Evaluation of a Non-Structural Flood Management and Habitat Enhancement Alternative at the San Joaquin River National Wildlife Refuge

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Abstract: As a result of the January 1997 floods, the San Joaquin River National Wildlife Refuge (SJRNWR) worked with the US Army Corps of Engineers (USACE) to plan a non-structural flood management alternative (NSA). This alternative included breaching existing mainstem San Joaquin River levees on recently acquired refuge land to protect and restore wetland and riparian habitat. The proposed NSA will provide floodplain inundation behind project levees of up to 3,100 acres of refuge land in some years. This paper describes methodology that is currently being used to evaluate flood hazard and habitat effects of proposed NSA levee breach sites. The evaluation will examine expected hydrologic and habitat interactions and outcomes of the proposed NSA, with particular attention to the needs of anadromous fish. It will identify potential benefits or risks to anadromous fish and other species of concern. The primary analysis tool used in this study is the one-dimensional, looped network hydrodynamic model, MIKE 11, used in combination with Geographical Information Systems (GIS) analyses. This paper describes the project in detail including the historical setting of the site, the hydrodynamic modeling methodology, evaluation criteria being used to assess the results and finally, the challenges of the project. Evaluation criteria being used include frequency, durations, depth and area of flooding; potential for fish stranding; potential for creation of non-native or predator fish species habitat; and flood effects on adjacent lands. In addition, potential refinements of the currently proposed NSA will be identified. This phase of the evaluation is expected to be completed in April 2001.

Introduction

Project Purpose

As a result of the January 1997 floods, the San Joaquin River National Wildlife Refuge (SJRNWR) is working with the US Army Corps of Engineers (USACE) to plan a non-structural flood management alternative (NSA). This alternative includes breaching existing mainstem San Joaquin River levees on recently acquired refuge land to protect and restore wetland and riparian habitat. The proposed NSA will provide floodplain inundation behind project levees of up to 3,100 acres of refuge land in some years.

The focus of this study is to examine habitat effects of proposed levee breaches and NSA refinements with particular emphasis on the needs of fish, while minimizing adverse impacts to adjoining land uses. The primary analysis tool used in this study is a onedimensional, looped network hydrodynamic model, MIKE 11, in combination with Geographic Information System (GIS) analysis. Model results include depth and time of inundation as well as simulated average flow velocities and area of inundation on reactivated floodplain at the refuge, identifying both flood risk to surrounding land-owners and potential benefits or risks to anadromous fish.

The study is being undertaken under a joint venture between Ducks Unlimited and Philip Williams & Associates, Ltd. (PWA), for the U. S. Fish and Wildlife Service (USFWS) Anadromous Fish Restoration Program (AFRP). Funding for the current study is provided by the AFRP.

Project Site

The SJRNWR is located on the San Joaquin River downstream of the confluence of the San Joaquin and Tuolumne rivers, approximately 9 miles west of the city of Modesto. Levee breach sites identified in the NSA plan prepared by the USACE are located on the San Joaquin River from approximately river mile RM 79 to RM 86. Three reclamation districts proposed for modification are included within the refuge. A photograph showing the SJNWR as viewed from the south of the site looking north along the project levee with the river to the east and the floodplain of the refuge to the west is shown in Photograph 1. A map of the site is shown in Figure 1.

Project History

Historic Land Use

The SJRNWR has historically been used for livestock grazing and cultivated agriculture including orchard and row crops. Evidence of agriculture and channel alterations in the SJRNWR are evident in documents from the early 1900's. In 1926, the West Stanislaus Irrigation District developed a canal system that

PHOTOGRAPH 1. SJRNWR looking from south to north.

included a diversion at the site of the SJRNWR. Irrigation systems on refuge lands were also constructed around this time (Griggs, 2000).

