5. STRESSORS

5.1 Water Diversions

Introduction

Water diversions are found throughout Central Valley rivers and the Delta. Water is diverted for irrigated agriculture, municipal and industrial use, and managed wetlands. It has been estimated that there are over 4,000 diversions and that greater than 90% of these are either unscreened or screened insufficiently to prevent fish entrainment. Most of the diversions are small (diameters of intake pipes less than 40 inches) but there are many large diversions as well.

Water diversions have two major impacts. One is the alteration of ecological processes such as channel forming flow regimes. The second is entrainment and loss of aquatic organisms at the point of diversion. The impact that diversions have on ecological processes is discussed in the sections that address Central Valley streamflows, floodplains, coarse sediment supply, and stream meander.

Water diversions in the Bay-Delta watershed directly and indirectly affect fish and other aquatic organisms, sediments, salinity, streamflow, habitat, food-web productivity, and species abundance and distribution. The rate at which water is diverted from the Delta affects the residence time of water in the Delta which, in turn, affects primary and secondary production.

Factors that affect the influence diversions have on aquatic organisms and overall ecosystem health include the rate, season, and location in which water is diverted; as well as the fish species present, their life stage periodicity, and whether or not the diversion is equipped with adequate fish protection facilities to begin with.

In most cases, entrained organisms do not survive. Some diversions have screens that exclude most juvenile and adult fish; however, eggs and larval fish, invertebrates, planktonic plants, organic debris and dissolved nutrients are sometimes lost to diversions.

Applicable ERP Vision, Goals, and Objectives

The ERP vision for water diversions is to reduce their adverse effects by installing fish screens, consolidating or moving diversions to less sensitive locations, removing diversions by finding substitute water supplies, or reducing the volume of water diverted. Achieving this vision will assist in the recovery of State and/or Federally listed

species, improve important sport fisheries, and improve the Bay-Delta food-web. Many of the projects that address the impacts of water diversions are program-wide in scope (CALFED 2000a).

Stage 1 Expectations

During Stage 1, it was expected that all water diversions with capacities greater than 250 cubic feet-per-second (cfs) within the Sacramento River watershed would be screened, the majority of diversions with capacities between 100 and 250 cfs would be screened, and a process would be in place to set priorities and screen diversions with capacities less that 100 cfs.

Stage 1 priority actions as defined in the Strategic Plan for Ecosystem Restoration (CALFED 2000b) and the Stage 1 Implementation Plan (CALFED 2001) included:

- Evaluate the need to screen all diversions smaller than 100 cfs on the Sacramento River and selected tributaries;
- Evaluate the effectiveness of timing diversions to reduce impacts upon juvenile anadromous fish;
- Study the loss of juvenile anadromous fish entrained into smaller diversions;
- Evaluate the need to screen small diversions in the Delta;
- Assess gains in fish passage so that priorities for future actions can be established;
- Participate in the new "Interagency Fish Screen Evaluation Program" in order to coordinate and prioritize ERP Central Valley fish screening efforts with other programs: Anadromous Fish Restoration program (AFRP), Anadromous Fish Screen Program (AFSP), CALFED, and CDFG;
- Increase efforts for restoring the Calaveras River and coordinate with other projects addressing instream flows, screening, and temperature monitoring programs to work towards the goal of obtaining unimpeded fish passage;
- Implement a program to improve fish passage and reduce predation on juvenile salmonids below Woodbridge Dam on the lower Mokelumne River including the following elements:
    - improving the form and function of the downstream river channel;
    - rebuilding the Woodbridge Dam fish passage and diversion screening facilities to minimize losses of downstream migrating juvenile salmon and steelhead;
    - improving the fish bypass discharge from the dam;
- Improve fish passage in Battle Creek by removing diversion dams, upgrading fish ladders, and screening diversions;
- Improve fish passage in Butte Creek by modifying or installing upgraded fish ladders and screens at existing diversions or by removing outdated diversion facilities;
- Screen the Sunset Pumps diversion on the Feather River to prevent entrainment of juvenile salmonids;

- Evaluate entrainment rates at small diversions on the Tuolumne River and assess their affect upon native and anadromous fish populations;
- Remove McCormick-Saeltzer Diversion Dam on Clear Creek.

