CALFED BAY-DELTA PROGRAM

# CALFED SCIENCE FELLOWS PROGRAM

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## FELLOWSHIP APPLICATION COVER PAGE

**APPLICANT TYPE** ☐ Postdoctoral Researcher ☒ Ph.D. Graduate Student

**PROJECT NUMBER** ____________

**PROJECT TITLE** Scenarios for Restoring Ecologically Functional Floodplains and Providing Flood Control Services in the Sacramento-San Joaquin Delta

**FINANCIAL SUMMARY**

| | |
|---|---|
| First Year CALFED Funds Requested: | $ 49,000 |
| Total CALFED Funds Requested: | $ 98,375 |
| Duration: | 2 yrs |
| Proposed Start/Completion Dates: | 9/01/2008-8/31/2010 |

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*Will animal subjects be used?* ☐ Yes ☒ No
APPROVAL DATE: ____________ PROTOCOL #: ____________ PENDING: ____________

*Does this application involve any recombinant DNA technology or research?* ☐ Yes ☒ No

Proposed Research Plan

## Scenarios for Restoring Ecologically Functional Floodplains and Providing Flood Control Services in the Sacramento-San Joaquin Delta

### Introduction

Once a vast and productive tidal marsh, the Sacramento-San Joaquin Delta remains one of the most economically and ecologically important areas in California. Flowing south, the Sacramento River drains the Sierra Nevada mountains and southern Cascades, meeting the northbound San Joaquin River in a 1,150 square mile web of channels and reclaimed islands (Figure 1). Precipitation from about 45 percent of the state eventually drains through to the Delta, from snowmelt draining from the Sierra Nevadas as well as from rainfall-fed tributaries. More than 100 years ago farmers began building levees to drain this wetland and convert the land to grow fertile crops. As the Delta's islands and tracts were kept dry by levees, many fields of rich peat soils began to oxidize and subside, and most islands are now below sea level. Recognizing the dangers posed by floodwaters to the farmland and growing urban population in the Delta, federal assistance for flood control planning started as early as 1911.

Because flooding in the Delta is both inevitable and costly, flood management in the region is critical (Kelley 1989). The Delta directly supports more than half a million people, a large agricultural industry, and is facing great urbanization pressure from the Bay Area, Central Valley and Sacramento housing markets. Mass failure of levees (e.g., Hurricane Katrina scale impacts) has great implications for flooding of agricultural islands and large numbers of residences built in the floodplain, with immense consequences for the economy of the entire state. Over the next 50 years, there is a two-thirds chance of widespread levee failure in the Delta, leading to multiple island floodings and the intrusion of seawater farther into the Delta (Lund et al. 2007). Planning for this type of scenario is even more critical because the Delta provides a route through which infrastructure supports the Bay Area's economy and passes water to Southern California's population. Further complicating the problems facing the region, populations of endangered species in the Delta (e.g., Delta smelt) are declining while invasive species are encroaching. Though institutional programs to address these problems have been created, the potential for economic disaster combined with environmental catastrophe is still driving widespread action to propose long-term solutions to threats from land subsidence, sea level rise, seismicity, regional climate change, and urbanization (Mount et al. 2006). The importance of the Delta to people who recreate and live there, or to people far away who obtain drinking water through it, is becoming increasingly acknowledged as threats to the Delta's services continue to grow.

The effects of rising sea level over the next 50 years in combination with further land subsidence will magnify the instability of the Delta levee network, increasing flood risk in the Delta (Mount and Twiss 2005). Levees now constrain where floodwaters can go during peak flow events, and those peaks will be intensified due to climate change increasing high flows from snowmelt. The significant likelihood of regional flooding in the Delta during the next 50 years due to earthquake-induced levee failures or sustained large floods will change the landscape and habitat available for Delta biota. Adapting to levee failure, saltwater intrusion, or earthquake disruption, as well as planning for habitat restoration and endangered species needs, will be constrained by structures on the ground. Thus, planning for landscape change and flood management is particularly important considering the challenges facing the Delta in the short and long-term.

After Hurricane Katrina triggered massive levee collapses that flooded New Orleans in 2005, public support for levee evaluation, repair, and maintenance was roused in California's Central Valley. In 2006 California voters approved billions of dollars to address concerns about their flood control structures and flood management measures--including setback levees for improved flood conveyance. A major challenge in current floodplain management is the lack of maintenance funds coupled with maintenance backlogs and there are long-term cost advantages of setback levees (Conrad 2004). Thus, restoring floodplains by setting back levees has the potential to meet public safety objectives more cost effectively and provide ecological benefits. Flood control provided by the Yolo bypass, for example, can be compatible with environmental needs of biota and agricultural land use (Sommer et al. 2001). Floodplain restoration projects could be designed to both lower the stages of large potentially damaging floods and increase areas that are inundated by ecologically beneficial non-damaging flow pulses (Williams et al. in press). An understanding of the basic processes that shape habitat, and the scales at which they operate, can aid the development of restoration strategies (Opperman et al. 2005).

