# Ecosystem Investments for the Sacramento-San Joaquin Delta: Development of a Portfolio Framework

Phillip Sandstrom, Jay R. Lund, Peter B. Moyle, William A. Bennett, and Jeffrey F. Mount

Delta Solutions
Center for Watershed Sciences
University of California – Davis
http://deltasolutions.ucdavis.edu

**DRAFT WORKING PAPER**
15 February, 2010

## Abstract

This paper provides background for discussion on prioritizing ecosystem investments in the Sacramento-San Joaquin Delta. Ecosystem investments involve the allocation and expenditure of financial resources, land, and water to improve ecosystem attributes, principally to support desirable plant and animal species. A framework using ten ecological criteria is provided for organizing these investments into a portfolio (or into regional portfolios) that can guide investment prioritization and timing. This framework is meant to be used in conjunction with non-ecological criteria, also presented. This portfolio contains 34 potential investments that are drawn mostly from the Bay Delta Conservation Plan, the CALFED Ecosystem Restoration Program Conservation Strategy, and the Delta Regional Ecosystem Restoration and Implementation Plan. Means to prioritize these investments are discussed.

## Introduction

The Sacramento-San Joaquin Delta has undergone significant physical and biological modification over the past 150 years. These modifications involve the reclamation of 700,000 acres of tidal marsh and adjoining floodplains, along with significant changes in flow timing, amount and quality. These changes, along with abundant invasive alien species, are the cause of dramatic declines in native fish populations in the Delta. In the past 20 years, the Delta has shifted from supporting fishes and other organisms characteristic of estuarine conditions, to supporting organisms characteristic of freshwater conditions (Moyle and Bennett 2008). The State Water Resources Control Board is now engaged in a process to determine the flow regime needed for maintaining appropriate ecological conditions in the Delta. However, an improved flow regime will be most effective if it is coupled with major habitat improvements. As Petersom (2003) points out, dynamic components of an estuarine ecosystem (such as flows) are most successful if they have positive interactions with the stationary components (such as tidal marshes and floodplains). Thus, habitat restoration is necessarily part of any long-term recovery effort for the Delta that involves flows. Multiple on-going planning efforts, with the Bay Delta Conservation Plan (BDCP, 2009) foremost, seek to identify and implement ecosystem restoration efforts that will avoid extinction of desirable species and, where possible, recover their populations. To date, these processes have not prioritized habitat restoration projects, nor have they integrated them with potential water operations and facility modifications.

This paper develops a framework for selecting stationary habitats for restoration in order to best take advantage of changes in flow regime designed to reverse negative trends in desirable fish species in the Delta. This work is not intended to supplant on-going efforts to develop conservation strategies, but rather, to suggest a systematic way of prioritizing these efforts. This paper builds upon Moyle et al. (2010) that identifies the key physical attributes of the Delta that must be developed in order to support the native fishes at all stages of their life histories. These attributes are: *complexity*, in the form of physical complexity of channel, marsh, river and floodplain habitat; *variability*, in the form of a more natural distribution of flows and water quality; and *connectivity* between dynamic and stationary aspects of Delta habitats in order to sustain them. Restoring complexity, variability and connectivity has the presumed added benefit of helping suppress non-native species which are best adapted to more the homogeneous system that currently exists (Moyle and Bennett, 2008; Lund et al., 2010). A second companion paper by Fleenor et al. (2010) focuses on alternatives for future water resource facilities and operations and paper describes how flow criteria can be developed that will support the ecosystem attributes described in Moyle et al. (2010). Guided by the principles and conclusions developed in these companion papers, we develop a portfolio approach to investments in Delta ecosystems.

**Ecosystem Investments**

In this paper we use “ecosystem investments” to reflect activities which require investments of money, water, and land for ecosystem purposes. The term “restoration” is avoided, because it is typically used to mean returning the area of interest or ecosystem to some original or prior state. We favor the shift in meaning suggested by Jackson and Hobbs (2009), who discuss, “ecological restoration [as] emphasizing restoration of ecosystem function, goods, and services (p. 568)”. For better or worse, human-caused changes in the Delta’s physical form (diking of marshlands, deepening of ship channels, subsidence of Delta islands, rip-rapping of levees, etc.), the depletion and alteration of its freshwater inflows and outflows, along with the invasion of alien species have combined to create a largely irreversible situation. Other ongoing trends, including sea level rise, land subsidence, regional warming, and changes in inflow preclude returning the Delta back to some historical state (Lund et al. 2007). Thus, we are faced with a novel and rapidly changing Delta ecosystem. At this point, the choice is either to let the change happen and accept the ecosystem consequences or to control and direct the changes as much as possible to help create a new Delta with traits we prefer, such as abundant populations of desirable fishes. A “new” Delta that is friendlier to native species will unavoidably retain and reflect the legacy of many extensive past physical, hydrologic, and biological alterations. However, with appropriate investments this Delta also can provide many valuable ecosystem goods and services and enhance investments in water devoted to ecosystem purposes. Like financial investments, ecosystem investments have elements of risk and unpredictability. Inevitably, ecosystem investments require the outlay of real financial resources for promising but uncertain yields in improved ecosystem conditions and functionality and in terms of recovery of endangered species.

Each ecosystem investment involves actions to create habitats useful for desired species and processes. In this report, each distinct unit of ecosystem investment is referred to as an activity and we focus on what the investment is likely to accomplish. For example, an activity might increase primary production, improve water quality, or create spawning habitat for a species of interest.  Each investment should improve some part of the Delta ecosystem in a specific way as part of a portfolio of investments that collectively favors native species.

**Characteristics of an ideal investment**

An inventory of ecosystem investments provides a foundation for selecting promising beneficial and cost-effective projects (*i.e.*, greatest benefit on an area/cost basis over the shortest period of time).  Prioritizing ecosystem investments in this way can help lead to a Delta containing dynamic heterogeneous habitats with significant seasonal and inter-annual variation. While the main purpose of ecosystem investments is to improve current environmental conditions, they should have the flexibility to remain useful in the face of incremental or rapid change. Ecosystem investments should be adaptable or resilient to environmental shifts (whether anthropogenic or natural), prolonged events such as sea level rise and shifts in runoff timing, or rapid events such as floods or earthquakes (leading to flooded islands).  Additionally, these investments should anticipate, where possible, the response of ecosystems to the impacts of non-native species, both existing within the current Delta system and likely to occur in the future.

Moyle et al. (2010) provide 10 key ways to increase habitat variability and complexity in the Delta and Suisun Marsh (Table 1) to improve their abilities to support native estuarine species.  These directions include: 1) establish internal Delta flows that create a tidally-mixed, upstream-downstream gradient  (without cross-Delta flows) in water quality; (2) create slough networks with more natural channel geometry and less diked rip-rapped channel habitat; (3) improve flows from the Sacramento and San Joaquin rivers; (4) increase tidal marsh habitat, including shallow (1-2 m) subtidal areas, in both fresh and brackish zones of the estuary; (5) create/allow large expanses of low salinity (1-4 ppt) open water habitat in the Delta;  (6) create a hydrodynamic regime where salinities in parts of the Delta and Suisun Bay and Marsh range from near-fresh to 8-10 ppt periodically (does not have to be annual) to discourage alien species and favor desirable species**;**  (7) take species-specific actions that reduce abundance of non-native species and increase abundance of desirable species; (8) establish abundant annual floodplain habitat, with additional large areas that flood in less frequent wet years; (9) reduce inflow of agricultural and urban pollutants; and (10) improve the temperature regime in large areas of the estuary so temperatures rarely exceed 20°C during summer and fall months.

The above recommendations, designed to help create the more diverse and variable Delta that favors native species, form the ecological basis for our criteria for selecting ecosystem investments.  These investments can then be integrated with other criteria (next section) to produce a framework for systematic ecosystem improvement (Table 1).

**Table 1: Desirable habitat conditions for the Delta (Moyle et al. 2010)**

| | Ecosystem Component | Action |
|---|---|---|
| **1** | Internal tidally mixed Delta flows | Create upstream-downstream mixing without cross Delta flows |
| **2** | Slough networks | Create natural drainage systems for marsh habitats |
| **3** | River inflows | Develop fish-friendly flow regime |
| **4** | Tidal marsh | Expand tidal marsh throughout Delta and Suisun Marsh |
| **5** | Open water | Flood subsided islands in the Delta and diked marshlands in Suisun Marsh |
| **6** | Variable salinity | Manipulate hydrodynamic regime where possible |
| **7** | Increase abundance of native species | Take species-specific actions |
| **8** | Floodplains | Expand floodplain habitat and increase frequency of flooding |
| **9** | Water quality | Reduce inputs of urban and agricultural pollutants |
| **10** | Cooler summer habitats | Expand tidal marshes in areas influenced by cooler marine temperatures |

The ideal Delta ecosystem investment portfolio would be a mix of short- and long-term projects that benefit ecosystem functions in the watershed and desirable species in specific regions. Implementation of the investments over an extended time would help with planning and potentially reduce costs through learning from management successes and failures.