Changes Attributable to ERP

During Stage 1, numerous projects were funded throughout the ERP Regions to address fish passage and entrainment issues. ERP funded 75 projects (Table 1); in addition there were 31 projects funded through CVPIA and AFRP (Table 2).

On the Sacramento River, 36 projects were funded by ERP for planning, feasibility, and construction of fish screens and passage projects. As a result of these projects, eight sites with diversion rates greater than 250 cfs were screened or are in the process of being screened:

- American Basin Fish Screen Project: *American Basin Fish Screen and Habitat Improvement Project* (**ERP-98-B29**); *American Basin Habitat Improvement Project* (**ERP-01-N60**); *American Basin Fish Screen and Habitat Improvement Project* (**ERP-02-P09-D**)
- Wilkins Slough Pumping Plant: *Feasibility Study for Intake Screen at Wilkins Slough Diversion* (**ERP-96-M19**); *Positive Barrier Fish Screen Project, Wilkins Slough Pumping Plant* (**ERP-97-C01**); *Wilkins Slough Positive Barrier Fish Screen Sediment Removal System* (**ERP-02D-P69**)
- Tisdale Pumping Plant: *Sutter Mutual Water Company Tisdale Positive Barrier Fish Screen and Pumping Plant* (**ERP-02-P24**); *Tisdale Positive Barrier Fish Screen/Pumping Plants Project - Phase IV* **(ERP-02D-P70)**
- Anderson-Cottonwood Irrigation District: *Fish Passage Improvement Project under Bay Delta Project - Category III* (**ERP-98-B03**); Fish Passage and Fish Screening Improvement Project, Phase II (**ERP-98-B24**); *Anderson-Cottonwood Irrigation District Fish Passage and Fish Screening Improvement Project, Phase III* (**ERP-99-B03**); *ACID Fish Passage Improvement Project, Phase III* (**ERP-99-N01**)
- City of Sacramento Fairbairn Water Treatment Plant: *The City of Sacramento Water Intake Fish Screen Replacement Projects: Sacramento River Water Treatment Plant and the E.A. Fairbairn Water Treatment Plant* (**ERP-98-B28**); *Water Intake Fish Screen Replacement Project* (**ERP-01-N51**)
- Reclamation District 108 Consolidated Diversions: *Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen* (**ERP-02-P10-D**)
- Princeton- Codora-Glen Irrigation District: *Princeton-Codora-Glenn Irrigation District and Provident Irrigation District Fish and Wetlands Restoration Project*

- Princeton Pumping Plant: *Princeton Pumping Plant Fish Barriers Feasibility Study* (**ERP-96-M04**); *Princeton Pumping Plant Fish Screen Facility* (**ERP-97-C02**)

Another large diversion (diversion rate greater than 250 cfs), Reclamation 2035, was funded for planning, feasibility and design through the projects: *Reclamation District 2035 Fish Screen Project Feasibility Study* (**ERP-98-N01**) and *RD 2035 Fish Screen and Environmental Design Review* (**ERP-01-N55**).

Six sites with diversion rates less than 250 cfs were screened:

- Boeger Family Farm: *Boeger Family Farms Fish Screen Feasibility Study* (**ERP-98-B02**); and *Boeger Family Farms Fish Screen Phase II: Construction* (**ERP-98-B26**)
- City of Redding Fish Screen: *Water Utility Fish Screen Rehabilitation* (**ERP-00-B01**)
- Small Fish Screen Project: *Sacramento River Small Diversion Fish Screen Program* (**ERP-98-R01**)
- M &T Pumping Plant: *M&T/Parrott Pumping Station and Fish Screen Project* (**ERP-95-M05**); and *M & T/Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project* (**ERP-02-P08-D**)
- Tuttle Pump Relocation: *Tuttle Pump Relocation Project* (**ERP-00-B02**)
- Deer and Mill Creek Water Diversion Screening: *Water Diversion Screening* (**ERP-97-C04a**)