This research project aims to examine scenarios of change for levee setbacks on rivers within the Delta and considering changes in the over watershed, in terms of runoff and flow. The plan involves defining and quantifying the area inundated by the regular, frequent flood pulse that supports floodplain ecological processes. The Flood Pulse Concept proposed by Junk et al. (1989) is that annual inundation drives the existence, productivity and interactions of the major biota in river-floodplain systems and this predictable duration allows biota to efficiently use the resources available in the aquatic/terrestrial transition zone. These shorter duration flood pulses can promote production of biologically-available carbon and spawning and rearing habitat for native fish. Floodplain restoration has been promoted to increase productivity for Delta species that are food-limited, as indicated by low first-year survival (Jassby and Cloern 2000). The reestablishment of flood pulsing in riverine and tidal systems is also becoming recognized as an important step in wetland restoration (Middleton 2002). The flood pulse concept has been examined in temperate systems, where the interaction between temperature and flow plays a major role in structuring habitat conditions and biotic communities (Tockner et al. 2000). While they suggested that expansion and contraction events below bankfull flooding (flow pulses) shapes environmental heterogeneity and biodiversity patterns, Tockner et al. (2000) cited urgent needs for more empirical data that address the dynamic nature of different riverine floodplains.

Land use planning for floods over the last half-century has hinged on the concept of the 100-year floodplain. The 100-year flood refers to the one percent probability that a certain discharge will be equaled or exceeded in any given year, whether as peak flow or as a volume over several days. The 100-year floodplain represents a larger area than the area affected by small frequent flood pulses. The 100-year flood metric and other similar derivations of frequency (i.e., 2-year flood) do not include the variables of inundation period and seasonality. Inundation duration and seasonality are important because fish and other biota have adapted their life histories to these variations (Benke 2001, Moyle 2008 in press). Williams et al. (in press) proposed a method to identify the area of floodplain inundated by this longer duration type of flood pulse in the Sacramento River watershed. Applying this "floodplain activation flood" (FAF) concept to another river system requires an ecologically-based conceptual model that links key floodplain functions to river stage, frequency, duration and seasonality (Williams et al. in press).

**Objectives**

The purpose of this project is to develop a spatially explicit model of potential floodplain restoration sites using a new indicator for quantifying floodplain function that can serve both ecological and public safety goals. Using a geographic information system (GIS) to synthesize high resolution spatial and hydrologic data will allow multiple scenarios to be run based on adjustments of flood stage. Baseline and climate change scenarios of sea level rise and increasing peak flows will create different extents of potential activated floodplain, as will siting levee setbacks that potentially connect more floodplain to the river.

This project aims to provide data to address questions such as the following:

- How much floodplain area might feasibly be restored through levee setback projects?
- Can flood management measures like levee setbacks for flood conveyance provide ecological benefits in the same places?
- How might climate change affect ecologically beneficial floodplain in the Delta and along upstream rivers?
- Can benefits of floodplain restoration projects be quantified monetarily as levee maintenance and repair costs avoided?

**Approach/Plan of Work**

Restoration actions can increase habitat heterogeneity that improves native fish habitat (Opperman and Merenlender 2004). Various flows shape the geomorphology of the floodplain and create types of habitat heterogeneity. Soils and sediment, topography, and hydroperiod (depth, duration, and frequency of inundation) create a physical mosaic of habitat forms that affect biota. The relationship between riparian forest dynamics and flow characteristics exemplifies linkages between hydrological variability and floodplain ecosystems development (Opperman 2008). The habitat mosaic thus includes the vegetative communities as well as topographic features (which may or may not be vegetated) such as bars, cut banks, oxbow lakes and side channels. Figure 2 shows a floodplain conceptual model that lays out variables composing the floodplain's physical template that allows for the establishment of plant communities that are adapted to flood disturbance.

I propose to develop a site selection model for floodplain restoration in the Delta. I plan to use the metric developed by Williams et al. (in press) called the Floodplain Activation Flood (FAF) to indicate when floodplain inundation can begin to offer beneficial ecological processes. For example, FAF in the Sacramento River watershed has been defined as the flow event that produces a river stage that occurs in 2 out of 3 years for at least 7 days from mid-March to mid-May (Williams et al. in press). To apply the FAF concept, this project will assess river stage, frequency, and duration characteristics for selected reaches of river based on gauge records or hydrodynamic modeling where possible. Floodplain topography detailed enough to establish connectivity with the river channel and inundated area can be generated from Light Detection and Ranging (LIDAR) elevation surveys now available for the Delta.