Portfolios of ecosystem investments can be created for different scenarios. For example, if an isolated facility is chosen to route export water to the Central Valley Project (CVP) and State Water Project (SWP) facilities in the South Delta—as currently favored by BDCP-- it is necessary to develop a concurrent portfolio of ecosystem investments that best compliment that action, as outlined in Lund et al. (2010). By developing a core list of Delta ecosystem investments and scoring each investment on multiple criteria, it should be easier to select and prioritize desirable ecosystem investments for the Delta.

**Development of a Portfolio**

There are multiple approaches to developing a portfolio of investments, based on certain criteria for selection. The Bay Delta Conservation Plan Conservation Strategy, DRERIP and ERP Conservation Strategy all have defined metrics for selection some of which are adopted here. For the purposes of this workshop, a simplified approach to investment criteria includes:

- *Cost versus return on investment*. Priority should be given to those investments that yield high near- and long-term benefits for relatively low costs.
- *Importance for reducing extinction risk of listed species*. Near-term investments will be necessary to prevent or forestall extinction of key species. Some of these investments may not meet general criteria, but are needed to avoid extirpation.
- *Compatibility with changing conditions*. Investments should be judged on their resiliency or adaptability to changes in physical and biological conditions, including sudden events such as earthquakes, floods, and levee failures. Additionally, these investments should be

evaluated on the basis of their likelihood of enhancing invasive, alien species populations.

- *Compatibility with water resource operations and facilities*. All choices should be evaluated based on whether they constrain or are constrained by facility locations and operations. Of particular concern are habitat investments that alter hydrodynamics in ways that conflict with the objectives of nearby investments.
- *Collateral benefits*. Improved habitat function often creates benefits beyond supporting desirable species. This includes recreation, water quality, flood reduction, etc.
- *Complexity*. Investments that increase physical habitat complexity as well as area should receive higher priority
- *Variability*. Investments that closely integrate stationary habitat with flows and water resource operations are highly desirable
- *Connectivity*. Habitats should receive high priority if they are large and/or are connected to adjoining high value investments. However, reducing connectivity (*e.g.* among Delta channels) may also be desirable in some situations. This recognizes the importance of scale in investments and the role that local habitat improvements play in improving ecosystem function over a larger area.

## Types of Investments

There is an array of investments that can be made to enhance or create desired ecosystem attributes. These include direct financial investments for the purchase of land, conservation or flowage easements, funding for habitat improvement design, permitting and construction, or support for activities that either enhance ecosystem services or improve access to them. Changes in flood and water resource operations and facilities can constitute an additional type of ecosystem investment, typically involving significant costs. Finally, policies and regulations are a form of investment because they usually involve financial costs and can be used to improve habitat.

For the purposes of this paper, the focus will be on identifying financial investments that conserve or create desired habitats or investments that improve the ecological function of emerging, novel habitats. These habitats are outlined below:

*Flooded Islands*

Levees protect island farmland and where the soils are mainly peat, there has been extensive subsidence, mainly in the south and central Delta. As discussed in a variety of recent papers (summaries in Mount and Twiss 2005; Lund et al. 2007, 2010) there is a very high probability that there will be an increase in frequency of island flooding in the future, with an equally high likelihood that some islands will not be restored following flooding (Suddeth et al. 2008, 2009). Managing these flooded islands as habitat for desirable species will be a significant challenge. Their suitability will depend upon the depth of subsidence prior to inundation as control on colonization by invasive aquatic plants, the location and size of breaches in relation to flooded island hydrodynamics and water quality, the effects on adjacent islands, and the influence of flooded islands on food webs both within the islands and in adjacent channels.

*Tidal Marsh*

Prior to reclamation of the Delta, the most extensive and productive habitat type within the Delta was tidal marsh. Most tidal marsh within the Delta was freshwater marsh, involving a complex mosaic of tidal channels, subtidal and intertidal flat, marsh plains (islands) and natural levees with riparian plant communities. In the far western Delta and within Suisun Marsh, tidal marsh habitat alternated between fresh and brackish, depending upon outflow conditions. All conservation efforts in the Delta, including the BDCP Conservation Strategy, have identified the development of thousands of acres of fresh and brackish tidal marsh as a high priority. While tidal marsh is not a novel habitat within the Delta, it cannot be easily created due to subsidence. For this reason, opportunities are largely limited to the fringes of the Delta and in Suisun Marsh where mineral soils or land management has reduced subsidence. Additionally, investments in creation of tidal habitat require careful planning for future conditions since tidal march dynamics are closely linked to sea level rise and sediment supply.

*Floodplain*

One of the unique aspects of the Delta as an estuary is its historic physical connection to two very large floodplain systems on the San Joaquin and Sacramento River (Moyle et al., 2009). Flood management infrastructure and water resource operations have disconnected the Delta from these floodplains except during high flow events. Extensive research funded by CALFED and other entities has demonstrated the importance of seasonally flooded habitat in supporting the life history strategies of numerous desirable fish and terrestrial species as well as supporting primary productivity and food webs within the Delta. Increasing the frequency, duration and areal extent of floodplain inundation along the periphery of the Delta has been identified as a high priority in all conservation efforts focused on the Delta and is emerging as a national priority (Opperman et al., 2009). The challenges facing investments in floodplain habitat are numerous, including current economic activity on floodplain lands, integration with flood management activity, and the potentially high costs of levee modifications and setbacks.

*Riparian and Upland Habitats*

Riparian zones and their connections to upland habitat once played a large role in the Delta ecosystem, supporting many physical and ecological processes and complexity including, providing large wood for cover, insects and other food sources, as well as carbon, nitrogen, phosphorous and other nutrients necessary for aquatic food webs. Although not a focus of this workshop, these habitats were critical to supporting diverse terrestrial communities. Land conversion and the construction and maintenance of levees have eliminated most riparian and upland habitat from the Delta. Creating riparian habitat is a significant challenge in most of the Delta. First, and foremost, subsided islands surrounded by narrow levees make it difficult to re-establish elevations suitable for large tracts of riparian plants. Rather, most opportunities exist in the lowermost reaches of tributaries to the Delta. Here, the greatest challenges lie in creating the physical processes necessary to recruit and sustain riparian communities. This includes setting back or breaching levees in order to establish channel migration that drives community succession and creating the proper flow regime to promote recruitment. The Cosumnes River Preserve provides the best model for investments in riparian and upland habitat.

## Inventory of Major Habitat Investments

This report presents a collection of promising ecosystem investments. All ecosystem investments have been categorized based on type (described above) and location (Table 2). The locations of investment opportunities are similar to, but distinct from, those listed as Restoration Opportunity Areas in the Draft BDCP Conservation Strategy. The locations, shown in Figure 1, can be grouped into seven general areas:

- The Steamboat and Sutter Slough complex. Comprised of Steamboat, Sutter, and Elkhorn, and Miner Sloughs.
- North main stem of the Sacramento River. Includes the channel from Freeport to the confluence of the Sacramento River, Cache Slough and Steamboat Slough.
- South main stem of the Sacramento River. Includes the region from Rio Vista to the confluence of the Sacramento and San Joaquin River.
- Yolo Bypass/Cache Slough complex. This includes Lindsay Slough, Cache Slough, Yolo Bypass, Liberty Island, and Prospect Island areas.
- Eastern Delta. This region includes the North and South Forks of the Mokelumne River, Georgiana Slough, Snodgrass Slough, Cosumnes River Preserve, and Potato Slough.
- San Joaquin River. This area runs from Stockton to the confluence with the Sacramento River.
- South Delta. This includes the area south of the San Joaquin River and East of Dutch Slough.
- Suisun Marsh in its entirety.

We have identified 38 potential ecosystem investments in the seven regions of the Delta and in Suisun Marsh. Summaries of each potential large habitat investment in this inventory appear in Appendix A. Each of these investments meets one or more of the general criteria outlined above (Table 3a, b).

The Delta serves more than ecological purposes and the ability of habitat investments to contribute to human, avian, and terrestrial species both in the Delta and elsewhere will be important for policy and implementation. In additional to the criteria laid out by Moyle et al (2010) or making the Delta more of a natural estuarine ecosystem, several other criteria are likely to be important in developing a portfolio of coherent ecosystem investments. These additional criteria include costs and other non-habitat benefits related to local economic, recreational, and other benefits of improving habitats in the Delta. These are summarized in Table 5.