Planning, feasibility and design for three small diversions were funded:

- FWA Small Diversions: *Sacramento River Small Diversion Fish Screen Program - Mechanical Monitoring and Maintenance Project* (**ERP-00-R01**); and *Sacramento River Fish Small Screen Project Vertical River Pump Diversions* (**ERP-01-N52**)
- Richter Brothers Fish Screen: *Richter Brothers Anadromous Fish Screen Project* (**ERP-98-B01**)
- Meridian Farms Fish Screen: *Meridian Farms Water Company - Positive Barrier Fish Screen Project* (**ERP-02-P15**)

There were three projects that performed planning and feasibility analysis for improving passage through the Red Bluff Diversion Dam: *Fish Passage Improvement at the Red Bluff Diversion Dam, Phase II* (**ERP-99-B07**); *Fish Passage Improvement at the Red Bluff Diversion Dam: Balance of Phase II Funding* (**ERP-01-N58**); and *Fish Passage Improvement Project at the Red Bluff Diversion Dam* (**ERP-98-B22**).

Eight projects provided funding for the Battle Creek Restoration Project. Three projects laid the groundwork for restoration efforts in Battle Creek by funding a Watershed Conservancy and determining life history strategies of salmonids in the watershed : *Battle Creek Watershed Management Strategy* (**ERP-96-M25**); *Monitoring Adult and Juvenile Spring and Winter Chinook Salmon and Steelhead in Battle Creek, California* (**ERP-98-C14**); and *Outreach and Technical Services to Support Landowner and Watershed Resident's Participation in the Battle Creek Salmon and Steelhead Restoration Project* (**ERP-03-M10**). Three projects were completed for planning and feasibility analysis: *Battle Creek Chinook Salmon and Steelhead Restoration Plan* (**ERP-96-M12**); *Engineering Investigation of Anadromous Fish Passage in Upper Battle Creek* Project (**ERP-97-M02**); and *Reconnaissance Investigation and Preliminary Design for Steelhead and Winter-run and Spring-run Chinook Passage Facilities* (**ERP-98-B16**). At the time of this writing ongoing projects in Battle Creek include: *Battle Creek Salmon and Steelhead Restoration Project* (**ERP-99-B01**) which has not been implemented; and *Improve Upstream Ladder and Barrier Weir at Coleman National Fish Hatchery at Battle Creek* (**ERP-99-B08**). A detailed description of Battle Creek projects is provided in the North Sacramento Valley EMZ chapter in Appendix A.

One demonstration project, conducted at the Coleman National Fish Hatchery on Battle Creek, provided new insight for small fish screens *Fish Screen Biological Performance Test* (**ERP-96-M23**).

On Mill Creek, *Anadromous Fish Passage at Clough Dam on Mill Creek* (**ERP-98-B21**) funded design and construction of fish passage facilities near Clough Dam for salmon and steelhead.

On Butte Creek, there were two grants that funded planning and then construction of a fish ladder at Adam's Dam: *Adams Dam Fish Screen and Fish Ladder Project* (**ERP-96-M21**); and *Adams Dam Fish Screen and Fish Ladder Project* (**ERP-97-M04**). Another construction phase project was funded as the *Lower Butte Creek Project: Phase III Facilitation/Coordination and Construction of Three Fish Passage Modifications to Sutter Bypass West Side Water Control Structures* (**ERP-01-N54**). Four planning and feasibility projects were funded for screening other diversions on Butte Creek: *Durham Mutual Water Company Diversion Dam Fish Screen and Ladder Project* (**ERP-95-M02**); *Gorrill Dam Fish Screen and Fish Ladder Project* (**ERP-96-M22**); *Gorrill Dam Fish Screen and Fish Ladder Project* (**ERP-97-M03**); and *Lower Butte Creek Project (Phase II: Preliminary Engineering and Environmental Analysis for Butte Sink Structural Modifications and Flow-Through System)* (**ERP-99-B02**). There were four projects that improved passage for 90 miles of habitat for salmon and steelhead, in particular for spring-run Chinook salmon: *Butte Creek Siphon and Associated Improvements* (**ERP-96-M01**); *Butte Creek/Sanborn Slough Bifurcation Upgrade Project* (**ERP-01-N16**); *White Mallard Dam and Associated Diversions* (**ERP-01-N53**); and *Butte Sink Water Control Structure Modifications - Phase III Construction* (**ERP-02-P07**).

