larger). On a reach by reach basis, levee setbacks were necessitated based on the following criteria:

- If the present floodway does not capture the magnitude of the expected flood frequency;
- Poor reliability and past performance of existing levees (levees in poor condition or with known foundation problems were strong candidates for realignment);

- Levees so close to the channel that they prevent geomorphologic processes from occurring without cutting into the levees.

The realignment of the levees was done on a reach by reach basis. The distance that they were set back was based upon the following:

- Hydrographic features of the river that create undesirable hydraulic conditions, such as levee scour occurring at sharp bends in the river;
- The proximity of nearby communities that are prone to flooding and would benefit from lower water surface elevations;
- The existence of flow constraints or ‘bottlenecks;
- The presence and quality of existing habitat between the levees;
- The potential for successful habitat development, including the seasonal availability of water to support vegetation growth in the proposed floodway.

Flood damage reduction benefits of Detailed Evaluation 1 are gained primarily through levee realignments that create wide floodways. The wider, more natural functioning floodways would carry more flow than existing conditions with levees immediately adjacent to the river channel. The components of Detailed Evaluation 1 are illustrated in Plate 55 for the Sacramento River Basin and in Plate 56 for the San Joaquin River Basin.

Sacramento River System

In the Sacramento River Basin, Detailed Evaluation 1 includes the following components:

- Sacramento River Levee realignments from Hamilton City to Knight’s Landing
- Feather River Levee realignments in a short reach below the confluence with the Yuba River
- Extension of the Fremont Weir by 3,000 feet at the existing sill elevation
- Levee strengthening at various locations to give 50-year performance on the following watercourses:
    - Sacramento River
    - Feather River
    - Yolo Bypass
    - Willow Slough
    - Haas Slough
    - Cache Slough
    - Lindsey Slough
    - Sutter Slough
    - Three Mile Slough
- Levees were strengthened for a 10-mile reach on the Sacramento River in the Natomas area to provide 200-year performance

- Ring levees were assumed to be in place to provide 100-year performance to isolated small communities.

The base condition UNET model was modified to reflect Detailed Evaluation 1. For areas of levee realignments, cross sections were extended, if necessary, out to the location of the new levee, and encroachments were placed at the new levee locations. For the Fremont Weir modification, the length of the weir was increased by 3,000 feet at the same elevation as the existing weir.

Reaches of the river in which the levees are to be realigned or strengthened would provide a 50-year level of performance. To establish the new levee elevations, a preliminary 50-year UNET run was developed that did not include levee failures in the areas of levee realignment or strengthening. From this run, levee elevations were set slightly above the peak 50-year water surface elevation. As a result of realignment or strengthening of upstream levees, the Yolo Bypass and the Lower Sacramento River levees were strengthened or raised to mitigate for increased flow. For small communities, ring levees were assumed to be in place to provide a 100-year level of performance.

San Joaquin River System

In the San Joaquin River Basin, Detailed Evaluation 1 includes the following components:

- San Joaquin River levee realignments from Gravelly Ford down to the Mariposa Bypass
- San Joaquin River levees strengthened from the Mariposa Bypass down to near the confluence with Bear Creek
- A San Joaquin River levee realignment in a short reach between the Merced and Tuolumne rivers
- A San Joaquin River levee realignment from between the Tuolumne and Stanislaus rivers down to Paradise Cut
- A San Joaquin River bypass channel that diverts high flows around Mendota Dam and the Mendota Pool
- A modified San Joaquin River Bifurcation structure to the Chowchilla Bypass that sends 5,500 cfs down the Chowchilla Bypass and the remainder of the 50-year flow down the San Joaquin River
- A modified Eastside Bypass Connector Channel control structure that forces the 50-year event in the San Joaquin River to continue down the river corridor
- Transitory floodplain storage totaling 52,000 acre-feet provided at the West Bear Creek and the San Joaquin River National Wildlife Refuge area (also referred to as the “ Three Amigos” area).
- Ring levees were assumed to be in place to protect isolated small communities.

The base condition UNET model was modified to reflect Detailed Evaluation 1. For areas of levee realignments, cross sections were extended, if necessary, out to the location of the new levee, and encroachments were placed at the new levee locations. For the Mendota Dam Bypass Channel, a lateral spill was included in the model that diverts flow from the San

Joaquin River just upstream of Mendota Dam, and returns just downstream of the dam. For the Chowchilla Bypass Bifurcation Structure modification, the bifurcation criteria was modified to reflect flow, up to 15,000 cfs, continuing down the San Joaquin River with additional flow up to the 50-year peak flow (26,000 cfs) splitting evenly into the San Joaquin River and to the Chowchilla Bypass (flow in excess of the 50-year peak is allowed to weir flow over the top of the bifurcation structure). The Eastside Bypass Connector Channel Control Structure was modified to force the 50-year peak flow down the San Joaquin River (flow in excess of the 50-year peak splits with a portion going down the San Joaquin River and the remainder spilling over a weir into the Connector Channel).

The transitory floodplain storage for the San Joaquin River was modeled in the following ways for each respective storage area. For the West Bear Creek area, three weir flow lateral spills were modeled on the San Joaquin River downstream of the Mariposa Bypass to divert flow into this area. This area drains to Salt Slough which flows into the San Joaquin River between Bear Creek and the Merced River. For the San Joaquin River National Wildlife Refuge, a weir flow lateral spill was modeled on the San Joaquin River near the confluence with the Tuolumne River to divert flow to this area. This area drains back through this same lateral spill to the San Joaquin River.