**Figure 1: Location map for major potential habitat investments**

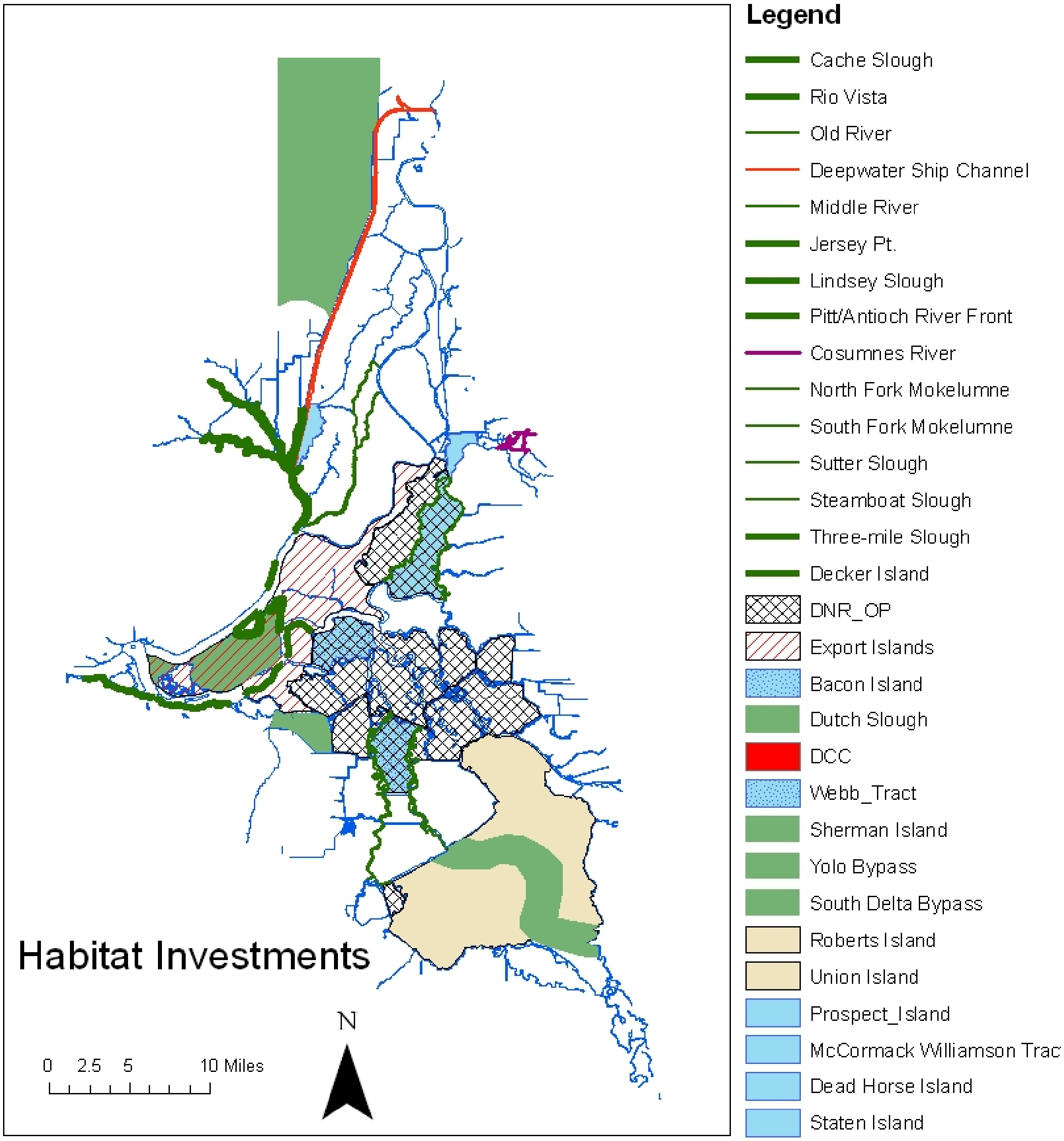

**Table 2. Potential habitat investments in the Delta and Suisun Marsh, indicating the habitat types they are likely to include (green bars)**

| Location | Investment Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | Habitat Type (by sea level) | | | | | Water Operations | Other |
| | Flooded Island | Tidal Marsh | Floodplain | Riparian | Levee Setbacks | | |
| Steamboat/ Sutter Complex | Prospect Island (2 & 3) | | | | | | |
| | Subsided Island Reversal (24) | | | | | | |
| | Levee Sebacks Sutter and Steamboat Sloughs (3) | | | | | | |
| North Main Stem Sacramento River | New Diversion Point (pc) (29) | | | | | | |
| Yolo Bypass/ Cache Slough Complex | Cache Slough (2) | | | | | | |
| | Yolo Bypass (1) | | | | | | |
| | Lindsay Slough (2) | | | | | | |
| | Relocate North Bay Aqueduct (2) | | | | | | |
| | Notch or Gate Fremont Weir (1) | | | | | | |
| South Main Stem Sacramento River | Decker Island (10) | | | | | | |
| | West Bank South of Rio Vista (9) | | | | | | |
| Eastern Delta | Cosumnes River (7) | | | | | | |
| | Levee Setbacks on North and South Forks of the Mokelumne (8) | | | | | | |
| | Flood McCormack Island (5) | | | | | | |
| | Partial Flooding of Staten Island | | | | | | |
| | Flood Dead Horse Island (6) | | | | | | |
| | Delta Cross Channel Operations (4) | | | | | | |
| San Joaquin River | Dutch Slough (22) | | | | | | |
| | Jersey Point (12) | | | | | | |
| | Three-mile Slough (11) | | | | | | |
| | Subsided Island Reversal (24) | | | | | | |
| South Delta | South Delta Flood Bypass (16) | | | | | | |
| | Old and Middle Rivers (13 & 14) | | | | | | |
| | Union Island (17) | | | | | | |
| | Roberts Island (18) | | | | | | |
| | Subsided Island Reversal (24) | | | | | | |
| | South Delta Exports (15) | | | | | | |
| | Tidal Gates on Old and Middle River 24 | | | | | | |
| Suisun Bay | New York Slough/Antioch/Pittsburg Riverfront 23 | | | | | | |
| Suisun Marsh | Salinity Control Gates 25 | | | | | | |
| | Montezuma 19 | | | | | | |
| | Nurse Slough/Blalock 21 | | | | | | |
| | Grizzly, Chipps, Van Sickle, and Wheeler 27 | | | | | | |
| | Joice Island 28 | | | | | | |
| | Hill Slough 20 | | | | | | |

**Desirable Ecosystem Investments**

Each investment option has different potential for addressing the general Moyle criteria for improving the Delta as a habitat for native estuarine fishes (Table 1 and Moyle et al. 2009). The Moyle criteria addressed by each investment are presented in Appendix A. These are used in our initial approach for evaluating potential investments, qualitatively (Tables 3 and 4).

…

**Table 3a. Number of investments in Table 2 that satisfy the ecosystem criteria in Moyle et al. (2010, see Table 1)**

| | Ecosystem Component | Number of investments |
|---|---|---|
| 1 | Internal tidally mixed Delta flows | 7 |
| 2 | Slough networks | 30 |
| 3 | River inflows | 3 |
| 4 | Tidal marsh | 27 |
| 5 | Open water | 4 |
| 6 | Variable salinity | 14 |
| 7 | Increase abundance of native species | 37 |
| 8 | Floodplains | 12 |
| 9 | Water quality | 12 |
| 10 | Cooler summer habitats | 3 |

**Table 3b: Number of investments by broad habitat type**

| Habitat Type/Mitigation Action | Number of Investments |
|---|---|
| Flooded Island | 4* |
| Tidal Marsh | 24 |
| Floodplain | 10 |
| Riparian | 3 |
| Water Operations | 9 |

*In addition to flooded islands, subsided island reversal has been proposed. These ecosystem investments have not been incorporated into the flooded island score. Islands considered for subsidence reversal have been identified and will be shallow or deeply subsided (Bates and Lund 2009).