On the Yuba River, there was one project funded to screen the Browns Valley Irrigation District diversion: *Browns Valley Irrigation District Fish Screen Project* (**ERP-96-M17**).

On the San Joaquin River, there were two projects that funded planning, design, and environmental permitting for a positive barrier fish screen on the Patterson Irrigation District water diversion: *Patterson Irrigation District Positive Barrier Fish Screen Study on San Joaquin River Diversion* (**ERP-01-N56**); and *Patterson Irrigation District Fish Screen Design and Environmental Review* (**ERP-02-P16**). One project funded the design and construction of an improved fish screen at the Banta-Carbona Canal Irrigation District's 260 cfs water diversion facility: *Banta-Carbona Irrigation District Fish Screen Project* (**ERP-97-M07**).

On the Cosumnes River, there was one project to evaluate and implement construction of structures to improve adult salmonid passage over existing diversion structures in the Cosumnes River: *Cosumnes River Salmonid Barrier Program* (**ERP-98-B25**). Tasks included evaluating alternatives, finalizing engineering specifications, bidding, and construction.

On the Mokelumne River, there were two projects that conducted feasibility analysis, permitting and design for replacement of the Woodbridge Dam, including new fish ladders, to improve passage on the Mokelumne River: *Lower Mokelumne River Restoration Plan - Phase 1* (**ERP-98-B11**) and *Lower Mokelumne River Restoration Program - Phase 2* (**ERP-01-N57**). The new dam and fish ladders currently are under construction, funded by bonds financed by the Woodbridge Irrigation District's sale of surplus water to the City of Lodi.

On the Calaveras River, there was one project that addressed the feasibility, planning, and design for improving fish passage at 29 unscreened diversions between Bellota Weir and New Hogan Dam; *Stockton East Water District and Calaveras County Water District Fish Screen Facilities - Calaveras River* (**ERP-01-N59**).

Opportunities to consolidate, screen, or eliminate diversions will be considered in the Suisun Marsh Charter Group's *Habitat Management, Preservation, and Restoration Plan for Suisun Marsh*. To date, three ERP projects have contributed towards screening or eliminating seven diversions: *Suisun Marsh Fish Screen Project* (**ERP-95-M07**); *Hill Slough West Habitat Restoration Demonstration Project* (**ERP-98-F08**); and *Hill Slough West Habitat Restoration Demonstration Project, Phase II* (**ERP-01-C09**). This represents only two percent of the diversions within the Suisun Marsh. The ERP has not yet determined if the goal to screen 25 percent of the unscreened diversions in Suisun Marsh will be beneficial to the Bay-Delta ecosystem or not. In an effort to make such a determination, the ERP will work with the Interagency Fish Screen Evaluation Program and the CVPIA/AFSP to assess the benefits of screening various diversion

sizes, and to determine if fish screens are necessary on the remaining diversions in the marsh.

In the North Delta, two projects were funded that addressed alternatives, analysis, selection, project development, and installation of fish screens at Cache and Lindsay sloughs: *Hastings Tract Fish Screen (Phase I: Feasibility Study)* (**ERP-97-M06**); and *Hastings Tract Fish Screen (Phase II: Construction)* (**ERP-98-B27**).

In the San Francisco Bay Region, three fish passage projects were funded to help salmon and steelhead migrate through Sonoma Creek: *Sonoma Creek Watershed Enhancement Plan - Phase II* (**ERP-98-E02**); *Sonoma Creek Watershed Conservancy* (**ERP-00-E04**); *Sonoma Creek Watershed Conservancy* (**ERP-01-N27**). On the Guadalupe River, *Steelhead and Chinook Salmon Fish Passage Barrier Remediation on the Guadalupe River* (**ERP-98-B23**) was funded to construct fish passage structures.