An overview of the research approach includes the following steps:

1. Assess baseline data and interview experts to define study watersheds/sites in the Delta region. Potential areas for further study in the Delta were suggested by Moyle (in press) and Lund et al. (2007). These locations are pointed out below and in Figure 1:
    a. Suisun Marsh
    b. Cache Slough
    c. Yolo Bypass
    d. San Joaquin River
2. Define FAF for selected river systems
3. Sensitivity analysis of seasonality and duration for areas selected
4. Access existing LIDAR topographic data
5. Assemble imagery for selected areas
6. Collect data from USGS CASCADE Project for four climate change scenarios
    a. Peak monthly flows (the highest flow recorded within each month) from tributaries feeding into the Delta
        i. Translate peak flows into stage
    b. Sea level rise elevations
7. Run GIS analysis for quantifying functional floodplains with baseline sea level and historical peak flows. Climate change scenarios will also be added after the baseline analysis is run. (process described below)

Suisun Marsh, Cache Slough, Yolo bypass, and the San Joaquin River floodplain might provide high quality habitat options for floodplain restoration for a variety of reasons and will be explored as suitable areas for analysis.

*Suisun Marsh*
Suisun Marsh is a large contiguous brackish water marsh in the San Francisco Bay-Delta estuary ecosystem. It encompasses 116,000 acres of managed wetlands, upland grasses, tidal wetlands, and bays and sloughs. Levees maintaining freshwater habitat in the marsh will need reinforcement in the future as marsh soils underlying levees continue to subside. Improving Suisun Marsh for fish will require systematically breaching or removing many levees, reconstruction of some original marsh drainage system, and removal of infrastructure (Moyle in press). The Rush Ranch that is part of the San Francisco Bay National Estuarine Research Reserve and an ongoing experimental levee breach at Blacklock are model sites that might provide information about rates of sedimentation and marsh development, the role of existing emergent vegetation in influencing sedimentation, channel network formation and overall geomorphology, hydrology, and species use.

*Cache Slough*
Cache Slough is located in the northwest corner of the Delta and has high restoration potential as tidal freshwater marsh and slough habitat because island subsidence is relatively low and it maintains much of its original drainage pattern. Restoration in the Cache Slough area would benefit delta smelt that use it as a major spawning and rearing region. Cache Slough is also near a large flooded island (Liberty Island flooded in 1998) that is being used as an example of a passive restoration project. The Cache Slough region can be relatively easily converted into an

expanded version of the favorable tidal habitat for native biota by improving circulation, breaching levees, and eliminating cross channels (Moyle in press).

*Yolo Bypass*

The Yolo Bypass is a 59,000 acre artificial floodplain constructed in the 1930s to protect Sacramento and other nearby communities from flooding. The Fremont Weir connects the bypass to the Sacramento River and when flood waters overflow the weir, they flow down the bypass and reenter the Sacramento River via Cache Slough. The major permanent water channel in the Yolo Bypass is the Toe Drain, which borders the eastern edge of the bypass. When the bypass is inundated it can create up to 60,000 acres of shallow water habitat, becoming high quality rearing habitat for Chinook salmon fry and splittail, as well as other fishes (Moyle in press). Flooding the bypass might also mobilize nutrients and contribute to Delta food webs. The Yolo Bypass has been maintained for flood control, and ecological benefits could be increased if it was allowed to flood more regularly (i.e., every year). Thus, flow regulation such as retrofitting Fremont Weir so that it can allow controlled flooding at different stages (as opposed to implementing levee setbacks) is another management option for restoring and enhancing functional floodplain areas.

*San Joaquin floodplain*

The channel of the San Joaquin River above and through the Delta is highly incised and provides little favorable habitat for desirable fishes (Moyle in press). Poor water quality and exotic species encroachment further constrain habitat availability for these desirable species. Creating a new bypass like the Yolo Bypass on the San Joaquin River is currently being discussed by stakeholders in the area of the Stewart Tract (Moyle, pers. comm.). Removing or breaching levees on islands that border the river would promote flooding and potentially open up new rearing habitat for juvenile salmon.