**Table 4: Ecosystem investments options by location and number of Moyle criteria met**

| Location | Ecosystem Investment | Number of Criteria Met |
|---|---|---|
| Yolo Bypass/ Cache Slough Complex | Cache Slough | 4 |
| | Lindsay Slough | 2 |
| | Fremont Weir | 1 |
| | Yolo Bypass | 3 |
| | Removal of the North Bay Aqueduct | 0 |
| Steamboat/Sutter Slough Complex | Flood Prospect Island | 5 |
| | Levee setbacks on Steamboat Slough | 5 |
| | Levee setbacks on Sutter Slough | 4 |
| Eastern Delta | Levee Setbacks on North Fork of Mokelumne | 4 |
| | Levee Setbacks on South Fork of Mokelumne | 4 |
| | Flood McCormack Island | 6 |
| | Flood Dead Horse Island | 6 |
| | Flood Staten Island | 6 |
| | Cosumnes River Floodplain/Flows | 6 |
| | DCC Operations | 2 |
| North Main Stem Sacramento River | New water diversion point (PC) | 3 |
| South Main-stem Sacramento River | Decker Island | 3 |
| | Sherman Island | 4 |
| | West bank south of Rio Vista | 3 |
| San Joaquin River | Subsided Island Reversal | 0 |
| | Tidal Marsh Jersey Point | 5 |
| | Tidal Marsh Three-mile Slough | 5 |
| | Prescribed Flows | 5 |
| | Dutch Slough | 3 |
| South Delta | Subsided Island Reversal | 0 |
| | South Delta Exports | 5 |
| | Interim Tidal Gates Old River | 1 |
| | Interim Tidal Gates Middle River | 1 |
| | Levee setbacks/channel restoration on Old River | 3 |
| | Levee setbacks/channel restoration on Middle River | 3 |
| | Mitigation on Union Island | 0 |
| | Mitigation on Roberts Island | 0 |
| | South Delta Flood Bypass (Stewart Tract and Paradise Cut) | 3 |
| Suisun Bay | New York Slough/Antioch/Pittsburg riverfront | 5 |
| Suisun Marsh | Suisun Marsh Restoration | 4 |
| | Individual areas: Blalock, Wheeler, Van Sickle, Chipps, Grizzly, Joice Island, Hill Slough, Peytonia Slough, Montezuma | 4 |
| | Operation of the Salinity Control Gates | 5 |

**Table 5: Major local non-habitat benefits of potential habitat investments**

| Location | Ecosystem Investment | Major local non-habitat benefits |
|---|---|---|
| Yolo Bypass/ Cache Slough Complex | Cache Slough | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Lindsay Slough | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Fremont Weir | N/A |
| | Yolo Bypass | Bird watching, Eco-tourism, Scientific assessment |
| | Removal of the North Bay Aqueduct | N/A |
| Steamboat/ Sutter Slough Complex | Flood Prospect Island | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Levee setbacks on Steamboat Slough | Recreational Fishing and Scientific Assessment |
| | Levee setbacks on Sutter Slough | Recreational Fishing and Scientific Assessment |
| Eastern Delta | Levee Setbacks on North Fork of Mokelumne | Recreational Fishing and Scientific Assessment |
| | Levee Setbacks on South Fork of Mokelumne | Recreational Fishing and Scientific Assessment |
| | Flood McCormack Island | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Flood Dead Horse Island | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Flood Staten Island | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Cosumnes River Floodplain/Flows | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | DCC Operations | N/A |
| N. Main Stem Sacramento R. | New water diversion point (PC) | N/A |
| S. Main-Stem Sacramento River | Decker Island | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Sherman Island | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | West bank south of Rio Vista | Recreational Fishing and Scientific Assessment |
| San Joaquin River | Subsided Island Reversal | N/A |
| | Tidal Marsh Jersey Point | Recreational fishing |
| | Tidal Marsh Three-mile Slough | Recreational Fishing, Bird watching, Eco-tourism |
| | Prescribed Flows | N/A |
| | Dutch Slough | Recreational Fishing, Bird watching, Eco-tourism |
| South Delta | Subsided Island Reversal | N/A |
| | South Delta Exports | N/A |
| | Interim Tidal Gates Old River | N/A |
| | Interim Tidal Gates Middle River | N/A |
| | Levee setbacks/channel restoration on Old River | N/A |
| | Levee setbacks/channel restoration on Middle River | N/A |
| | Mitigation on Union Island | Eco-tourism |
| | Mitigation on Roberts Island | Eco-tourism |
| | South Delta Flood Bypass (Stewart Tract and Paradise Cut) | Eco-tourism, Bird watching, Scientific assessment |
| Suisun Bay | New York Slough/Antioch/Pittsburg riverfront | Urban riverfront beautification, Recreational Fishing |
| Suisun Marsh | Suisun Marsh Restoration | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Individual areas: Blalock, Wheeler, Van Sickle, Chipps, Grizzly, Joice Island, Hill Slough, Peytonia Slough, Montezuma | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |
| | Salinity Control Gates Operation | Recreational Fishing, Bird watching, Eco-tourism, Scientific assessment |

## Conclusions

What is presented here is an approach to prioritizing ecosystem investments that can increase the value of investments made in improving Delta inflows and outflows. We see ecosystem investments of this kind listed here as fitting into an overall plan to make the Delta a place that favors desirable species and ecosystem services. We think that a prioritization scheme based on ecological benefits, when combined with others based on costs and additional benefits, could be put in place fairly rapidly and improve decision making for ecosystem investments. Such a process is necessary if we are going to prevent extinction of listed species and find ways to work with, rather than against, the inevitable physical and biological changes that are coming to the Delta.

**Literature Cited** (see reference section at end of Appendix A).

**Acknowledgements**
This work was supported by grants and gifts from the David and Lucile Packard Foundation, the Stephen Bechtel Fund, the Resources Legacy Fund, and The Nature Conservancy as part of the Delta Solutions program at the University of California - Davis.

**Appendix A - Summary of Major Potential Ecosystem Investments**

**1. Name:** Prospect Island
**Location:** Cache Slough Complex/Steamboat/Sutter Slough Complex
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Prospect Island has flooded seven times since 1981, and has little value for agriculture (Reynolds, 1998 site assessment). Purposefully breaching and re-flooding Prospect Island could create beneficial habitat for Delta and migratory species. This island is immediately east of Cache Slough and the Yolo Bypass and could create refuge habitat for species of concern in the form of tidal marsh and shallow water habitat. Reclaiming this island as an ecosystem investment would also increase connectivity of heterogeneous habitat, to increase the size and health of the Cache Slough Complex and base of the Yolo Bypass. Additionally this area is just north of the confluence of the Sacramento River and Steamboat Slough. Outmigrating salmonids have been noted to follow the direction of the tide and move toward this region. Creating additional tidal marsh and shallow water habitat could improve survival for these fish by creating refuge habitat while they are holding.
**References**: Reynolds, 1998

**2. Name:** Subsided Island Reversal
**Location:** Delta-wide or location-specific
**Aerial Extent:** Variable
**Implementation Horizon:** Longer than 5 years
**Seasonality:** None
**Annual Frequency:** None
**Description:** Subsidence reversal involves shifting land from agricultural use to controlled marshland which slowly raises land elevations. Reversal is probably only viable for a few whole islands, but could be beneficial for sections of other islands. Subsidence reversal rate estimates are 4 cm/yr. The most promising islands and areas for subsidence reversals are either deeply subsided or have subsided relatively little. One concern for subsided island reversal is that levees protecting the projects will fail after they have reached the ideal depth zone for water weed invasion (between 1.5 and 4.6 meters depth). Lands subsided more than 4.6 meters below sea level will hinder water weed establishment due to inadequate light. For land less than 1.5m below sea level, tules can establish and presumably out-compete invasive water weeds and create habitat for native species. Islands in the deep category are Mandeville Island, Webb Tract, Empire Tract, Bouldin Island, McDonald Tract, and Bacon Island; and islands in the shallow category are Terminous Tract, Brack Tract, Grand Island, Canal Ranch Tract, Hotchkiss Tract, Roberts Island, Union Island, and Coney Island (Bates and Lund 2009). Roberts and Union Islands have been proposed as potential riparian zones next to a south Delta flood bypass, while Bacon Island and Webb Tract have been proposed potential water storage areas. Subsidence reversal in the shallow subsided islands could be beneficial in keeping up with sea level rise (Bates and Lund 2009).
**References**: Bates and Lund 2009

**3. Name:** Levee setbacks on Steamboat and Sutter Sloughs
**Location:** Steamboat/Sutter Slough Complex
**Aerial Extent:** Local to sloughs
**Implementation Horizon:** 3-5 years
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Permanent
**Description:** Levee setbacks on Steamboat and Sutter Sloughs would create additional riparian, floodplain, and tidal marsh. This would facilitate the re-working of soils and movement of the main channel. Levee setbacks must move back levees adequately. Moving levees back a small amount can have little to no measurable benefit (Chapin 1997). If agencies seek to encourage migratory fish to use this route rather than Georgiana Slough and the Delta Cross Channel (DCC) it is important to create a corridor of heterogeneous habitat. There are already areas of the levees with significant vegetation and tree growth. Setbacks in the proper areas could create small riparian and tidal marsh zones along this corridor.
**References**: Perry et al. 2009; Jeffres 2008; BDCP 2009