Finally, the ERP funded the program-wide *Fish Treadmill Developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes* (**ERP-99-N02**). The primary ecological/biological objective and benefit of this project is to provide the data necessary to develop the "proven technology" for protective positive barrier fish screens for priority native fishes in the Sacramento-San Joaquin watershed.

Additional information on fish screens and water diversions within a specific EMZ/EMU can be found in Appendix A.

Project Summary

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
Sacramento River Mainstem				
ERP-00-B01	**Water Utility Fish Screen Rehabilitation** Installed a positive barrier fish screen structure on intake structure at City of Redding Pump Station #1 which will meet NOAA and CDFG screen criteria. Tasks included: design, engineering, permitting, construction, installation, inspection and monitoring.	4/1/2006	$985,400	Complete.
ERP-00-B02	**Tuttle Pump Relocation Project** Relocated Tuttle's Diversion to the Maxwell Irrigation District's pumping plant and removed the existing pumping facilities approximately 450 feet south of the District's plant.	2/28/2003	$452,900	Complete.
ERP-00-R01	**Sacramento River Small Diversion Fish Screen Program - Mechanical Monitoring and Maintenance Project** Provided technical assistance, planning, engineering, design, environmental documentation, administration and oversight of projects to install fish screens for agricultural land users along the Sacramento River.	9/30/2003	$312,700	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-N51	**Water Intake Fish Screen Replacement Project** Improved fish screens to reduce entrainment of all runs of Chinook salmon, steelhead trout, Sacramento splittail, and green sturgeon in the lower American and Sacramento Rivers at two water treatment facilities.	5/28/2004	$6,142,142	Complete.
ERP-01-N52	**Sacramento River Fish Small Screen Project Vertical River Pump Diversions** Funded a cooperative ongoing effort to provide information about vertical fish screens for small screen diversions (less than 40 cfs) to provide technical and financial assistance to landowners interested in installing fish screens along the Sacramento River.	10/31/2004	$1,800,000	Complete.
ERP-01-N55	**Reclamation District 2035 Fish Screen Design and Environmental Design Review** Funded screen installation to reduce entrainment of juvenile Chinook salmon, steelhead trout, Sacramento splittail, and green sturgeon at Reclamation District 2035's water diversion structure.	12/31/2003	$1,384,000	Ongoing. Design and permitting ongoing. Construction has not begun.
ERP-01-N58	**Fish Passage Improvement at the Red Bluff Diversion Dam: Balance of Phase II Funding** This project funded actions to reduce or minimize the impacts of the Sacramento River's Red Bluff Diversion Dam on upstream and downstream migration of juvenile and adult anadromous fish, while improving agricultural water supply.	9/30/2004	$734,000	Complete.
ERP-01-N60	**American Basin Habitat Improvement Project** This project was to support the American Basin Fish Screen and Habitat Improvement Project which will improve fish passage, reduce entrainment, and improve aquatic, riverine, and riparian habitats along the Sacramento River.	12/31/2006	$1,450,000	Ongoing.
ERP-02D-P69	**Wilkins Slough Positive Barrier Fish Screen Sediment Removal System** The project added sediment removal facilities to an existing fish screen at Reclamation District 108's Wilkins Slough irrigation water diversion on the Sacramento River's west bank, near Grimes	9/15/2007	$535,000	Complete.
ERP-02D-P70	**Tisdale Positive Barrier Fish Screen/Pumping Plants Project - Phase IV** This is a fish screen to minimize entrainment of fish at a large (960cfs) irrigation water diversion on the Sacramento River's east bank, south of Meridian.	12/31/2008	$8,256,500	Ongoing.
ERP-02-P08-D	**M & T/Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project** Funded actions to protect the existing M&T/Llano Seco fish-screen facility and its beneficiaries while investigating and identifying a technically and economically feasible long-term solution to adapt the fish-friendly pumping facility to the lateral migration of the Sacramento River.	06/30/2008	$4,390,087	Ongoing.