Reaches of the river in which the levees are to be realigned or strengthened would provide a 50-year level of performance. To establish the new levee elevations, a preliminary 50-year UNET run was developed that did not include levee failures in the areas of levee realignment or strengthening. From this run, levee elevations were set slightly above the peak 50-year water surface elevation. For small communities, ring levees were assumed to be in place to provide a 100-year level of performance.

Detailed Evaluation 2 – River Corridor with Floodplain Storage

Like Detail Evaluation 1, Detailed Evaluation 2 seeks to establish a self-sustaining floodway that would reduce flood damages, restore degraded physical and biological river functions, and reduce operation and maintenance requirements. Detailed Evaluation 2 provides increased flood performance through the development of a continuous, natural floodway corridor along the Sacramento and San Joaquin rivers.

Sacramento River System

For the Sacramento River system, Detailed Evaluation 2 is primarily comprised of levee realignments to develop continuous floodway corridors. The levee realignments reflected in Detailed Evaluation 2 are the same as the levee realignments in Detailed Evaluation 1. Transitory floodplain storage was added to provide additional flood flow attenuation to reduce flows into the Delta to baseline levels.

The flood damage reduction benefits of Detailed Evaluation 2 are gained primarily through levee realignments that create wide floodways. The wider, more naturally functioning floodways would carry more flow than existing conditions in which the levees are immediately adjacent to the river channel. Flow reduction and attenuation would be accomplished through transitory floodplain storage. The components of Detailed Evaluation 2 are illustrated in Plate 57 for the Sacramento River Basin and include the following:

- Transitory floodplain storage (58,500 acre-feet, 50-year flood) in Elkhorn storage area (RD 1600)
- Transitory floodplain storage (582,500 acre-feet, 50-year flood) in RD 1500
- Sacramento River Levee realignments from Hamilton City to Knight's Landing including 50-year flood performance
- Feather River Levee realignments and 50-year flood performance in a short reach below the confluence with the Yuba River
- Extension of the Fremont Weir by 3,000 feet at the existing sill elevation
- Levee strengthening at various locations to give 50-year performance on the following watercourses:
    - Sacramento River
    - Feather River
    - Yolo Bypass
    - Willow Slough
    - Haas Slough
    - Cache Slough
    - Lindsey Slough
    - Sutter Slough
    - Three Mile Slough
- Levees were strengthened for a 4-mile reach on the Sacramento River in the Natomas area to provide 200-year performance
- Ring levees were assumed to be in place to provide 100-year performance to isolated small communities.

The base condition UNET model was modified to reflect Detailed Evaluation 2. For areas of levee realignments, cross sections were extended, if necessary, out to the location of the new levee, and encroachments were placed at the new levee locations. For the Fremont Weir modification, the length of the weir was increased by 3,000 feet at the same elevation as the existing weir. No modifications were made to the Yolo Bypass downstream from the weir as a result of the weir extension.

Reaches of the river in which the levees are to be realigned or strengthened would provide a 50-year level of performance. To establish the new levee elevations, a preliminary 50-year UNET run was developed that did not include levee failures in the areas of levee realignment or strengthening. From this run, levee elevations were set slightly above the peak 50-year water surface elevation. As a result of realignment or strengthening of upstream levees, the Yolo Bypass and the Lower Sacramento River levees were strengthened or raised to mitigate for increased flow. For small communities, ring levees were assumed to be in place to provide a 100-year level of performance.

Flow into the Elkhorn storage area would be controlled by a lateral weir placed in the left bank levee of the Yolo Bypass at RM 55. The weir would be 5,000 feet long and set at elevation 33.00 feet to divert up to 13,000 cfs for the 50-year flood, with at total storage of

58,500 acre-feet. The storage area would drain back into the Yolo Bypass at the lower end of the area near I-5.

Flow into the RD 1500 storage area would be controlled by a lateral gated weir placed in the right bank levee of the Sutter Bypass at RM 63.87. The weir would be 3,000 feet long with an invert elevation of 34.5 feet. When the elevation of water into the Sutter Bypass exceeded 40.5 feet, the gate controls would begin to operate and a maximum of 119,000 cfs would be diverted during the 50-year flood, with a total storage of 582,500 acre-feet. A gated weir was selected because of the difficulty of diverting up to 120,000 cfs over an uncontrolled weir while at the same time minimizing the required transitory floodplain storage. For an uncontrolled weir, this structure would need to be 4 miles long and it still would not have provided the same amount of control as the proposed gated weir structure. The storage area would drain into the Sutter Bypass at its confluence with the Sacramento River.

San Joaquin River System

For the San Joaquin River system, Detailed Evaluation 2 is primarily comprised of levee realignments to develop continuous floodway corridors. The levee realignments reflected in Detailed Evaluation 2 are the same as the levee realignments reflected in Detailed Evaluation 1. Upstream reservoir re-operation and floodplain transitory storage was added to provide additional flood flow attenuation and habitat restoration.