4. **Name:** New water diversion point (peripheral canal)
**Location:** North Mainstem Sacramento River
**Aerial Extent:** N/A
**Implementation Horizon:** Longer than 5 years
**Seasonality:** Summer
**Annual Frequency:** Yearly/++Dry years
**Description:** Construction of a new water diversion upstream on the Sacramento River would make for a cleaner and more reliable water supply. Drawing water from further upstream would allow south Delta pumping and Delta Cross Channel operations to be altered to be more beneficial to fisheries while still supplying urban and agricultural user with water (Moyle and Bennett 2008). A northern diversion point could help promote natural flow regimes and benefit south Delta ecosystem investments (BDCP 2009). Researchers believe that salmonids entrained into the central Delta typically exhibit lower survival than fish that utilize the main stem Sacramento River due to predation (Brandes pers. comm..).
**References**: BDCP 2009

**5. Name:** Cache Slough
**Location:** Cache Slough Complex
**Aerial Extent:** ~30,000 acres
**Implementation Horizon:** 1-3 years
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Continuous
**Description:** The Cache Slough area could support large areas of various habitat types in a dynamic region while promoting connectivity. The area is just south of the Yolo bypass and north of Steamboat Slough and the mainstem Sacramento River. There are strong tidally-driven flows and water elevations in this area and seasonal flows and habitat linked with the Yolo Bypass. This area is also the transition zone from floodplain, marsh, and slough habitats generally dominated by river flow to a deep, wide, tidally influenced region with little refuge area for fish. Ecosystem investments could improve up to 45,000 acres of habitat by creating

riparian, floodplain, tidal marsh, and open water areas for species of concern in the Delta (Kirkland, 2008 (Interim Delta Actions). Much baseline scientific work has been conducted in this area (Sommer et al. 2004, Sommer et al. 2004, Kirkland 2008) and this ecosystem investment could be ideal for scientific evaluation of actions, creating a stronger scientific basis for future actions.
**References**: Sommer et al. 2004, Sommer et al. 2004, Kirkland 2008, Aasen 1999, DWR, BDCP 2009

**6. Name:** Yolo Bypass
**Location:** Cache Slough Complex
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Yearly/++Wet Years
**Description:** The Yolo Bypass has great potential to create a vast area of floodplain habitat and act as a nutrient, productivity, and food source for the Delta. Many studies support the idea that the bypass could benefit native species of concern in the Delta. Ecosystem investment in the bypass would connect areas of importance and act as a refuge and nursery for many aquatic and avian species. Management of flows through the bypass will determine the size of the area inundated and residence time of the water, which will affect primary production and transport to adjacent habitats. The bypass will need to be inundated under an appropriate seasonal regime to deter establishment of undesirable species.
**References**: Lehman et al. 2008; Benigno 2008; Feyrer et al. 2006, 2006b, 2004; Sommer et al. 2004, Sommer et al. 2001a, 2001b; Schemel et al. 2004; Jeffres 2008; BDCP 2009

**7. Name:** Lindsey Slough
**Location:** Cache Slough Complex
**Aerial Extent:** 138 acres
**Implementation Horizon:** 1-3 years
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Continuous
**Description:** Investment in this slough will increase habitat availability and heterogeneity within the Cache Slough complex. Reclaiming diked wetlands in this area would create freshwater tidal marsh for fish and birds. The open water habitat within this slough has not been colonized by dense invasive aquatics and this area is important to species of concern such as delta smelt (USFWS, 1996; Bennett, 2005; SLT 2006). It would also be desirable to create floodplain connectivity with this habitat (SLT, 2006).
**References**: USFWS, 1996; Bennett, 2005; SLT 2006

**8. Name:** Relocation of North Bay Aqueduct
**Location:** Cache Slough Complex
**Aerial Extent:** N/A
**Implementation Horizon:** 1-3 years
**Seasonality:** N/A
**Annual Frequency:** N/A

**Description:** The North Bay Aqueduct currently diverts much of the water entering Barker Slough. The net flow can run backwards and directly affect entrainment of larvae and reduce the organic carbon and nutrients that may otherwise be transported to the Delta. Movement of the Aqueduct could improve the survival of larval fish and food supply for the region. The aqueduct was constructed to deliver water to users in Solano and Napa Counties and currently does not deliver the contracted amount of water to the users (GEI Consultants, 2009) and provides poor quality water for local drinking water treatment plants (Bookman Edmonston 2003). There are currently pumping restrictions on the North Bay Aqueduct to protect delta smelt.
**References**: Edmonston 2003 and GEI Consultants 2009

**9. Name:** Notch/Gate Fremont Weir
**Location:** Cache Slough Complex/North Mainstem Sacramento
**Aerial Extent:** 1,461 acres
**Implementation Horizon:** 1-3 years
**Seasonality:** Winter/Spring
**Annual Frequency:**
**Description:** Notching or putting a gate on the Fremont Weir is essential for managing the Yolo Bypass for fish. Installing a gate would allow managers to introduce variation to the bypass at desired times and intervals. Inundating the bypass at proper times will create habitat on the Yolo Bypass which will hopefully also fuel other areas of the Delta (BDCP 2009).
**References**: Feyrer 2006, BDCP 2009

**10. Name:** Decker Island
**Location:** South Mainstem Sacramento River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Creation of tidal marsh on eastern Decker Island will help create refuge habitat and connectivity between other ecosystem investments within the region, especially Three-mile Slough and Jersey Point tidal marsh areas. Additionally this area is relatively well sheltered and has the potential for positive feedback.
**References**: DWR Interim Actions

**11. Name:** West bank south of Rio Vista
**Location:** South Mainstem Sacramento River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** The west bank south of Rio Vista is currently a sandy shallow water habitat. There are occasional isolated tree islands as you approach the area opposite of Decker Island. This location could be ideal for re-establishing tidal marsh along the margins of the Sacramento River and could provide valuable refuge for outmigrating fish or species moving from the Cache Slough/Yolo Bypass Complex.
**References**: BDCP 2009, Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000

**12. Name:** Cosumnes River
**Location:** Eastern Delta
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Winter/Spring
**Annual Frequency:** Yearly
**Description:** The Cosumnes River Preserve already protects a section of this river, but additional investment in this area will facilitate fisheries recovery and the creation of more naturalized habitat which will also aid flood control in the eastern Delta.
**References**: Jeffres et al. 2008, Trowbridge 2007, Ahearn et al. 2006, Florsheim et al. 2006, Ribeiro et al. 2004, Florsheim and Mount 2003

**13. Name:** Levee setbacks on North and South Fork of the Mokelumne
**Location:** Eastern Delta
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Levee setbacks on the North and South Forks of the Mokelumne River would help create additional floodplain or bench habitat as well as tidal marsh beneficial for Delta flora and fauna. Such an investment coupled with flooding of select Delta islands in the eastern Delta would facilitate flood control in the eastern Delta and create a naturalized corridor of habitat for native species before reaching the interior Delta.
**References**: NDFM & ERP (DWR) 2008

14. **Name:** McCormack-Williamson Tract
**Location:** Eastern Delta
**Aerial Extent:**
**Implementation Horizon:** Shovel ready
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Yearly
**Description:** This island is currently owned by The Nature Conservancy and has the potential to create significant amounts of tidal and shallow water habitat in addition to increase flood control below the Cosumnes and Mokelumne River.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Brown and Pasternack 2005, Brown and Pasternack 2004, Jassby and Cloern 2000

**15. Name:** Staten Island
**Location:** Eastern Delta
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Yearly

**Description:** Completely or partially flooding Staten Island will create a considerable amount of habitat and also add flood mitigation to the Cosumnes/Mokelumne River area. Depending on the specific implementation, a variety of subtidal and supratidal habitat could be created here.
**References**: NDFM & ERP (DWR) 2008, Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000

**16. Name:** Dead Horse Island
**Location:** Eastern Delta
**Aerial Extent:**
**Implementation Horizon:** Shovel ready
**Seasonality:** Winter/Spring/Continuous
**Annual Frequency:** Yearly
**Description:** Dead Horse Island is directly north of the forks of the Mokelumne River. It is a small island with little infrastructure and the levees protecting the island failed frequently. Breaching this island would create additional tidal freshwater marsh and floodplain habitat with some nominal flood mitigation. Creating productive habitat in this region is essential as many juvenile salmonids pass through this region either intentionally or unintentionally. Fish entrained by the Delta Cross Channel are sucked into Snodgrass Slough and towards the Mokelumne Forks and interior Delta. Additionally fish migrating from the Mokelumne and Cosumnes River must pass through this area.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000

**17. Name:** Delta Cross Channel Operations
**Location:** Eastern Delta/North Mainstem Sacramento River
**Aerial Extent:** N/A
**Implementation Horizon:** Shovel ready
**Seasonality:** Summer/Continuous
**Annual Frequency:** Continuous
**Description:** If a new water diversion point was built in the north Delta, the Delta Cross Channel (DCC) could be operated to favor fisheries rather than diverting water toward the interior Delta. The question would be if the gate could be operated to benefit Mokelumne and Sacramento River fish at the same time. Additionally operation of the DCC affects the water quality of the north, central, and south Delta and could raise salinities in the south and central Delta if not mitigated by strategic operation (BDCP 2009).
**References**: Brandes and McClain 2001, Perry et al. 2009