ERP-02-P09-D	**American Basin Fish Screen and Habitat Improvement Project** This project removed a diversion dam, consolidated diversions and added state-of-the-art fish screens to NMWC's diversion on the Sacramento River, between Verona and the American River, and on the Cross Canal.	12/31/2009	$12,600,000	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P10-D	**Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen** Funded environmental compliance, permitting, and final design for screening three of RD108's Sacramento River diversions.	6/30/2006	$690,000	Complete. Project in construction phase.
ERP-02-P15	**Meridian Farms Water Company - Positive Barrier Fish Screen Project** Completed the final engineering design, conducted the final environmental analyses, and secured the necessary permits for the fish screen project for the positive barrier fish screen project.	11/30/2007	$750,000	Ongoing.
ERP-02-P24	**Sutter Mutual Water Company Tisdale Positive Barrier Fish Screen and Pumping Plant** Created final designs, environmental documentation, and permitting for a fish screen structure at the Tisdale Pumping plants.	5/31/2005	$1,270,000	Complete.
ERP-95-M05	**M&T/Parrott Pumping Station and Fish Screen Project** Funded relocation of M&T Ranches' Parrot-Phelan Pumping Station and implementation of fish screens on diversion structures to reduce fish entrainment on Big Chico Creek.	12/31/1997	$1,610,000	Complete.
ERP-96-M04	**Princeton Pumping Plant Fish Barriers Feasibility Study** Funded design and construction a fish screen at the Reclamation District 1004's Princeton Pumping Plan to prevent the entrainment of winter-run Chinook salmon on the Sacramento River.	12/31/1997	$75,000	Complete.
ERP-96-M05	**Princeton-Codora-Glenn Irrigation District and Provident Irrigation District Fish and Wetlands Restoration Project** Funded environmental documentation and engineering feasibility of consolidation of three pumping plants along the Sacramento River to reduce entrainment of Chinook salmon and improve the aesthetics of the river.	8/31/1998	$75,000	Complete.
ERP-96-M07	**Princeton-Codora-Glenn Irrigation District and Provident Irrigation District Fish and Wetlands Restoration Project** Funded the construction phase of consolidating and screening three pumping sites on the Sacramento River to reduce entrainment of salmon and improve aesthetics along the river corridor.	12/31/1999	$5,500,000	Complete.
ERP-96-M19	**Feasibility Study for Intake Screen at Wilkins Slough Diversion** Phase II (feasibility study) of a five-phase project to design and construct a state-of-the-art fish screen at Reclamation District 108's Wilkins Sough diversion facility on the Sacramento River to reduce entrainment of anadromous fish.	6/30/1997	$100,000	Complete.
ERP-97-C01	**Positive Barrier Fish Screen Project, Wilkins Slough Pumping Plant** This project provided funding for the construction of a positive fish barrier intake screen at Reclamation District 108's diversion structure at Wilkins Slough for the protection of Chinook, splittail, and other fish species.	12/31/1999	$2,500,000	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-97-C02	**Princeton Pumping Plant Fish Screen Facility** This project provided funds to relocate Reclamation District 1004's unscreened diversion on the Sacramento River and construct a new positive barrier fish screen to prevent entrainment of anadromous fish.	6/30/1999	$1,750,000	Complete.
ERP-97-C04a	**Water Diversion Screening** This project provided funds to install two demonstration fish screens at water diversions located on the Sacramento River and to conduct outreach activities to encourage other private owners to participate in voluntary screening of their diversions to prevent entrainment of anadromous fish species.	2/28/2002	$374,850	Complete.
ERP-98-B01	**Richter Brothers Anadromous Fish Screen Project** This project evaluated alternatives for placing a positive barrier fish screen on three water diversion structures on the Sacramento River to reduce entrainment of anadromous fish.	8/15/1999	$49,000	Complete.
ERP-98-B02	**Boeger Family Farms Fish Screen Feasibility Study** This project conducted the required initial studies for screening of the Boeger Family Farm pumping plant on the Sacramento River near Colusa for the benefit of reducing entrainment of anadromous fish.	4/30/1999	$13,811	Complete.