Flood Setting

Precipitation in the San Joaquin Valley occurs primarily from November to April with very little precipitation occurring during summer months. Snowpack accumulates on the east side of the basin above an elevation of about 5,000 feet; snowmelt generally begins to affect runoff by April. Two types of floods may be identified in the basin: rainfall floods during late fall and winter and snowmelt floods during spring and summer. Highest peak discharges are due to floods driven by rainfall runoff; however their duration tends to be lower than floods driven by snowmelt.

Prior to construction of Friant Dam, very high late spring and early summer flows declined gradually over summer to reach minimum flow levels in the fall and early winter. Today, the system is highly regulated by storage reservoirs, and is further affected by groundwater withdrawals, diversions for irrigation, power, municipal supply, and imported water. During summer months, base flow is low, and consists mainly of return water from irrigated areas. In winter and early spring, higher flows still occur; however, levees currently prevent most of the SJRNWR from flooding. Channel design flow at Maze Road Bridge is 46,000 cfs. Levees begin to fail, or are overtopped when flows exceed 40,000 cfs. Out of channel flows may have occurred in 1938 (41,600 cfs), and did occur in 1969 (41,800 cfs), 1983 (38,400 cfs), and 1997 (59,300 cfs) (USACE, 2000).

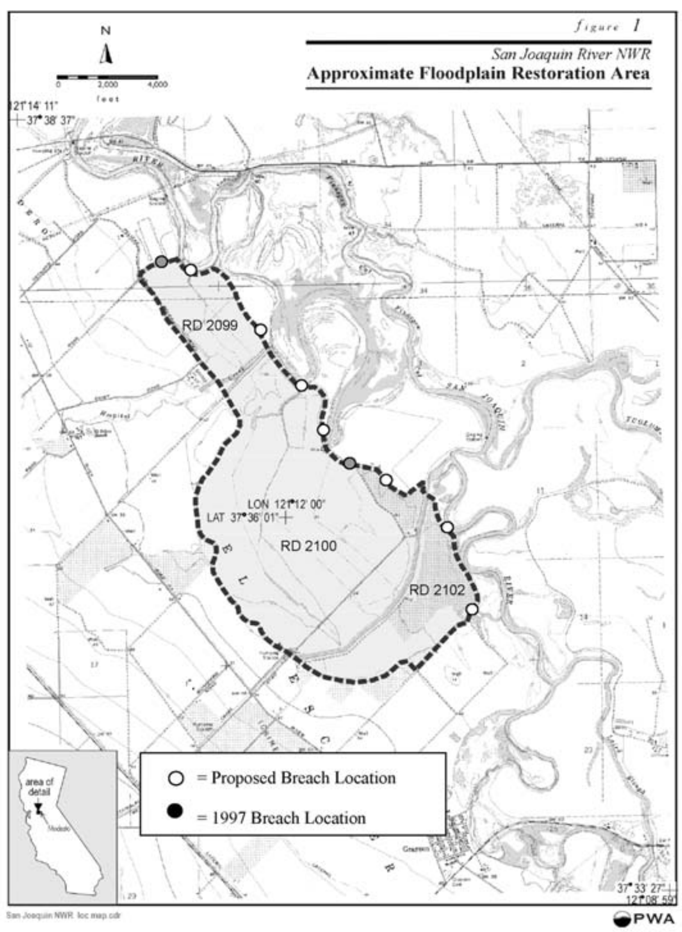
Purchase of the Study Site

In 1999, the USFWS purchased 3,166 acres of floodprone farmland consisting of three properties located on the west bank of the San Joaquin River between RM 77 and RM 84, near the confluence of the Tuolumne River with the San Joaquin River. Levees protecting these parcels had failed in 1983 and 1997. One of the principal reasons for the purchase of the land, which became a significant portion of the West Unit of the SJRNWR, was to provide a demonstration of a non-structural flood control alternative. Plans for the site include breaching of levees to allow flood waters from the river to spread over its former floodplain. It is intended that such levee breaches would relieve pressure on the other local levees as well as surrounding communities during times of high flows.