**18. Name:** Dutch Slough
**Location:** San Joaquin River
**Aerial Extent:** 1, 200 acres
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** PWA has developed a restoration plan for 1200 acres in the Dutch Slough area to create tidal marsh, riparian, and coastal dune habitat (PWA 2003). This investment will create more tidal marsh in a transition zone for fisheries where they are beginning to leave the sloughs of the Delta and work their way towards the bays and greater tidal influence. This area could

create additional refuge habitat for fisheries whose movements are heavily influenced by the tides.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000, Dutch Slough EIR 2008

**19**. **Name:** Jersey Point
**Location:** San Joaquin River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Jersey Point on the San Joaquin River has been suggested for tidal marsh restoration (BDCP Plan 2009). There is already aquatic vegetation on the western shore, however, the eastern shore is an armored levee comprised of bare rock. A large amount of barge traffic passes through this region and occasionally moors in the area, hence the depth and width of the channel. Many Central Valley migratory fish species will pass through the Jersey Point area on their way to and from the sea, including green sturgeon, white sturgeon, Chinook salmon, steelhead trout, or striped bass. Tidal marsh in this area could also benefit life history stages of these and resident species. Proposed by BDCP 2009.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000, BDCP 2009

**20. Name:** Three-mile Slough
**Location:** San Joaquin River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Three-mile Slough is a short slough connecting the Sacramento and San Joaquin Rivers. The slough connects to the San Joaquin River north of Jersey Point, and connects to the Sacramento River on the north side of Decker Island. Creating tidal marsh in this area could be particularly important for providing connectivity within the region and being a refuge for native species. Proposed by BDCP 2009.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000, BDCP 2009

**21. Name:** South Delta flood bypass
**Location:** South Delta
**Aerial Extent:**
**Implementation Horizon:** 3-5 years
**Seasonality:** Winter/Spring
**Annual Frequency:** Yearly/++Wet years
**Description:** Creation of a south Delta Bypass would create flood control while providing rearing habitat for young salmonids leaving the San Joaquin watershed in addition to benefiting other local fish species. The floodplain would also increase habitat connectivity and facilitate seasonal and interannual variation. Additionally the floodplain would increase primary production and have potential to provide food and nutrients for the southern Delta in late winter and early spring.

**References**: Jeffres 2008; Sommer 2001

**22. Name:** Old and Middle Rivers
**Location:** South Delta
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Creation of tidal marsh/channel restoration, riparian zone and levee setbacks have been proposed for both Old and Middle Rivers. Proposed by BDCP 2009.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000, BDCP 2009

**23. Name:** Union Island
**Location:** South Delta
**Aerial Extent:**
**Implementation Horizon:** 3-5 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** This area has been proposed as a riparian zone ecosystem investment. Located in the southeastern Delta this riparian zone could potentially flank a south Delta flood bypass created along Paradise Cut.
**References**: BDCP 2009

**24. Name:** Roberts Island
**Location:** South Delta
**Aerial Extent:**
**Implementation Horizon:** 3-5 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** This area has been proposed as a riparian zone ecosystem investment. Located in the southeastern Delta this riparian zone could potentially flank a south Delta flood bypass created along Paradise Cut.
**References**: BDCP 2009

25. **Name:** Curtail South Delta Exports
**Location:** South Delta
**Aerial Extent:** N/A
**Implementation Horizon:** Shovel ready
**Seasonality:** Spring/Summer
**Annual Frequency:** Yearly
**Description:** Curtailing south Delta exports will decrease the cross Delta flows thought to be troublesome for many fish species. It will also reduce the number of fish from the south Delta entrained at the pumping facility
**References**: OCAP BA 2008

**27. Name:** New York Slough/Antioch/Pittsburg Riverfront

**Location:** Suisun Bay
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:**
**Annual Frequency: Little**
**Description:** This area has been heavily developed and much of this region is flanked been urban or industrial areas. New York Slough has several large marinas (two in Pittsburg and Antioch) and a large ship dock area on the south shore. There is a power plant located just west of New York Slough directly south of Chipps Island. Creating additional habitat in this area is important as many fish species are affected by the flows and move back and forth with ebb and flood tides. This area is a transition zone from a rip-rapped and channelized delta to more of an open water estuary.
**References**: Ganju et al. 2005, Hammersmark et al. 2005, Jassby and Cloern 2000, BDCP 2009

**28. Name:** Montezuma Slough Salinity control gate operations
**Location:** Suisun Marsh
**Aerial Extent:** N/A
**Implementation Horizon:** Shovel ready
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** The salinity control gates are already in place, but reoperation of the gates to benefit the flora and fauna of the Delta and Suisun Marsh may be possible. The gates could be used to alter the salinity to benefit desirable species. Ideally this option coupled with other ecosystem investments would help tip the scales in the proper direction.
**References**: N/A

**29. Name:** Suisun Marsh
**Location:** Suisun Marsh
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Strategic purchase of duck clubs, Meins Landing, Blacklock Island, Grizzly Island, Joice, Island, Wheeler Island, Van Sickle Island, Chipps Island, Hill Slough, Peytonia Slough, Montezuma Slough**.** Breeching the small earthen dikes within Suisun Marsh will introduce variability, salinity, tidal processes, and hopefully native fauna. Connecting the diked wetlands will promote habitat connectivity and exchange between what will soon be tidal marsh and adjacent sloughs. Many studies have examined the effect of slough features and fish assemblages/abundances (Meng 1994; Matern et al. 1997, 1998, 1999, 2002; Suisun Marsh Ecological Workgroup 2001). Larger sloughs are typically more heavily utilized by seasonal species, but smaller sloughs were home to larger abundances of native species (Meng 1994). The Suisun Marsh Ecological workgroup found the highest diversity and abundances of fish species in a small slough with undiked tidal wetlands located in Suisun Marsh. Aspects proposed by BDCP 2009.
**References**: Meng 1994; Matern et al. 1997, 1998, 1999, 2002; Suisun Marsh Ecological Workgroup 2001

**30. Name:** Sherman Island
**Location:** South Mainstem Sacramento River
**Aerial Extent:**
**Implementation Horizon:** Shovel Ready
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:**
**References**: Aasen 1999, NHI 2002

**31. Name:** Moveable Gates
**Location:** South Delta
**Aerial Extent**: South Delta
**Implementation Horizon:** Shovel Ready
**Seasonality:** Summer
**Annual Frequency:** Yearly/++Dry Years
**Description:** Two moveable gates would be seasonally installed along Old and Middle Rivers to facilitate water operations without the creation of net flows drawing fish toward the pumping facility. Proposed in BDCP 2009.
**References**: 2 Gates fish protection demonstration project

**32. Name:** Webb Tract
**Location:** Mainstem San Joaquin River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** This island will be used as a water storage facility. It also has the potential to be utilized as a rearing habitat for species requiring open water habitat. Such an investment meets the needs of improving water supply while potentially assisting species of concern in the Delta. If the flooded island were to become inhabited by invasive species it could easily be drained and repopulated with desirable species again.
**References**: DWR

**33. Name:** Bacon Island
**Location:** Mainstem San Joaquin River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** This island will be used as a water storage facility. It also has the potential to be utilized as a rearing habitat for species requiring open water habitat. Such an investment meets the needs of improving water supply while potentially assisting species of concern in the Delta. If the flooded island were to become inhabited by invasive species it could easily be drained and repopulated with desirable species again.
**References**: DWR

**34. Name:** Sacramento Wastewater Treatment Facilities
**Location:** North Mainstem Sacramento River
**Aerial Extent:**
**Implementation Horizon:** 1-3 years
**Seasonality:** Continuous
**Annual Frequency:** Continuous
**Description:** Increase treatment levels for the Sacramento Metropolitan wastewater treatment plant. Contamination of Sacramento River water is a major issue for the Delta. Effluent from waste water treatment plants has higher than desirable levels of pollutants.
**References**: Dougdale et al. 2007

## References


2 Gates fish protection demonstration Project: Summary document. July 2009. Prepared for CALFED Science Program Independent Review Panel.

Aasen, G. A. 1999. Juvenile delta smelt use of shallow-water and channel habitats in California's Sacramento-San Joaquin Estuary. *California Fish and Game* 85(4): 161-169.

Ahearn, D. S., J. H. Viers, J. F. Mount, and R. A. Dahlgren. 2006. Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain. *Freshwater Biology* 51: 1417-1433.

Amoros, C. 1991. Changes in side-arm connectivity and implications for river system management. *Rivers* 2: 105-112.

Atwater, B. F. and D. F. Belknap. 1980. Holocene intertidal deposits of Sacramento-San-Joaquin Delta, California. *AAPG Bulletin-American Association of Petroleum Geologists*. 64 (3): 438.