The flood damage reduction benefits of Detailed Evaluation 2 are gained primarily through levee realignments that create wide floodways. The wider, more naturally functioning floodways would carry more flow than existing conditions where the levees are immediately adjacent to the river channel. Flow reduction and attenuation would be accomplished through transitory floodplain storage. The components of Detailed Evaluation 2 are illustrated in Plate 58 for the San Joaquin Basin. In the San Joaquin River Basin, Detailed Evaluation 2 includes the following components:

- San Joaquin River levee realignments from Gravelly Ford down to the Mariposa Bypass
- San Joaquin River levees strengthened from the Mariposa Bypass down to near the confluence with Bear Creek
- San Joaquin River right bank levee strengthened from the Eastside Bypass/Bear Creek confluence to part way down to the Merced River
- San Joaquin River levee realignment in a short reach between the Merced and Tuolumne rivers
- San Joaquin River levee realignment from between the Tuolumne and Stanislaus rivers down to Paradise Cut
- A San Joaquin River bypass channel that diverts high flows around Mendota Dam and the Mendota Pool
- A modified San Joaquin River Bifurcation structure to the Chowchilla Bypass that sends 5,500 cfs down the Chowchilla Bypass and the remainder of the 50-year flow down the San Joaquin River

- A modified Eastside Bypass Connector Channel control structure that forces the 50-year event from the San Joaquin River to continue down the river corridor
- Transitory floodplain storage totaling 98,000 acre-feet provided at the West Bear Creek, East Bear Creek, Sandy Mush, and the San Joaquin River National Wildlife Refuge areas
- Eastside Bypass strengthened levees in a short reach upstream of the Eastside Bypass Connector Channel
- Eastside Bypass strengthened levees in a reach between the Eastside Bypass Connector Channel to the Mariposa Bypass
- A Friant Dam-Millerton Lake re-operation that would increase the objective flow release from 8,000 cfs up to 16,000 cfs.
- Ring levees were assumed to be in place to protect isolated small communities.

The base condition UNET model was modified to reflect Detailed Evaluation 2. For areas of levee realignments, cross sections were extended, if necessary, out to the location of the new levee, and encroachments were placed at the new levee locations. For the Mendota Dam Bypass Channel, a lateral spill was included in the model that diverts flow from the San Joaquin River just upstream of Mendota Dam, and returns just downstream of the dam. For the Chowchilla Bypass Bifurcation Structure modification, the bifurcation criteria was modified to reflect flow, up to 9,000 cfs, continuing down the San Joaquin River with additional flow up to the 50-year peak flow (20,000 cfs) splitting evenly into the San Joaquin River and to the Chowchilla Bypass (flow in excess of the 50-year peak is allowed to weir flow over the top of the bifurcation structure). The Eastside Bypass Connector Channel Control Structure was modified to force the 50-year peak flow down the San Joaquin River (flow in excess of the 50-year peak splits with a portion going down the San Joaquin River and the remainder spilling over a weir into the Connector Channel).

This evaluation also included a reservoir re-operation scenario at Friant Dam. This re-operation scenario reflects the objective flow increasing from 8,000 cfs to 16,000 cfs and no additional flood storage. This reservoir re-operation reduces the 50-year peak flow in the San Joaquin River at the Chowchilla Bypass Bifurcation Structure by 6,000 cfs (for this evaluation, the peak 50-year flow is 20,000 cfs and for Detailed Evaluation 1 the peak 50-year flow is 26,000 cfs).

The transitory floodplain storage for the San Joaquin River was modeled in the following ways for each respective storage area. For the Sandy Mush area, a weir flow lateral spill was modeled on the Eastside Bypass just downstream of the San Joaquin River Connector Channel, to divert flow to this area. This area drains back through a culvert connection into Deep Slough just downstream of the Mariposa Bypass Bifurcation Structure. For the East Bear Creek area, a weir flow lateral spill was modeled on Deep Slough just downstream of the Mariposa Bypass Bifurcation Structure to divert flow to this area. This area drains back through a culvert connection in the San Joaquin River just upstream of Bear Creek. For the West Bear Creek area, three weir flow lateral spills were modeled on the San Joaquin River downstream of the Mariposa Bypass to divert flow into this area. This area drains to Salt Slough which flows into the San Joaquin River between Bear Creek and the Merced River. For the San Joaquin River National Wildlife Refuge, a weir flow lateral spill was modeled on the San Joaquin River near the confluence with the Tuolumne River to divert flow to this area. This area drains back through this same lateral spill to the San Joaquin River.

Reaches of the river where the levees are realigned or strengthened would provide a 50-year level of performance. To set the new levee elevations, a preliminary 50-year UNET run was developed that did not include levee failures in the areas of levee realignment or strengthening. From this run, levee elevations were set slightly above the peak 50-year water surface elevation. For small communities, ring levees were assumed to be in place to provide a 100-year level of performance.

Detailed Evaluation 3

Detailed Evaluation 3 is different for the two river basins. In the Sacramento River Basin Detailed Evaluation 3 simply adds foothill storage to Detailed Evaluation 2. In the San Joaquin Basin Detailed Evaluation 3 focuses on providing a consistent level of flood performance throughout the San Joaquin River basin without the extent of levee realignment included in Detailed Evaluations 1 and 2. Detailed Evaluation 3 provides increased flood performance in the Sacramento and San Joaquin River basins through levee strengthening, levee realignment, increased reservoir storage, and transitory floodplain storage.

Sacramento River System

For the Sacramento River system, Detailed Evaluation 3 is primarily comprised of levee realignments to develop continuous floodway corridors. The levee realignments reflected in Detailed Evaluation 3 are the same as the levee realignments in Detailed Evaluations 1 and 2. Additional foothill storage and re-operation were added at Oroville Dam to supplement the transitory floodplain storage in Detailed Evaluation 2 which provides additional flood flow attenuation for the purpose of lowering flows into the Delta to baseline levels.