<u>Analysis for quantifying functional floodplain</u>

An assessment of the available data and interviews with experts in the Delta will further direct the areas selected for the GIS analysis. After an area has been chosen for modeling, definition of a customized floodplain activation flow will require an ecologically-based conceptual model that links key floodplain functions to river stage, frequency, duration and seasonality. Figures 2 and 3 display elements of a floodplain conceptual model demonstrating interactions of the physical floodplain habitat, management actions, hydrology, and inundation characteristics. While all these variables will not be included in the GIS analysis, further refinement of the model by including newly available datasets will be possible. The following steps for a GIS analysis will be used to determine the spatial extent of potential functional floodplain:

1. Select area to quantify potential activated floodplain extent
2. Define FAF for area (stage is function of flood frequency, duration, and seasonality)
3. Obtain three-dimensional floodplain topography from LIDAR based surveys
    a. Ground based LIDAR will be taken for select sites where aerial LIDAR is unavailable upstream of the 2007 Delta flight paths
    b. Ground based LIDAR elevations will also provide another level of resolution to quantify physical habitat characteristics in comparison to any coarser spatial data

4. Derive two-dimensional water surface profile at FAF stage
5. Intersect the floodplain topography and FAF water surface profile
6. Eliminate areas floodable but disconnected from river channel at FAF stage
7. Quantify metrics of size, shape, connectivity, and proximity (to other patches/exotics/land use/etc.) for potential floodplain restoration sites

*Hydrologic analysis*

Where small extended flood hydrographs have not been modeled, interpolation of water surface slopes between sets of recorded water levels at paired gauging stations can be done. FAF river stage can be determined by examining the stage-duration-frequency of paired gauge records. Figure 4 shows an example of how the FAF can be identified using methods presented by Williams et al. (in press). First the flood season is selected (Figure 4a). Next, a moving window can be run through the flood season to identify minimum 7-day stages for each year of record (i.e., the flow that is equaled or exceeded during a 7-day period; Figure 4b). The maximum low stage from the entire period is then selected. Lastly, each year's maximum low stage is ranked and the flow that occurs approximately 2 out of every 3 years with the given duration and season can be identified as the FAF (Figure 4c).

*GIS Analysis*

ESRI ArcGIS will be used to conduct the spatial analysis. Data from LIDAR flights of the Sacramento-San Joaquin Delta conducted during late January and February of 2007 will be used to create the floodplain topography. The aerial LIDAR resolution of 1m provides a significant refinement of the 10m elevation data also available for the region. Where ground based sub-meter resolution LIDAR elevations are taken, they will be used to supplement and/or compare to the floodplain topography and activated floodplain metrics. Climate change scenarios will be an added feature of the analysis that will affect the extent of potential functional floodplain by altering flows. Spatial analyst tools will be used to manipulate the data in a raster format for overlays of FAF and floodplain topography.

The project is anticipated to run for two years. The following tasks will be undertaken in those years.
<u>Year 1</u>
Task 1: Scoping, interviews, and identification of analysis watersheds
Task 2: Data collection (aerial LIDAR, ground-based LIDAR, field visits, and hydrologic data)
Task 3: Coding and testing of initial GIS and hydrological analysis methodology
Task 4: Preparation of year 1 results (spatial statistics, maps, and code)
<u>Year 2</u>
Task 1: Collection of ground based LIDAR if necessary to characterize more sites
Task 2: Run climate change scenarios on selected floodplain landscape
Task 3: Preparation/refinement of all metrics of floodplain size, shape, connectivity, and proximity for potential floodplain restoration
Task 4: Final processing code, maps, and spatial layer development
Task 5: Final results documentation