Non Structural Alternative for Flood Control

In February 1998, the USACE, USFWS and the Reclamation Board (RCB) signed an outline of issues and preliminary agreements regarding a nonstructural flood control alternative. In this agreement, the USACE provided recommendations to the RCB and USFWS for breaching of levees at the seven locations shown in FIGURE 1, including a onedimensional steady state hydraulic analysis of the expected flood impacts of the proposed breaches

FIGURE 1. Boundaries of SJRNWR, levee breach locations, and reclamation districts.



through the project reach, using the HEC-RAS numerical model. The study analyzed conditions at a project design flood of 46,000 cfs, as shown in TABLE 1.

The USACE proposed seven breach locations as shown in FIGURE 1, two locations in each of the levee systems of RD's 2099 and 2102 and three locations in the levees of RD 2100. The breach locations were chosen at known structurally weak areas of the project levees and at topographically low areas along the line of the project levees.

METHODS

The primary objective of this analysis is to examine effects of proposed levee breaches on anadromous fish habitat and secondarily to evaluate flood risk to neighboring landowners. The analysis will also be used to identify potential refinements to the current NSA that may provide improved habitat conditions. The primary analysis tool being used for this investigation is a hydrodynamic model capable of simulating water flow over the floodplain during flood events. This tool is being used in conjunction with habitat criteria that have been developed for the evaluation of simulated flood conditions. A five-year simulation period (1993 to 1998) was chosen to include the 1997 flood and also to encompass a range of hydrologic conditions.

Hydrodynamic Model

To determine if restoration areas will provide appropriate habitat, a hydrodynamic model is being used to simulate flow depth and velocities under a levee breach scenario. The approach taken in this modeling study has been to model the system using a one-dimensional looped network hydrodynamic model that describes floodplains as separate channels, each with its own hydrodynamic characteristics. This approach allows simulation of velocity and depth in the floodplain as well as in the main channel.

The numerical model MIKE 11 is being used to simulate system hydrodynamics. This commercially available model has been used to simulate behavior of both simple and complex rivers and floodplain systems (DHI, 2000). MIKE 11 uses an implicit finite difference scheme for computation of unsteady flow based on the Saint Venant Equations.

One of the major advantages of using a looped network system is the ability to describe separate flow patterns and flow exchange in the floodplain. The modeling area is typically divided into major channels and floodplains depending on topography, cross-section shape and estimated flow patterns. Interaction between individual branches is accomplished through connecting channels to describe flow over banks or levees. A schematic of the MIKE 11 looped network developed for the study site is shown in FIGURE 2.

The HEC-RAS study simulated results for a single, steady flow, and was intended to evaluate severe flood conditions (i.e. flow at the capacity of the levee system). In contrast, a measured hydrograph for the period of record 1993 to 1998 will be used in the MIKE 11 simulations. MIKE 11 is a dynamic model that simulates conditions during both the rising and falling limbs of the hydrograph, as well as at the peak flow period. A measured hydrograph for the period of record 1993 to 1998 will be used in the MIKE simulations. The use of a continuous measured hydrograph provides a representation of floodplain conditions throughout several seasons of flood events. MIKE 11 model results will include simulation of the time-varying inundation of the floodplain, during both the rising and falling limbs of the flood hydrograph. Habitat conditions will be primarily supported by more frequent floodplain flows and will depend significantly on the duration of floodplain inundation. Model results include depth, duration of inundation and velocity in the floodplain during the flood period, and will be used to estimate expected habitat conditions on the project site.

TABLE 1. Results of the USACE Non-Structural Alternative Analysis.