ERP-98-B03	**Fish Passage Improvement Project under Bay Delta Project - Category III** Funded the planning phase for construction of fish passage improvement structures at the Anderson-Cottonwood Irrigation District main diversion dam for the benefit of anadromous fish.	3/31/1999	$325,000	Complete.
ERP-98-B22	**Fish Passage Improvement Project at the Red Bluff Diversion Dam** This project provided funds for identifying the best alternative for operation of the Red Bluff Diversion Dam that maximizes fish passage for anadromous fish while minimizing adverse impacts to agricultural irrigation supply.	2/28/2000	$340,164	Complete.
ERP-98-B24	**Fish Passage and Fish Screening Improvement Project, Phase II** This project provided funds for completing the final design, environmental documentation, and permitting for improved fish passage structures on the Anderson-Cottonwood Irrigation District diversion dam on the Sacramento River.	8/31/1999	$840,759	Complete.
ERP-98-B26	**Boeger Family Farm Fish Screen Phase II: Construction** Funded screen construction to increase upstream passage of returning adults.	1/1/2004	$192,210	Complete.
ERP-98-B28	**The City of Sacramento Water Intake Fish Screen Replacement Projects: Sacramento River Water Treatment Plant and the E.A. Fairbairn Water Treatment Plant** This project provided funds to prepare final design for replacing fish screens at two water treatment plants, one on the Sacramento River and the other on the American, to reduce entrainment of anadromous fish.	6/30/2001	$1,964,500	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-B29	**American Basin Fish Screen and Habitat Improvement Project** This project provided funds for the feasibility study and preliminary design and environmental compliance work for the American Basin Fish Screen and Habitat Improvement Project, which will remove migration barriers and prevent straying and entrainment of anadromous fish.	6/30/2002	$450,000	Complete.
ERP-98-N01	**Reclamation District 2035 Fish Screen Project Feasibility Study** This project conducted a feasibility study for installing positive barrier fish screens at a Reclamation District 2035 (RD2035) diversion on the Sacramento River.	9/30/2000	$100,000	Complete.
ERP-98-R01	**Sacramento River Small Diversion Fish Screen Program** Funded screening diversions on the mainstem Sacramento River in the area between Keswick Dam and the Red Bluff Diversion Dam.	9/30/2003	$1,240,991	Complete.
ERP-99-B03	**Anderson-Cottonwood Irrigation District Fish Passage and Fish Screen Improvement Project, Phase III** This project supported Phase III of the Anderson-Cottonwood Irrigation District (ACID) Fish Screen Project to improve fish passage and habitat for salmon and steelhead on the Sacramento River by providing funds for the construction bidding process and construction phase of the project.	12/31/2005	$4,637,278	Complete.
ERP-99-B07	**Fish Passage Improvement at the Red Bluff Diversion Dam, Phase II** This project funded a portion of Phase II of the Tehama-Colusa Canal Fish Passage Project at Red Bluff Dam, which involves modifying the Red Bluff Diversion Dam (RBDD) to reduce or minimize the impacts of the RBDD on upstream and downstream migration of juvenile and adult anadromous fish migration.	3/31/2002	$1,839,888	Complete.
ERP-99-N01	**ACID Fish Passage Improvement Project, Phase III** This project funded construction of improved fish passage structures on the Anderson-Cottonwood Irrigation District diversion dam on the Sacramento River.	9/1/2002	$5,100,000	Complete.
Battle Creek				
ERP-03-M10	**Outreach and Technical Services to Support Landowner and Watershed Resident's Participation in the Battle Creek Salmon and Steelhead Restoration Project** The project provides the technical resources required providing a sound scientific basis for the Conservancy's expression of local concerns to the agencies and its outreach activities related to the Battle Creek Restoration Project.	7/1/2008	$300,000.00	Ongoing.
ERP-96-M12	**Battle Creek Chinook Salmon and Steelhead Restoration Plan** This project collected data to create a watershed plan that will comprise a part of the overall watershed strategy used for implementing the Battle Creek Salmon and Steelhead Restoration Project.	10/1/1999	$306,000	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-96-M23	**Fish Screen Biological Performance Test** Funded demonstration of the feasibility of the application of an innovative fish screen design to smaller (< 50 cfs) unscreened diversion in the Central Valley of California.	6/30/1998	$90,000	Complete.