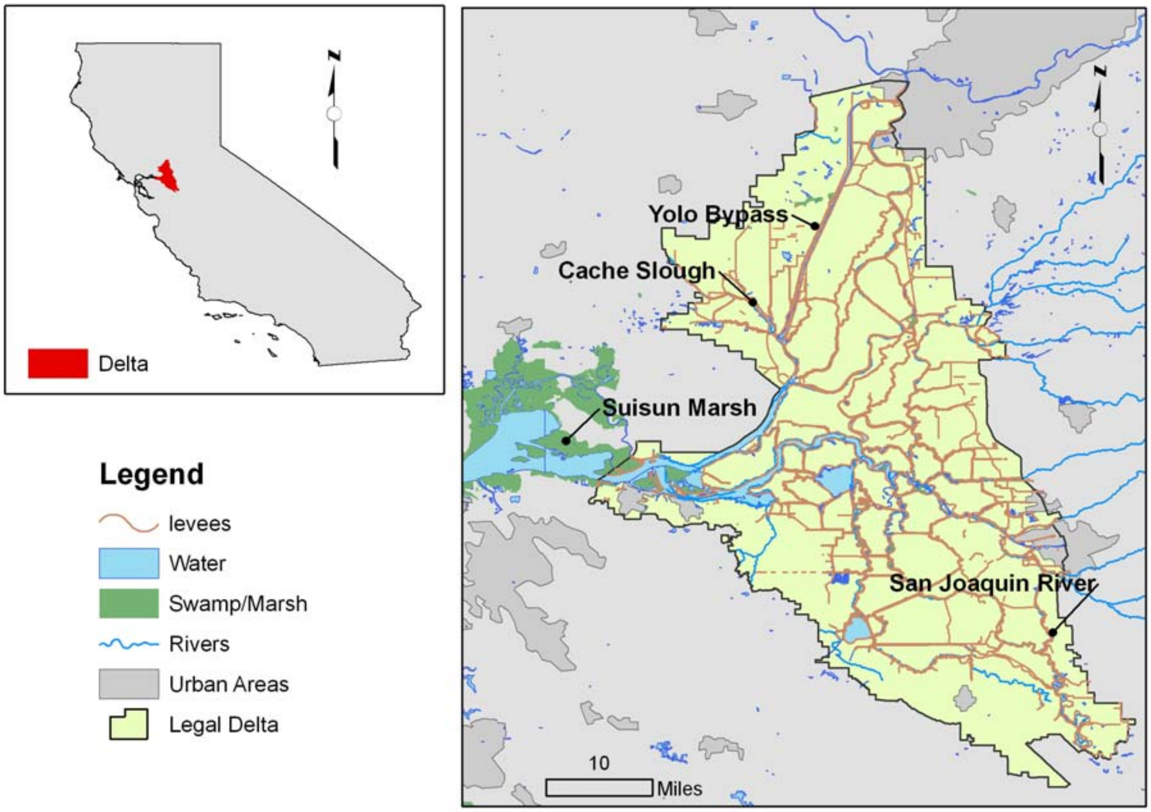
**Output/Anticipated Products and/or Benefits**

Within the same geographic areas I will evaluate, there are two main public policy goals: reducing flood risk and restoring ecosystems. Levee setbacks can help accomplish both of these goals. However, there needs to be more research on where levee setbacks can have the greatest benefit for the Delta. This project will assess the feasibility of creating ecological benefits from floodplains when subjected to long-duration, frequent, springtime floods (the FAF concept). This project will also evaluate the capacity for creating functional floodplain in areas where managers may consider doing levee setbacks for public safety. Thus, this research could begin to address the ecological implications of those public safety management strategies. The proposed spatially explicit integration of a response indicator (FAF) for functional floodplains will allow managers to assess where levee setbacks or other floodplain restoration actions might be more effective or suitable under current conditions. Adding scenarios of climate change as additional analysis will demonstrate the versatility of the GIS model for supporting decision makers.