The flood damage reduction benefits of Detailed Evaluation 3 are gained primarily through levee realignments that create wide floodways. The wider, more naturally functioning floodways would carry more flow than existing conditions in which the levees are immediately adjacent to the river channel. Flow reduction and attenuation would be accomplished through foothill and transitory floodplain storage. The components of Detailed Evaluation 3 are illustrated in Plate 59 for the Sacramento River Basin. In the Sacramento River Basin, Detailed Evaluation 3 includes the following components:

- Transitory floodplain storage (47,500 acre-feet, 50-year flood) in Elkhorn storage area (RD 1600)
- Transitory floodplain storage (405,000 acre-feet, 50-year flood) in RD 1500
- Sacramento River Levee realignments from Hamilton City to Knight’s Landing including 50-year flood performance
- Feather River Levee realignments and 50-year flood performance in a short reach below the confluence with the Yuba River
- Extension of the Fremont Weir by 3,000 feet at the existing sill elevation

- Levee strengthening at various locations to give 50-year performance on the following watercourses:
    - Sacramento River
    - Feather River
    - Yolo Bypass
    - Willow Slough
    - Haas Slough
    - Cache Slough
    - Lindsey Slough
    - Sutter Slough
    - Three Mile Slough
- Levees were strengthened on the Sacramento River at two locations in the Natomas area to provide 200-year performance
- Ring levees were assumed to be in place to provide 100-year performance to isolated small communities.

The base condition UNET model was modified to reflect Detailed Evaluation 3. For areas of levee realignments, cross sections were extended, if necessary, out to the location of the new levee, and encroachments were placed at the new levee locations. For the Fremont Weir modification, the length of the weir was increased by 3,000 feet at the same elevation as the existing weir. No modifications were made to the Yolo Bypass downstream from the weir as a result of the weir extension.

Reaches of the river in which the levees are to be realigned or strengthened would provide a 50-year level of performance. To establish the new levee elevations, a preliminary 50-year UNET run was developed that did not include levee failures in the areas of levee realignment or strengthening. From this run, levee elevations were set slightly above the peak 50-year water surface elevation. As a result of realignment or strengthening of upstream levees, the Yolo Bypass and the Lower Sacramento River levees were strengthened or raised to mitigate for increased flow. For small communities, ring levees were assumed to be in place to provide a 100-year level of performance.

Flow into the Elkhorn storage area would be controlled by a lateral weir placed in the left bank levee of the Yolo Bypass at RM 55. The weir would be 5,000 feet long and set at elevation 33.00 feet to divert up to 11,300 cfs for the 50-year flood, resulting in a total storage of 47,500 acre-feet. The storage area would drain back into the Yolo Bypass at the lower end of the area near I-5.

Flow into the RD 1500 storage area would be controlled by a lateral gated weir placed in the right bank levee of the Sutter Bypass at RM 63.87. The weir would be 2,500 feet long with an invert elevation of 35 feet. When the elevation of water into the Sutter Bypass exceeded 40 feet, the gate controls would begin to operate and a maximum of 86,200 cfs would be diverted during the 50-year flood, with a total storage of 404,800 acre-feet. A gated weir was selected because of the difficulty of diverting up to 90,000 cfs over an uncontrolled weir while at the same time minimizing the required transitory floodplain storage. For an uncontrolled weir, this structure would need to be 4 miles long and it still would not have provided the same amount of control as the proposed gated weir structure. The storage area would drain into the Sutter Bypass at its confluence with the Sacramento River.

This evaluation also includes a reservoir re-operation scenario at Oroville Dam. This re-operation scenario reflects decreasing the objective flow from 150,000 cfs to 90,000 cfs and 200,000 acre feet of additional flood storage. For this evaluation, the peak 50-year flow in the Feather River that reaches Yuba City is 110,000 cfs. For Detailed Evaluation 1 (existing conditions Oroville Dam hydrology), the peak 50-year flow in the Feather River at Yuba City is 160,000 cfs.

San Joaquin River System

Model simulations for Detailed Evaluation 3 evaluated new upstream storage to reduce valley flood flows. Based upon past modeling experience (as described in Chapter IV), increased flood storage at Friant Dam was determined to have the greatest ability to reduce downstream flooding, as compared to modified operations of reservoirs located lower in the river system. New flood hydrographs were developed to reflect the revised hydrologic conditions with additional upstream flood storage.

Detailed Evaluation 3 includes levee realignments in certain reaches. The levee realignment areas were chosen because of geotechnical constraints with the location of the existing alignments.

The measures included in this detailed evaluation were selected to support a consistent level of flood performance throughout the San Joaquin River basin. The flood damage reduction benefits of Detailed Evaluation 3 are gained through reservoir storage, levee strengthening, levee realignments, and transitory floodplain storage. This evaluation maximizes the use of existing facilities and minimizes the need for additional land acquisition and impacts to infrastructure and land use. The components of Detailed Evaluation 3 are illustrated in Plate 60 for the San Joaquin Basin. In the San Joaquin River Basin, Detailed Evaluation 3 includes the following components:

- San Joaquin River levee realignments from Gravelly Ford down to the Mendota Dam
- San Joaquin River levees strengthened from the Mendota Dam down to the Eastside Bypass Connector Channel
- San Joaquin River levee realignments from the Eastside Bypass Connector Channel down to the Mariposa bypass
- San Joaquin River levee realignment in a short reach between the Merced and Tuolumne rivers
- San Joaquin River levee realignment from between the Tuolumne and Stanislaus rivers down to Paradise Cut
- A San Joaquin River overflow weir adjacent to the Mendota Dam that diverts flow around Mendota Dam
- A modified San Joaquin River Bifurcation structure to the Chowchilla Bypass that sends 5,500 cfs down the Chowchilla Bypass and the remainder of the 50-year flow down the San Joaquin River

- A modified Eastside Bypass Connector Channel control structure that forces the 50-year event in the San Joaquin River to continue down the river corridor
- Transitory floodplain storage totaling 52,000 acre-feet provided at the West Bear Creek and the San Joaquin River National Wildlife Refuge areas.
- A Friant Dam-Millerton Lake re-operation that would increase the objective flow release from 8,000 cfs up to 12,000 cfs, and 50,000 acre feet of additional flood flow storage.
- Ring levees were assumed to be in place to protect isolated small communities.