Reclamation District	**Area** (Acres)	**Floodplain Elevation** (feet)	**Project Levee Crown** (feet)	**Project Flood Water Surface Elevation** (feet)	**Area Inundated** (Acres)
2099	530	20.0 to 25.0	40.5 to 41.5	37.0 to 38.5	530 Complete inundation of district. Occasional inundation to adjacent properties
2100	1,535	20.0 to 40.0	41.0 to 43.5	38.0 to 40.5	1,535 Complete inundation of district. Minor inundation (15 acres) to adjacent properties
2102	400	30.0 to 40.0	43.5 to 46.0	40.5 to 42.3	400 Complete inundation of district. No inundation to adjacent landowners

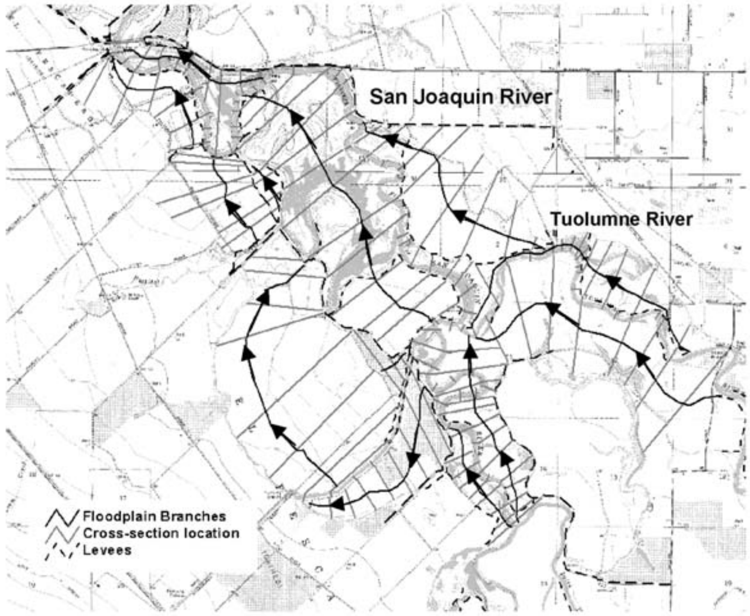


FIGURE 2. Schematization of Project Site for Hydrodynamic Modeling.

Hydrologic Data

A five–year simulation period (1993 to 1997) was chosen for simulation. This period was chosen because it included both low flow periods and the 1997 El Nino flood. Flow hydrographs were obtained at the upstream model boundaries on the San Joaquin River at Crows Landing (USGS # 11274550) and the Tuolumne River at Modesto (USGS # 11290000). Stage data was also obtained from the Department of Water Resources (DWR) at Maze Road Bridge, the downstream boundary of the model.

Topographic Data

The USACE has conducted hydrographic, topographic and photogrammetic surveys of the study region, including the mainstem of the San Joaquin and Tuolumne Rivers. This data was collected as part of the development of basin-wide hydraulic modeling by the USACE and is available to the public as part of the Sacramento and San Joaquin River Basins Comprehensive Study (SSJCS). Data collection was conducted under the SSJCS to create a digital terrain model (DTM), representing the topographical surface above and below the waterline along the river and the immediate floodplain either side of the river (usually to the toe of the project levee). Topography of floodplains and refuge lands was supplemented by the U.S. geological Survey (USGS) 30 meter digital elevation model (DEM) data, and private surveys.

Habitat Evaluation

Simulation of hydrologic conditions on proposed floodplain is a meaningful tool for habitat evaluation only to the extent that linkages between the two are identified. Science that relates inundation conditions to resulting habitat value in rivers of California's Central Valley is extremely young; however, it is of critical importance to planning effective floodplain restoration actions. An important component of this study effort has been to preliminarily identify key floodplain inundation parameters that can be used as indicators of habitat value. These criteria were developed based on consultation with several researchers active in the field as well as from available literature, and may be further revised for use in comparing alternative NSA refinement scenarios in a subsequent phase of the study. Current habitat evaluation criteria are shown in Table 2.

PROJECT CHALLENGES

In general, natural systems are far too complex to model perfectly. Often the greatest challenge of a modeling project is not the modeling exercise itself, but selection of the appropriate model, one whose limitations and strengths are aligned with project objectives. Provided that the appropriate model has been chosen, the accuracy of any model simulation is a function of the availability and quality of input data, as well as appropriate choices of system schematization, and model assumptions.