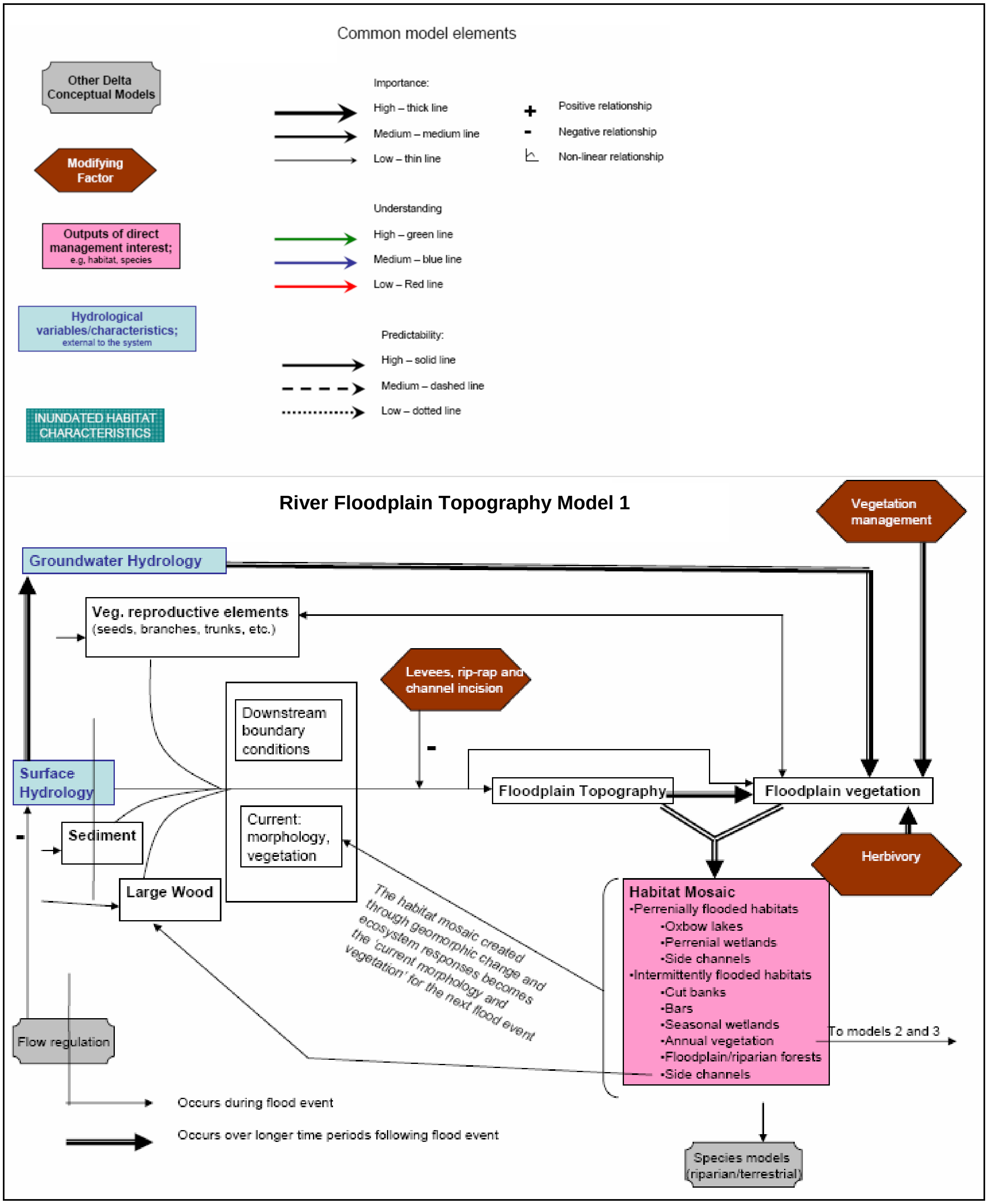
Spatial scale and context affect the benefits provided by the floodplain habitat mosaic, as the site size, shape, connectivity, and proximity to other similar patches, and fragmentation influence the functions provided by the floodplain (Opperman 2008). Benefits produced by floodplains are typically proportional to the spatial extent of floodplains. The small size of the Cosumnes floodplain (89 acres) was found to limit its ability to process materials and increase food web productivity during large flow events (Ahearn et al. 2006). The comparatively greater extent of the Yolo Bypass (60,000 acres) creates population-scale benefits for splittail (Moyle et al. 2004). Connectivity of restored floodplains will be assessed by this project so that benefits can be discussed in more terms than size alone.

Maps and derived spatial data layers will be products of the GIS analysis, and code for processing scenarios will be available in the form of a GIS extension. The model will allow identification of where floodplain restoration work such as levee setback projects have significant potential benefits. Methods for increasing activated floodplain area are displayed in Figure 5, and modeling the implementation of management strategies such as floodplain excavation would further inform restoration options. An analysis of the physical floodplain template can serve as a starting point for building vegetation and fish linkages to flood flows. Quantifying savings in levee maintenance and repair costs would be a future benefit of assessing floodplain restoration scenarios as well.