The base condition UNET model was modified to reflect Detailed Evaluation 3. For areas of levee realignments, cross sections were extended, if necessary, out to the location of the new levee, and encroachments were placed at the new levee locations. For the Mendota Dam Overflow Weir, the weir that represents Mendota Dam was lengthened to reflect an overflow weir along the right bank of the San Joaquin River. For the Chowchilla Bypass Bifurcation Structure modification, the bifurcation criteria was modified to reflect flow, up to 2,000 cfs, continuing down the San Joaquin River with additional flow up to the 50-year peak flow (13,000 cfs) splitting evenly into the San Joaquin River and the Chowchilla Bypass (flow in excess of the 50-year peak is allowed to weir flow over the top of the bifurcation structure). The Eastside Bypass Connector Channel Control Structure was modified to force the 50-year peak flow down the San Joaquin River (flow in excess of the 50-year peak splits with a portion going down the San Joaquin River and the remainder spilling over a weir into the Connector Channel).

This evaluation also included a reservoir re-operation scenario at Friant Dam. This re-operation scenario reflects the objective flow increasing from 8,000 cfs to 12,000 cfs and 50,000 acre feet of additional flood storage. For this evaluation, the peak 50-year flow in the San Joaquin River that reaches the Chowchilla Bypass Bifurcation Structure is 13,000 cfs. For Detailed Evaluation 1 (existing conditions Friant Dam hydrology), the peak 50-year flow in the San Joaquin River that reaches the Chowchilla Bypass Bifurcation Structure is 26,000 cfs.

Transitory floodplain storage for the San Joaquin River was modeled in the following ways for each respective storage area. For the West Bear Creek area, three weir flow lateral spills were modeled on the San Joaquin River downstream of the Mariposa Bypass to divert flow into this area. This area drains to Salt Slough which flows into the San Joaquin River between Bear Creek and the Merced River. For the San Joaquin River National Wildlife Refuge, a weir flow lateral spill was modeled on the San Joaquin River near the confluence with the Tuolumne River to divert flow to this area. This area drains back through this same lateral spill to the San Joaquin River.

Reaches of the river in which the levees are to be realigned or strengthened would provide a 50-year level of performance. To set the new levee elevations, a preliminary 50-year UNET run was developed that did not include levee failures in the areas of levee realignment or strengthening. From this run, levee elevations were set slightly above the peak 50-year water surface elevation. For small communities, ring levees were assumed to be in place to provide a 100-year level of performance.

RESULTS OF DETAILED EVALUATIONS

Detailed Evaluation 1 - River Corridor

UNET models that reflect all of the components of Detailed Evaluation 1 were developed for the Sacramento and San Joaquin River Basins. The models were run for the 10-, 25-, 50-, 100-, 200-, and 500-year events. The evaluation is intended to provide 50-year level of performance to all areas adjacent to improved reaches of the river. Model runs for the additional events were completed to determine the effect that the evaluation has on flooding at these other frequencies.

Sacramento River System

- Levee setbacks along the Sacramento River increased the flow but lowered the water surface in the reach between Colusa Weir and Tisdale Weir.

- The peak latitude Sacramento flow increased after levee setback and Fremont Weir lengthening, while the flow in the Sacramento River below Sacramento was slightly changed. This also means that the increased flow was directed into Yolo Bypass.

- The increased flow in the Yolo Bypass resulting from the Fremont Weir lengthening raised the water surface in the Yolo Bypass and caused significant backwater effects on Willow, Cache, and Lindsey Slough. As a result levee strengthening was required on these reaches and the lower Yolo Bypass above Cache Slough.

- The peak latitude Sacramento flow for the 50-yr flood was about the same as the 100-yr flood due to upstream levee breaks (because LFP for new and strengthened levees was set to 50-year water surface).

San Joaquin River System

Under existing conditions, only approximately 2,500 cfs continues down the San Joaquin River past the Chowchilla Bypass Bifurcation Structure and the remainder of flow continues down the Chowchilla Bypass. With Detailed Evaluation 1, approximately 20,000 cfs continues down the San Joaquin River past the Chowchilla Bypass Bifurcation Structure. The large decrease in flow just upstream of the Mendota Dam (and the large increase downstream of the dam) is a result of the Mendota Dam Bypass Channel. The diversion into the Chowchilla Bypass is limited to 5,000 cfs. Downstream of the Eastside Bypass Connector Channel, the flow that continues down the San Joaquin River under existing conditions is limited to 300 cfs. With Detailed Evaluation 1, the total flow in the San Joaquin River (approximately 17,000 cfs) stays in the river and is not diverted to the Eastside Bypass. The maximum stage in the San Joaquin River downstream of the Bifurcation Structure is significantly higher with Detailed Evaluation 1 as compared to existing conditions. This stage increase continues down to the Mariposa Bypass. This entire reach would be located in an area of levee realignment. The new levees would be built to convey the additional flow at the stage shown.