The model used in this study, MIKE 11, is designed for floodplain analysis. Its formulation and design are in many ways quite suitable for this application.

However, the performance of even the best suited and well chosen model is severely limited by the availability of input data, in this case topographic and flow information.

Lack of Detailed Topography

The hydrodynamic model is severely limited by the coarseness of USGS data that describes the floodplain outside the boundaries of the SSJCS DTM. Limited surveys are available for non-project levees and canals and have been incorporated into the dataset. However, further refinement of model topography could dramatically increase the ability of the hydrodynamic model to accurately simulate flow in the refuge, particularly on the floodplains.

Limited Hydrodynamic Data

Hydrologic information is required at any location where water leaves or enters the boundaries of the model (e.g. upstream boundary, downstream boundary, tributaries and diversions). Ideally, model boundaries would be defined just upstream and downstream of the SJRNWR sufficiently removed from study boundaries in order to minimize any artificial influence. The nearest suitable upstream gauge for the flow boundary on the San Joaquin River is located approximately 33 miles upstream of the confluence of the refuge, at Crows Landing, necessitating extension of the model domain (and input hydrologic data) a significant distance upstream of the refuge boundary; however, a simplified description of the system upstream of the study site is being used to address this need.

In addition to flow estimates at the model boundaries, calibration data is also required for good confidence in model predictions. Model calibration is an essential process to establish appropriate values for parameters in the model's mathematical formulation (e.g., Manning's 'n'). The process of calibration is to fit the model to the system being modeled, trying to match model simulation with observed data. The "goodness" of fit of a calibration exercise is often a function of the objective of the modeling study. Ideally, flow depth and velocity information would

TABLE 2. Habitat Evaluation Criteria.

PARAMETER	VALUE	SPECIES	BIOLOGICAL IMPORTANCE
Recurrence Interval	Minimum 2-3 year return period[1]	Splittail	ensure adequately-frequent spawning
Timing of flooding	Late February →April[1,2,3, 6]	Splittail	principal spawning and rearing months
	May[1,3,6]	Splittail	spawning and rearing may extend into May
	December →May[1, 7]	Chinook salmon	rearing habitat for juveniles
	Prior to February[1]	Splittail	may increase habitat value by providing additional forage habitat for adults
	December →May[4]	Phytoplankton Zooplankton	Improved production prior to arrival of juvenile and adult salmon, splittail
Duration of flooding/Mean Hydraulic Residence Time	$\geq$ 2 days[4]	Phytoplankton	Improved production
	14 days – several weeks[2,4]	Zooplankton	improved production
	$\geq$ 14 days[3, 6]	Splittail,chinook salmon	adult spawning, incubation and larvae to develop sufficiently to move with receding flow
End of Inundation; connectivity	Avoid non-draining floodplain with depressions greater than 1 feet in depth[1]	non-native fish	Avoidance of predator or non-native fish and reduction of salmon and splittail stranding.
Velocity and depth	Mean velocity: >0[2,4], < 3 ft/sec[7]	Splittail Chinook salmon	Adult splittail spawning in faster water, juvenile splittail use of slower water; salmon rearing only in moving water; both need flow cues to avoid stranding
	Total surface area between 6 inches and 6 feet depth[2,3,4]	Splitttail Salmon	Splittail spawning, splittail and salmon habitat [1,2]

[1] Jones & Stokes. 2000. Functional Relationships for the Ecosystem Functions Model, Sacramento-San Joaquin Rivers Basin Comprehensive Study. Final. (J&S F022). December. Sacramento, CA. Prepared for Sacramento-San Joaquin Rivers Basin Comprehensive Study Team, U.S. Army Corps of Engineers, Sacramento, CA.
[2] Keith Whitener, Project Ecologist, Cosumnes River Preserve, 2001. Personal communication.
[3] Randy Baxter, CA Department of Fish and Game, 2001. Personal communication.
[4] Ted Sommer, Environmental Specialist, CA Department of Water Resources, 2001. Personal communication.
[5] Jones & Stokes, 1999. Use of Restored Floodplain Habitat on the American River by Juvenile Chinook Salmon and other Fish Species. June. Prepared for the Sacramento Area Flood Control Agency, Sacramento, CA.

be available for calibration purposes within the model domain, including the refuge floodplain. Once levees have been breached, depth and velocity could and should be monitored in order to improve model description of this complicated system. Presently, such calibration data is not available. Future monitoring should collect suitable calibration data if further refinement of the NSA is desired as a means of adaptive management.