Baltz, D. M. and P. B. Moyle. 1993. Invasion resistance to introduced species by a native assemblage of stream fishes. *Ecological Applications*. 3: 246-255.

Baranyi, C., T. Hein, C. Holarek, S. Keckeis, and F. Schiemer. 2002. Zooplankton biomass and community structure in a Danube River floodplain system: effects of hydrology. *Freshwater Biology* 47: 473-482.

Bates, M. and J.R. Lund, "Delta Subsidence Reversal, Levee Failure, and Aquatic Habitat - A Cautionary Tale," Working Paper, Delta Solutions Program, Center for Watershed Sciences, University of California – Davis, http://deltasolutions.ucdavis.edu.

Bayley, P. B. 1995. Understanding large river floodplain ecosystems. Biosceince. 45 (3): 153-158.

Bay Institute, "From the Sierra to the Sea: The Ecological History of the San Francisco Bay–Delta Watershed," 1998.

Beechie, T., Pess, G., and P. Roni. 2008. Setting river restoration priorities: a review of approaches and general protocol for identifying and prioritizing actions. *North American Journal of Fisheries Management*. 28 (3): 891-905.

Benigno, G. M. and T. R. Sommer. 2008. Just add water: Sources of chironmid drift in a large river floodplain. *Hydrobiologia* 600: 297-305.

Bookman Edmonston. 2003. *North Bay Aqueduct Alternative Intake Study*. Solano County Water Agency, Vacaville, CA.

Brandes, P. L. and J. S. McLain. 2001. Juvenile chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin estuary. *California Department of Fish and Game Fish Bulletin*.

Brown, K. J. and G. B. Pasternack. 2004. The geomorphic dynamics and environmental history of an upper deltaic floodplain tract in the Sacramento-San Joaquin Delta, California, USA. *Earth Surface Processes and Landforms* 29(10): 1235-1258.

Brown and May 2007 *SFEWS*

Brown, L. R. and D. Michniuk. 2007. Littoral fish assemblages of the alien dominated Sacramento San Joaquin Delta, California, 1980-1983 and 2001-2003. *Estuaries and Coasts*. 30: 186-200.

Bunn, S. E., P. M. Davies, and M. Winning. 2003. Sources of organic carbon supporting the food web of an arid zone floodplain river. *Freshwater Biology* 48: 619-635.

CALFED Bay-Delta Program. 2000. Ecosystem restoration program plan. Volume I: Ecological attributes of the San Francisco Bay-Delta watershed. Pages 532 pp. CALFED.

Chapin, 1997

Chotkowski M. 1999. List of fishes found in San Francisco Bay-Delta shallow water habitats. Interagency *Ecological Program Newsletter* 12(3):12-18.

Crain, P. K., K. Whitener, and P. B. Moyle. 2004. Use of a restored Central California floodplain by larvae of native and alien fishes. Pages 125-140 in F. Feyrer, L. R.

Dougdale, R.C., Wilkerson, F.P., Hogue, V.E. and A. Marchi, 2007, The role of ammonium and nitrate in spring bloom development in San Francisco Bay, *Estuarine Coastal and Shelf Science*, 73 (2007) 17-29

Faber, M. ed. California Riparian Systems: Processes and Floodplain Management, Ecology, and Restoration. 2001 Riparian Habitat and Floodplains Conference Proceedings. Riparian Habitat Joint Venture, Sacramento, CA.

Feyrer, F. and M. P. Healey. 2003. Fish community structure and environmental correlates in the highly altered southern Sacramento-San Joaquin Delta. *Environmental Biology of Fishes* 66(2): 123-132.

Feyrer, F. T., Sommer, T. R., Zeug, S. C., G. O'Leary and W. Harrell. 2004. Fish assemblages of perennial floodplain ponds of the Sacramento River, California (USA), with implications for the conservation of native fishes. *Fisheries Management and Ecology* 11 (5): 335-344.

Feyrer, F., T. Sommer, and W. Harrell. 2006a. Managing floodplain inundation for native fish: production dyanmics of age-0 splittail (Pogonichtys macrolepidotus) in California's Yolo Bypass. *Hydrobiologia* 573: 213-226.

Feyrer, F. T., T. Sommer and W. Harrell. 2006b. Importance of flood dynamics versus intrinsic physical habitat in structuring fish communities: Evidence from two adjacent engineered floodplains on the Sacramento River, California. *North American Journal of Fisheries Management* 26 (2): 408-417.

Fleenor, W. E., W. A. Bennett, P.B. Moyle, and J. L. Lund. 2010. On developing prescriptions for freshwater flows to sustain desirable fishes in the Sacramento-San Joaquin Delta. Working Paper, Delta Solutions Program, Center for Watershed Sciences, University of California – Davis, http://deltasolutions.ucdavis.edu.

Florsheim, J. L. and J. F. Mount. 2003. Changes in lowland floodplain sedimentation processes: Pre-disturbance to post-rehabilitation, Cosumnes River, CA. *Geomorphology* 56 (3-4): 305-323.

Florsheim, J. L., J. F. Mount and C. R. Constantine. 2006. A geomorphic monitoring and adaptive assessment framework to assess the effect of lowland floodplain river restoration on channel-floodplain sediment continuity. *River Research and Applications* 22 (3): 353-375

Ganju, N. K., Schoelhamer, D. H., and B. A. Bergamaschi. 2005. Suspended sediment fluxes in a tidal wetland: Measurement, controlling factors, and error analysis. *Estuaries* 28: 812-822.

Grimaldo L. and Z. Hymanson. 1999. What is the impact of the introduced Brazilian waterweed *Egeria densa* to the Delta ecosystem? *Interagency Ecological Program Newsletter* 12(1):43-45.

Grosholz, E., and E. Gallo. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. *Hydrobiologia* 568: 91-109.

Gurnell, A. M., and G. E. Petts. 2002. Island-dominated landscapes of large floodplain rivers, a European perspective. *Freshwater Biology* 47: 581-600.

Hammersmark, C. T., Fleenor, W. E. and S. G. Schladow. 2005. Simulation of flood impact and habitat extent for a tidal freshwater marsh restoration. *Ecological Engineering*. 25 (2): 137-152.

Isenberg P, Florian M, Frank RM, McKernan T, McPeak SW, Reilly WK, Seed R. 2008. *Blue Ribbon Task Force Delta vision: Our vision for the California Delta. Sacramento* (CA): State of California Resources Agency, Sacramento, CA.

Jackson ST and RJ Hobbs 2009 Ecological restoration in the ligh of ecological history. *Science* 325:567-569.

Jassby, A. D., and J. E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento - San Joaquin Delta (California, USA). *Aquatic Conservation: Marine and Freshwater Ecosystems* 10: 323-352.

Jassby, A. D., J. E. Cloern, and A. B. Mueller-Solger. 2003. Phytoplankton fuels Delta food web. *California Agriculture* 57: 104-109.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle.2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. *Environmental Biology of Fishes* 83: 449-458.

Kirkland, M. 2008. Cache Slough Area Restoration. Interim Delta Actions DWR. http://www.water.ca.gov/deltainit/docs/6-16-08CacheSlough.pdf

Larsen, E. W., Girvetz, E. H. and A. K. Fremier. Assessing the effects of alternative setback channel constraint scenarios employing a river meander migration model. *Environmental Management.* 37 (6): 880-897.

Lehman, P. W., T. Sommer and L. Rivard. 2008. The influence of floodplain habitat on the quantity and quality of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. *Aquatic Ecology* 42 (3): 376-378.

Lucas, L.V., Sereno, D.M., Burau, J. R., Schraga, T.S., Lopez, C. B., Stacey, M.T., K. V. Parchevsky and V. P. Parchevsky. 2006. Intradaily variability of water quality in a shallow tidal lagoon: Mechanisms and implications. *Estuaries and Coasts* 29 (5): 711-730.

Lund, J., Hanak, E., Fleenor, W., Howitt, R., J. Mount and P. B. Moyle. 2007. *Envisioning Futures for the Sacramento-San Joaquin Delta*. Public Policy Institute of California.

Lund, J., E. Hanak, W. Fleenor, W. Bennett, R. Howitt, J. Mount, and P. B. Moyle. 2010. Comparing Futures for the Sacramento-San Joaquin Delta. Berkeley, University of California Press. 230 pp.

Natural Heritage Institute. 2002. Subsided island restoration design in the Sacramento-San Joaquin Delta: A solution for levee fragility and water supply vulnerability in the Delta.

North Delta Flood Control and Ecosystem Restoration Project. 2008. Group 1 and Group 2 alternatives. http://www.water.ca.gov/floodmgmt/dsmo/sab/ndp/alternatives/

Matern, S.A., L. Meng and P. B. Moyle. 1997. *Trends in fish populations of Suisun Marsh: January 1996- December 1996*. Annual report to California Department of Water Resources, Environmental Services Office, Sacramento (CA). Davis (CA): University of California.