For this evaluation, the Mariposa Bypass would not be used for events up to and including 50-years. The reach of the San Joaquin River located downstream of the Mariposa bypass would need to be strengthened since the peak flow entering this reach is approximately 17,000 cfs and the present capacity is only 10,000 cfs. The levees in this reach are not included to be realigned because there are breaches in the levees that vent flow off into the West Bear Creek area. The flow in this reach drops from approximately 17,000 cfs down to approximately 7,000 cfs as a result of the West Bear Creek breaches.

On the San Joaquin River between the Bear Creek/Eastside Bypass confluence down to the Tuolumne River, there is a slight difference between existing conditions and Detailed Evaluation 1. The difference is a short reach of realigned levees between the Merced River and the Tuolumne River, but this has no significant effect on peak flows and stages.

On the San Joaquin River near the Tuolumne River, there is a weir flow lateral spill that flows into the San Joaquin River National Wildlife Refuge (SJRNWR). The peak flow in the San Joaquin River drops approximately 7,000 cfs as a result of this diversion to the SJRNWR.

For existing conditions, the peak flow from the San Joaquin River into the Upper Eastside Bypass (Chowchilla Bypass) is approximately 10,000 cfs. The advertised capacity of this reach is 5,500 cfs. Detailed Evaluation 1 diverts 5,000 cfs into this reach. No improvements to the Eastside Bypass were included in Detailed Evaluation 1. Levee failures occur under existing conditions and they still occur with Detailed Evaluation 1. However, conditions along this reach are improved since the peak flow coming into this reach from the San Joaquin River is significantly reduced.

Detailed Evaluation 1 provides 50-year performance to areas adjacent to realigned or strengthened levees. Ring levees were assumed to be in place around small communities such as Mendota and Firebaugh give the additional performance for events up to 100-year. No improvements were made to protect the large urban areas of Modesto and Stockton.

All of the above discussion has been with regard to the 50-year event. For the 10-year event, generally, more flow is conveyed down the San Joaquin River than under existing conditions simply because the system would be designed to convey the 50-year event. Much less pressure would be put on the Eastside Bypass with Detailed Evaluation 1 as compared to existing conditions.

For the 100-year event, levee failures occur upstream of the Chowchilla/Eastside Bypass Bifurcation Structure with Detailed Evaluation 1, as they do under existing conditions. These levee failures basically limit the amount of flow that continues down the San Joaquin River. Between the Mariposa Bypass and the Tuolomne River, there is very little difference between Detailed Evaluation 1 and existing conditions. Downstream of the SJRNWR outlet, there appears to be a large difference in flow between existing conditions and Detailed Evaluation 1. Again, this is not a true comparison and the reason for the difference is explained above for the 50-year event.

Detailed Evaluation 2 – River Corridor With Floodplain Storage

UNET models that reflect all of the components of Detailed Evaluation 2 were developed for the Sacramento and San Joaquin River Basins. The models were run for the 10-, 25-, 50-, 100-, 200-, and 500-year events. The evaluation is intended to provide 50-year level of performance to all areas adjacent to improved reaches of the river. Model runs for the additional events were completed to determine the effect that the evaluation has on flooding at these other frequencies.

Sacramento River System

- Levee Setbacks along the Sacramento River increased the flow but lowered the water surface in the reach between Colusa Weir and Tisdale Weir.
- The peak Latitude Sacramento flow increased after levee setback and Fremont Weir Lengthening, while the flow in the Sacramento River below Sacramento was slightly changed. This also means that the increased flow was directed into Yolo Bypass.
- The increased flow in the Yolo Bypass resulting from the Fremont Weir Lengthening raised the water surface in the Yolo Bypass and caused significant backwater effects on Willow, Cache, and Lindsey Slough. As a result levee strengthening was required on these reaches and the lower Yolo Bypass above Cache Slough.
- The peak Latitude Sacramento flow for the 50-yr flood was about the same as the 100-yr flood due to upstream levee breaks (because LFP for new and strengthened levees was set to 50-year water surface).

San Joaquin River System

The inflow hydrograph to the San Joaquin River from Friant Dam would be revised because this evaluation includes a reservoir re-operation as described previously. Therefore, the peak flow on the San Joaquin River upstream of the Chowchilla/Eastside Bypass Bifurcation Structure would be considerably less than existing conditions and Detailed Evaluation 1.

Under existing conditions, only approximately 2,500 cfs continues down the San Joaquin River past the Chowchilla Bypass Bifurcation Structure and the remainder of flow continues down the Chowchilla Bypass. With Detailed Evaluation 2, approximately 14,000 cfs would continue down the San Joaquin River past the Chowchilla Bypass Bifurcation Structure. The large decrease in flow just upstream of the Mendota Dam (and the large increase downstream of the dam) is a result of the Mendota Dam Bypass Channel. The diversion into the Chowchilla Bypass is limited to 5,500 cfs. Downstream of the Eastside Bypass Connector Channel, the flow that continues down the San Joaquin River under existing conditions is limited to 300 cfs. With Detailed Evaluation 2, the total flow in the San Joaquin River (approximately 15,000 cfs) stays in the river and is not diverted to the Eastside Bypass. The maximum stage in the San Joaquin River downstream of the Bifurcation Structure is significantly higher with Detailed Evaluation 2 as compared to existing conditions. This stage increase continues down to the Mariposa Bypass. This entire reach of the San Joaquin River is located in an area of levee realignment, in which the new levees would be built to convey the additional flow at the stage shown.