Complexity of Levee and Drainage Network

The USGS 30 meter DEM information can provide only limited representations of levee geometry and floodplain topography, including drainage features. Model representation of levee and drainage features is severely limited by the lack of topographic data. Future modeling studies should include tasks to identify key areas for improvement of topographic data, collect suitable data and incorporate it into the model data set.

FURTHER DEVELOPMENT

Additional Pre-Project Analysis

In a subsequent phase of the study, we hope to conduct the following additional steps in developing analyses to refine the design of the NSA to benefit floodplain habitat:

1) refine the hydrodynamic model using improved topographic data;

2) refine the habitat evaluation criteria for comparison of alternative NSA scenarios;

3) conduct a geomorphic assessment of potential NSA conditions to guide alternative scenario development and comparison of expected outcomes;

4) develop alternative NSA scenarios for evaluation using the hydrodynamic model and habitat evaluation criteria.

Implementation and Monitoring

Adaptive management is a systematic process for continually improving management policies by learning from the outcomes of restoration programs. It allows resource managers a way to proceed responsibly, improving understanding for future decisions. As restoration takes place, better understanding of habitat use by birds, fish and mammals can improve the development of habitat evaluation criteria. Moreover, it is extremely important to continue to improve understanding of underlying physical processes including changes in topography, groundwater levels, flow depth and velocity as well as soils as a basis for understanding restoration success and failure.

Once implementation of the selected NSA scenario has occurred, monitoring data may become available for model calibration, thereby allowing reassessment of the merits of the implemented project, and further modification of the project, if appropriate, as an adaptive management effort.

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LITERATURE CITED

Danish Hydraulic Institute. 2000. MIKE 11, User guide and reference manual. Hørsholm, Denmark.

Griggs, F.T. 2000. Pre-restoration plan for west units of the San Joaquin River National Wildlife Refuge. Prepared by Sacramento River Partners.

Jones and Stokes. 1998. Analysis of Physical Processes and Riparian Habitat Potential of the San Joaquin River. Sacramento, CA

Jones & Stokes. 1999. Use of restored floodplain habitat on the American River by juvenile chinook salmon and other fish species. June. Prepared for the Sacramento Area Flood Control Agency, Sacramento, CA.

Jones & Stokes. 2000. Functional relationships for the ecosystem functions model, Sacramento-San Joaquin Rivers Basin Comprehensive Study: final. [J&S F022]. December. Sacramento, CA. Prepared for Sacramento-San Joaquin Rivers Basin Comprehensive Study Team, U.S. Army Corps of Engineers, Sacramento, CA.

Sommer, T., R. Baxter, and B. Herbold. 1997. The resilience of splittail in the Sacramento-San Joaquin Estuary. Trans.Am.Fish.Soc.126:961-976.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enchanced growth and survival. Can. J. Fish. Aquat. Sci. 58(2):325-333.

United States Army Corps of Engineers, Sacramento District. 2000. Post-flood assessment for 1983, 1986, 1995, and 1997 Central Valley, California. Appendix F; Regulated Flood Flow-Frequency Analysis for the Sacramento / San Joaquin River Basins and Delta Tributaries.

PERSONAL COMMUNICATION

Baxter, Randy, CA Department of Fish and Game, February 2001. Personal communication.

Sommer, Ted, Environmental Specialist, CA Department of Water Resources, February 2001. Personal communication.

Whitener, Keith, Project Ecologist, Cosumnes River Preserve, February 2001. Personal communication.