Matern, S. A., L. Meng and P. B. Moyle. 1998. *Trends in fish populations of Suisun Marsh: January 1997- December 1997*. Annual report to California Department of Water Resources, Environmental Services Office, Sacramento (CA). Davis (CA): University of California.

Matern, S.A., P. B. Moyle and L. C. Pierce. 2002. Native and alien fishes in a California estuarine marsh: twenty-one years of fluctuating coexistence. *Transactions of the American Fisheries Society* 131:797-816.

Matern, S. A., L. Meng and P. B. Moyle. 1999. *Trends in fish populations of Suisun Marsh: January 1998- December 1998*. Annual report to California Department of Water Resources, Environmental Services Office, Sacramento (CA). Davis (CA): University of California.

McGowan, M. and A. Marchi. 1998. Fishes collected in submersed aquatic vegetation, Egeria densa, in the delta. *Interagency Ecological Program Newsletter* 11(1):9-10.
Meng, L., Moyle, P. B., and B. Herbold. 1994. Changes in abundance and distribution of native and introduced fishes of Suisun Marsh. *Transaction of the American Fisheries Society* 123(4): 498-507.
Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands. J. Wiley & Sons, New York. Moyle, P. B. 2002. *Inland Fishes of California*. University of California Press, Berkeley, CA.
Mount, J. F. and R. Twist. 2005. Subsidence, sea level rise, and seismicity in the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*. Vol. 3, Issue 1 (March 2005), Article 5. http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art5
Moyle, P.B. 2008. The future of fish in response to large-scale change in the San Francisco Estuary, California. Pages 357-374 *In* K.D. McLaughlin, editor. *Mitigating Impacts of Natural Hazards on Fishery Ecosystems*. American Fishery Society, Symposium 64, Bethesda, Maryland.
Moyle, P. B., and W. A. Bennett, "The Future of the Delta Ecosystem and Its Fish," in J. Lund et al., *Comparing Futures for the Sacramento–San Joaquin Delta*, Appendix D. Public Policy Institute of California. San Francisco, California, 2008.
Moyle, P. B. and T. Light. 1996. Fish invasions in California: Do abiotic factors determine success?. *Ecology* 77: 1666-1670.
Moyle, P.B., W.A. Bennett, W.E. Fleenor, and J.R. Lund, 2010, "Habitat Variability and Complexity in the Upper San Francisco Estuary", Working Paper, Delta Solutions Program, Center for Watershed Sciences, University of California – Davis, http://deltasolutions.ucdavis.edu.
Moyle P.B., Crain P.K., and Whitener K. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. *San Francisco Estuary and Watershed Science* 5(3):1-27. http://repositories.cdlib.org/jmie/sfews/vol5/iss3/art1
Moyle, P. B., R. D. Baxter, T. R. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and population dynamics of Sacramento splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: a review. *San Francisco Estuary and Watershed Science* 2: article 3.
Muller-Solger, A. B., A. D. Jassby, and D. C. Muller-Navarra. 2002. Nutritional quality of food resources for zooplankton (Daphnia) in a tidal freshwater system (Sacramento-San Joaquin River Delta). *Limnology and Oceanography* 47: 1468- 1476.
Myrick, C. A., and J. J. Cech. 2004. Temperature effects on juvenile anadromous salmonids in California's Central Valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14: 113-123.
Perry, R. W., Brandes, P. L., Sandstrom, P. T., Ammann, A., MacFarlane, R. B., A. P. Klimley and John R. Skalski. 2009. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. In Press. *North American Journal of Fisheries Management*.
Peterson, M. S. 2003. A conceptual view of environment-habitat-production linkages in tidal river estuaries. *Reviews in Fisheries Science* 11: 291-313.
Power, M. E., Parker, G., Dietrich, W. E. and A. Sun. How does floodplain width affect floodplain river ecology – a preliminary exploration using simulations. *Geomorphology* 13 (1-4): 301-317.
Ribiero, F., P. K. Crain and P. B. Moyle. 2004.Variation in condition factor and growth in young-of-year fishes in floodplain and riverine habitats of the Cosumnes, California. *Hydrobiologia* 527 (1): 77-84.

Schemel, L. E., T. R. Sommer, A. B. Muller-Solger, and W. C. Harrell. 2004. Hydrological variability, water chemistry, and phytoplankton biomass in a large floodplain of the Sacramento River, CA, USA. *Hydrobiologia* 513: 129-139.

Schramm Jr., H. L., and M. A. Eggelton. 2006. Applicability of the Flood Pulse Concept in a temperate floodplain river ecosystem: thermal and temporal components. *River Research and Applications* 22: 543-553.

Scott, M. L., M. A. Wondzell, and G. T. Auble. 1993. Hydrograph characteristics relevant to the establishment and growth of Western riparian vegetation.

Sheibley, R. W., D. S. Ahearn, and R. A. Dahlgren. 2006. Nitrate loss from a restored floodplain in the lower Cosumnes River, California. *Hydrobiologia* 571: 261-272.

Sobczak, W. V., J. E. Cloern, A. D. Jassby, and A. B. Muller-Solger. 2002. Bioavailability of organic matter in a highly disturbed estuary: the role of detrital and algal resources. *Proceedings of the National Academies of Science* 99: 8101-8105.

Sommer, T. R., L. Conrad, G. O'Leary, F. Feyrer, and W. C. Harrell. 2002. Spawning and rearing of spittail in a model floodplain wetland. *Transactions of the American Fisheries Society* 131: 966-974.

Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001a. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 325-333.

Sommer, T. R., W. C. Harrell, A. M. Solger, B. Tom, and W. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. *Aquatic Conservation-Marine and Freshwater Ecosystems* 14: 247-261.

Sommer, T. R., W. C. Harrell, and M. L. Nobriga. 2005. Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain. *North American Journal of Fisheries Management* 25: 1493-1504.

Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001b. California's Yolo Bypass: evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries* 26: 6-16.

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

Swenson, R. O., K. Whitener, and M. Eaton. 2003. Restoring floods on floodplains: riparian and floodplain restoration at the *Cosumnes River Preserve*. Pages 224-229 in P.

Thorp, J. H. and M. D. Delong. 1994. The riverine productivity model – An heuristic view of carbon-sources and organic-processing in large river ecosystems. *Oikos* 70 (2): 305-308.

Trowbridge, W. B. 2007. The role of stochasticity and priority effects in floodplain restoration. *Ecological Applications* 17 (5): 1312-1324.

U.S. Geological Survey, 1911. Topographical map of the Sacramento Valley, California. U.S. Geological Survey Atlas Sheets.

Whitener, K., and T. Kennedy. 1999. Evaluation of fisheries relating to floodplain restoration on the Cosumnes River Preserve. *Interagency Ecological Program (IEP) Newsletter* 12: 50-57.

Williams, P. B. E. Andrews, J. J. Opperman, S. Bozkurt, P. B. Moyle 2009. Quantifying activated floodplains on a lowland regulated river: its application to floodplain restoration in the Sacramento Valley. *San Francisco Estuary and Watershed Science*.

| Location | Investment Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | Habitat Type (by sea level) | | | | | Water Operations | Other |
| | Flooded Island | Tidal Marsh | Floodplain | Riparian | Levee Setbacks | | |
| **Steamboat/ Sutter Complex** | Prospect Island | - | - | - | Sutter & Steamboat Sloughs | - | Subsided Island Reversal |
| **North Main Stem Sacramento River** | - | - | - | - | - | New diversion point (pc) | - |
| **Yolo Bypass/ Cache Slough Complex** | - | Cache and Lindsay Slough | - | - | - | Fremont Wier | - |
| | - | Yolo Bypass | Yolo Bypass | - | - | Relocate N. Bay Aqueduct | - |
| **South Main Stem Sacramento River** | - | Decker Island and West bank South of Rio Vista | - | - | - | - | - |
| **Eastern Delta** | Dead Horse, McCormack, & Staten Is. | - | Cosumnes River | - | N. and S. forks of the Mokelumne | Delta Cross Channel Operations | Subsided Island Reversal |
| **San Joaquin River** | - | Dutch Slough, Jersey Point, & Three-mile Sl. | - | - | - | - | Subsided Island Reversal |
| **South Delta** | - | Tidal Marsh on Old and Middle Rivers | South Delta Flood Bypass | Union & Roberts Islands Old & Middle Rivers | - | South Delta exports | Subsided Reversal, Tid Gates Old & Middle River |
| **Suisun Bay** | - | New York Slough/Antioch/ Pittsburg Riverfront | - | - | - | - | - |
| **Suisun Marsh** | - | Hill Slough, Blalock, and Montezuma | - | - | - | Salinity Control Gates | - |