In this evaluation, the Mariposa Bypass would not be used for events up to and including 50-years. Therefore, there is no change in flow at the Mariposa Bypass. The reach of the San

Joaquin River located downstream of the Mariposa bypass would need to be strengthened because the peak flow coming into this reach is approximately 15,000 cfs and the advertised capacity is 10,000 cfs. The levees in this reach are not included to be realigned because there are breaches in the levees that vent flow off into the West Bear Creek area. The flow in this reach drops from approximately 15,000 cfs down to approximately 7,000 cfs as a result of the West Bear Creek breaches.

On the San Joaquin River between the Bear Creek/Eastside Bypass confluence down to well below the Merced River, the peak flow is higher with Detailed Evaluation 2 than existing conditions. The reason for this is that the right bank levee of the San Joaquin River between the Eastside Bypass and the Merced River would be strengthened to convey the 50-year flow. Flow in the San Joaquin River downstream of the Merced River eventually equalizes with existing conditions. There is a short reach of realigned levees between the Merced River and the Tuolumne River, but this has no significant effect on peak flows and stages.

On the San Joaquin River near the Tuolumne River, there is a weir flow lateral spill that flows into the San Joaquin River National Wildlife Refuge (SJRNWR). The peak flow in the San Joaquin River drops approximately 7,000 cfs as a result of this diversion to the SJRNWR.

For existing conditions, the peak flow from the San Joaquin River into the Eastside Bypass is approximately 10,000 cfs. The advertised capacity of this reach is 5,500 cfs. Detailed Evaluation 2 diverts 5,500 cfs into this reach. Detailed Evaluation 2 includes two areas of levee strengthening along the Eastside Bypass. The first area is just upstream of the Connector Channel. The second area is between the Connector Channel and the Mariposa Bypass. These levees need to be improved to effectively utilize the Sandy Mush and East Bear Creek transitory floodplain storage areas. If levee failures occurred, the available storage in these areas might be used up before the peak of the hydrograph reached the area. Levee improvements were not included on the Fresno River, Berenda Slough, and Ash Slough, so existing failures that occur in these reaches would continue to occur with Detailed Evaluation 2. Conditions along the Eastside Bypass are additionally improved because the peak flow coming into this reach from the San Joaquin River is significantly reduced as a result of Detailed Evaluation 2.

Detailed Evaluation 2 provides 50-year performance to areas adjacent to realigned or strengthened levees. Ring levees were assumed to be in place around small communities such as Mendota and Firebaugh give additional performance up to the 100-year event.

All of the above discussion has been with regard to the 50-year event. For the 10-year event, in general, more flow is conveyed down the San Joaquin River simply because the system would be designed to convey the 50-year event. Much less pressure is put on the Eastside Bypass with Detailed Evaluation 2 as compared to existing conditions.

For the 100-year event, levee failures occur upstream of the Chowchilla/Eastside Bypass Bifurcation Structure with Detailed Evaluation 2, as they do under existing conditions. These levee failures basically limit the amount of flow that continues down the San Joaquin River. Between the Mariposa Bypass and the Tuolomne River, there is very little difference between Detailed Evaluation 2 and existing conditions. Downstream of the SJRNWR outlet, there appears to be a large difference in flow between existing conditions and Detailed

Evaluation 2. Again, this is not a true comparison and the reason for the difference is explained above for the 50-year event.

Two additional sets of runs were completed for Detailed Evaluation 2. These runs involved reservoir re-operation scenarios for New Don Pedro Reservoir and for Lake McClure. The first set of runs involved re-operating New Don Pedro Reservoir. This re-operation scenario reflects the objective flow increasing from 9,000 cfs to 15,000 cfs and no additional flood storage. The second set of runs involved re-operating New Don Pedro Reservoir and Lake McClure. For New Don Pedro Reservoir, the re-operation scenario reflects the objective flow increasing from 9,000 cfs to 15,000 cfs and no additional flood storage. For Lake McClure, the re-operation scenario reflects the objective flow increasing from 6,000 cfs to 8,000 cfs and no additional flood storage. Results of modeling for events up to 50-years were not favorable. For the 50-year event, the peak flow profiles were very similar to Detailed Evaluation 2. However, the hydrographs from these two reservoirs were considerably drawn out and had the effect of stacking on top of the San Joaquin River hydrograph. Under existing conditions for the 50-year event and with Detailed Evaluation 2, there are uncontrolled releases from these two reservoirs. These uncontrolled releases occur before the peak from the San Joaquin River reaches this area. These reservoir re-operation scenarios hold the flow back and release it more on top of the peak from the San Joaquin River. Therefore, these reservoir re-operation scenarios were not included in Detailed Evaluation 2.

Detailed Evaluation 3

UNET models that reflect all of the components of Detailed Evaluation 3 were developed for the Sacramento and San Joaquin River Basins. The models were run for the 10-, 25-, 50-, 100-, 200-, and 500-year events. The evaluation is intended to provide 50-year level of performance to all areas adjacent to improved reaches of the river. Model runs for the additional events were completed to determine the effect that the evaluation has on flooding at these other frequencies.

Sacramento River System

- The foothill storage in Oroville helped to reduce Latitude Sacramento peak flows to baseline levels, but it was less effective than transitory floodplain storage. Both Elkhorn and the entire Tisdale storage area (RD 1500) were still needed.

- An active control weir must be used for sending water to the Tisdale Storage Area, but the length of the weir was shorter than RC5. Less storage was used in Tisdale than for RC5.

- The peak Latitude Sacramento flow for the 50-yr flood was about the same as the 100-yr flood due to upstream levee breaks (because LFP for new and strengthened levees was set to 50-year water surface).