**Figure 1. Map of Delta and regions of interest for restoration**



# Figure 2. Floodplain conceptual model template (Opperman 2008)



## Figure 3. Floodplain conceptual model for inundation (Opperman 2008)

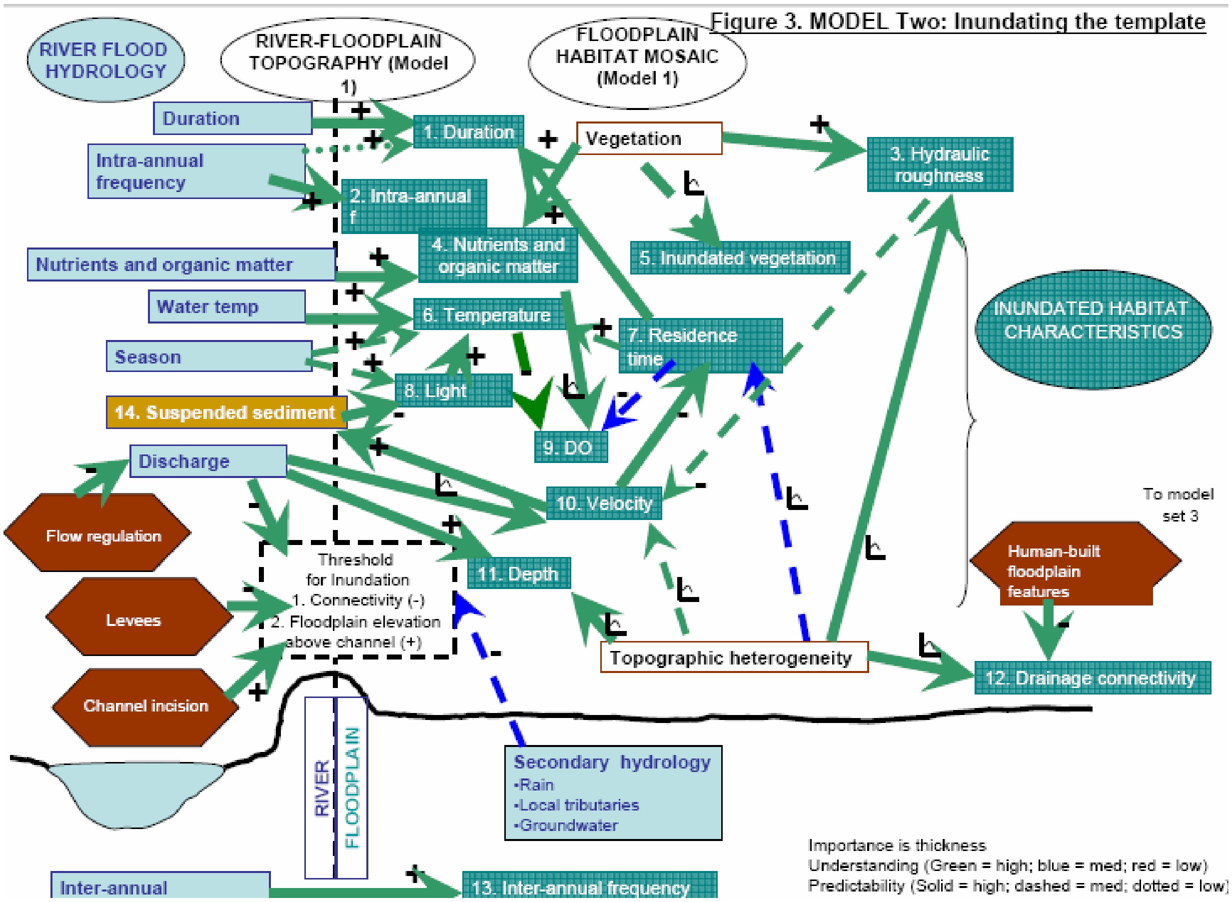


**Figure 4. Methodology for hydrologic analysis to