- Levee strengthening measures were significantly reduced in terms of length and height on Willow, Cache, and Lindsey Slough. The levee strengthening in the lower Yolo Bypass was eliminated.

San Joaquin River System

The inflow hydrograph to the San Joaquin River from Friant Dam would be revised because this evaluation includes a reservoir re-operation as described previously. Therefore, the peak flow on the San Joaquin River upstream of the Chowchilla/Eastside Bypass Bifurcation Structure is considerably less than existing conditions and Detailed Evaluations 1 and 2.

Under existing conditions, only approximately 2,500 cfs continues down the San Joaquin River past the Chowchilla Bypass Bifurcation Structure and the remainder of flow continues down the Chowchilla Bypass. With Detailed Evaluation 3, approximately 7,000 cfs continues down the San Joaquin River past the Chowchilla Bypass Bifurcation Structure. The diversion into the Chowchilla Bypass is limited to 5,500 cfs. Downstream of the Eastside Bypass Connector Channel, the flow that continues down the San Joaquin River under existing conditions is limited to 300 cfs. With Detailed Evaluation 3, the total flow in the San Joaquin River (approximately 9,000 cfs) stays in the river and is not diverted to the Eastside Bypass. The maximum stage in the San Joaquin River downstream of the Bifurcation Structure is significantly higher with Detailed Evaluation 3 as compared to existing conditions. This stage increase continues down to the Mariposa Bypass. This entire reach is located in an area of levee realignment or levee strengthening. The new levees would be built to convey the additional flow at the stage shown.

In this evaluation, the Mariposa Bypass would not be used for events up to and including 50-years. There is an increase in flow just upstream of the Mariposa Bypass. This is a result of a levee failure on the Eastside Bypass into the Turner Island area. The Eastside Bypass levee failure causes a levee failure on the San Joaquin River from the land side. This levee failure causes flow to spill into the San Joaquin River. On the San Joaquin River downstream of the Mariposa Bypass, there are breaches in the levees that vent flow off into the West Bear Creek area. The flow in this reach drops from approximately 14,000 cfs to approximately 7,000 cfs as a result of the West Bear Creek breaches.

On the San Joaquin River between the Bear Creek/Eastside Bypass confluence down to the Tuolumne River, there is very little difference between existing conditions and Detailed Evaluation 3. There is a short reach of realigned levees between the Merced River and the Tuolumne River, but this has no significant effect on peak flows and stages.

On the San Joaquin River near the Tuolumne River, there is a weir flow lateral spill that flows into the San Joaquin River National Wildlife Refuge (SJRNWR). The peak flow in the San Joaquin River drops approximately 7,000 cfs as a result of this diversion to the SJRNWR.

For existing conditions, the peak flow from the San Joaquin River into the Eastside Bypass is approximately 10,000 cfs. The advertised capacity of this reach is 5,500 cfs. Detailed Evaluation 3 diverts 5,500 cfs into this reach. No improvements to the Eastside Bypass were included in Detailed Evaluation 3. Levee failures occur under existing conditions and they still occur with Detailed Evaluation 3. Conditions along this reach are improved however, because the peak flow coming into this reach from the San Joaquin River is significantly reduced.

A variation of Detailed Evaluation 3 was developed. This evaluation is called Detailed Evaluation 3A and is illustrated on Plate 61. Detailed Evaluation 3A varies from Detailed Evaluation 3 in that the entire Eastside Bypass system including all of its tributaries are improved to contain the 50-year flow. The tributaries include the Fresno River, Berenda Slough, Ash Slough, and Bear Creek. The peak flow profile on the Eastside Bypass is considerably higher as a result of this variation. It also somewhat increases the peak flow profile on the San Joaquin River from just upstream of the Mariposa Bypass down to near Paradise Cut.

Detailed Evaluation 3 (and 3A) provide 50-year performance to areas adjacent to realigned or strengthened levees. Ring levees were assumed to be in place around small communities such as Mendota and Firebaugh give the additional performance for events up to 100-year. No improvements were made to protect the large urban areas of Modesto and Stockton.

All of the above discussion has been with regard to the 50-year event. For the 10-year event, in general, more flow is conveyed down the San Joaquin River simply because the system would be designed to convey the 50-year event. Much less pressure is put on the Eastside Bypass with Detailed Evaluation 3 as compared to existing conditions.

For the 100-year event, levee failures occur upstream of the Chowchilla/Eastside Bypass Bifurcation Structure with Detailed Evaluation 3, as they do under existing conditions. These levee failures basically limit the amount of flow that continues down the San Joaquin River. Between the Mariposa Bypass and the Tuolomne River, there is very little difference between Detailed Evaluation 3 and existing conditions. Downstream of the SJRNWR outlet, there appears to be a large difference in flow between existing conditions and Detailed Evaluation 3. Again, this is not a true comparison and the reason for the difference is explained above for the 50-year event.

REFERENCES

PUBLICATIONS

FLO Engineering, *FLO-2D User's Manual*, Version 98.2, October 1998

U.S. Army Corps of Engineers, Hydrologic Engineering Center, *UNET: One-Dimensional Unsteady Flow Through a Full Network of Open Channels, User's Manual*, Version 3.2, August 1997

U.S. Army Corps of Engineers, *Post-Flood Assessment*, March 1999

U.S. Army Corps of Engineers & The Reclamation Board, State of California, *Sacramento and San Joaquin River Basins Comprehensive Study Phase I Documentation Report*, March 1999

OTHER SOURCES

Internet sites for various public agencies

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