determine FAF (Adapted from Williams et al. in press)**

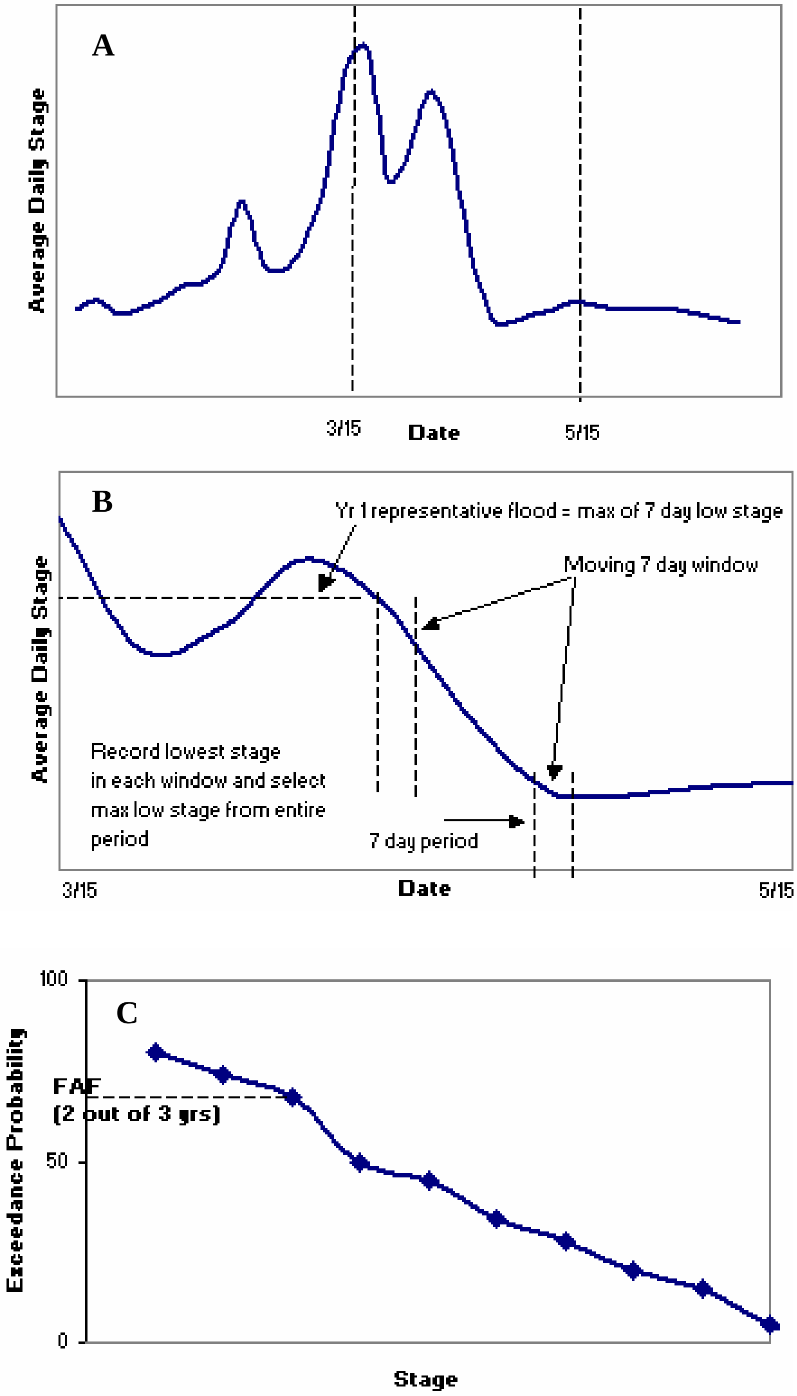
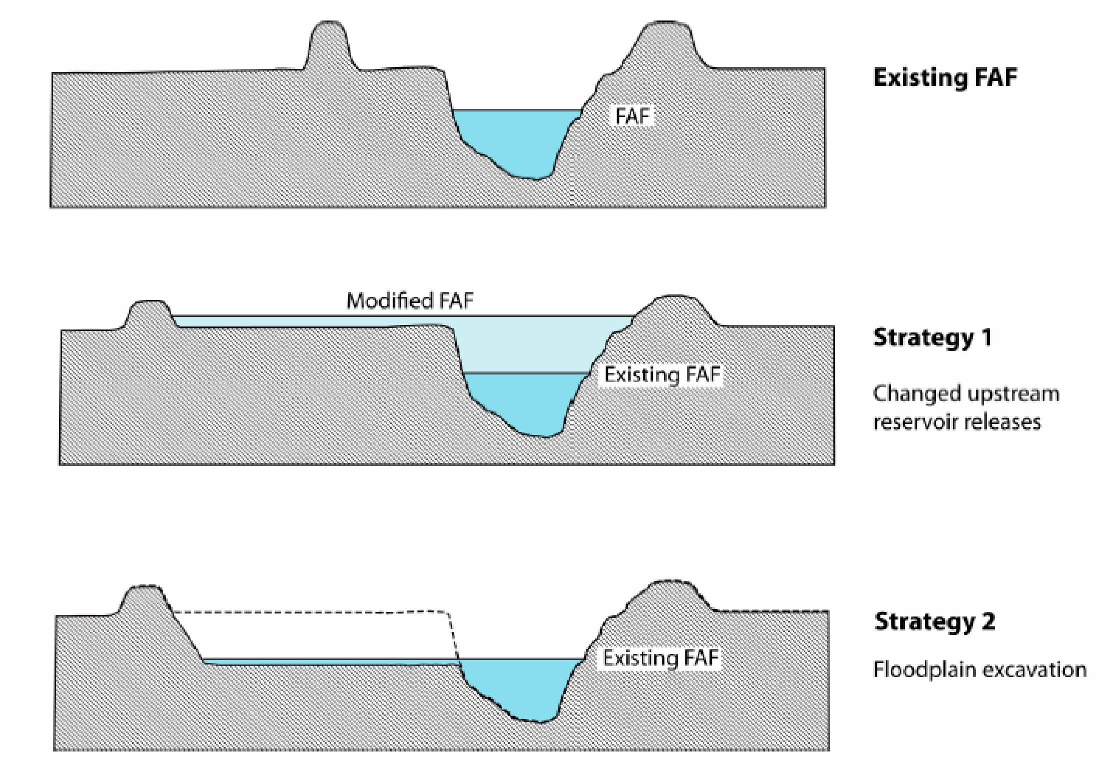


**Figure 5. Cross-sections illustrating methods for increasing activated floodplain area (Williams et al. in press)**



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