ERP-96-M25	**Battle Creek Watershed Management Strategy Project** This project provides funds to form a watershed conservancy and create a "community plan" for the Battle Creek watershed that will supplement the existing "technical plan" and provide a two-tiered document for restoration activities in the watershed based on collaboration between stakeholders.	10/15/1999	$100,000	Complete.
ERP-97-M02	**Engineering Investigation of Anadromous Fish Passage in Upper Battle Creek Project** This project consisted of the preliminary design phase for construction of fish screens and ladders to improve passage of anadromous fish along the North and South Forks of Battle Creek.	6/30/2002	$395,000	Complete.
ERP-98-B16	**Reconnaissance Investigation and Preliminary Design for Steelhead and Winter-run and Spring-run Chinook Passage Facilities** This project represents the planning and preliminary design phase for the improvement of anadromous fish passage on Battle Creek through analysis of five sites for construction of fish screens and ladders.	6/30/2001	$395,000	Complete.
ERP-98-C14	**Monitoring Adult and Juvenile Spring and Winter Chinook Salmon and Steelhead in Battle Creek, California** This project monitored salmon and steelhead in Battle Creek to obtain life history information to be used to assess the current health of the habitat and provide an evaluation tool for restoration activities.	8/31/2002	$150,000	Complete.
ERP-99-B01	**Battle Creek Salmon and Steelhead Restoration Project** This project will restore 42 miles of habitat for anadromous fish and improve water quality for the Coleman National Fish Hatchery in the Battle Creek Watershed by decommissioning several PG&E diversion dams, providing fish ladders and screens for those that remain, and increasing instream flows for fish.	Unknown	$27,200,000	Ongoing
ERP-99-B08	**Improve Upstream Ladder and Barrier Weir at Coleman National Fish Hatchery at Battle Creek** This project will improve the fish ladder at the Coleman National Fish Hatchery barrier weir and modify the barrier weir to repair existing damage to assist management in restoring fish populations on Battle Creek.	12/31/2009	$9,326,820	Ongoing
Mill Creek				
ERP-98-B21	**Anadromous Fish Passage at Clough Dam on Mill Creek** Funded identification of the best alternative for operation of the Red Bluff Diversion Dam that maximizes fish passage for anadromous fish while minimizing adverse impacts to agricultural irrigation supply.	6/30/2003	$1,013,906	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
Butte Creek and Basin				
ERP-01-N16	**Butte Creek/Sanborn Slough Bifurcation Upgrade Project** Funded improvement of fish passage structures in Butte Creek to enhance habitat for spring-run Chinook salmon and is the result of a collaborative effort between water users and resource agencies.	12/31/2003	$1,059,454	Complete.
ERP-01-N53	**White Mallard Dam and Associated Diversions** Funded engineering design, permitting, and bidder's assistance to improve anadromous fish passage in Butte Creek, a tributary to the Sacramento River, while maintaining the viability of agriculture and managed wetlands in the Butte Sink and surrounding area.	4/30/2003	$84,938	Complete.
ERP-01-N54	**Lower Butte Creek Project: Phase III Facilitation/Coordination and Construction of Three Fish Passage Modifications to Sutter Bypass West Side Water Control Structures**. The goal of this project is to increase self-sustaining populations of spring-run and winter-run Chinook salmon, steelhead, and splittail by significantly improving accessibility to the natal holding and spawning areas in Butte Creek through improvement/installation of fish ladders and screens at three locations along the creek.	12/31/2008	$3,047,227	Ongoing.
ERP-02-P07	**Butte Sink Water Control Structure Modifications - Phase III Construction** Goal is to provide passage for adult salmonids by installing fish ladders and overflow gates at the Morton and End weirs and a control weir at the North Weir site to keep adult salmon and steelhead in the main migration path of Butte Creek.	7/31/2008	$5,748,112	Ongoing.
ERP-95-M02	**Durham Mutual Water Company Diversion Dam Fish Screen and Ladder Project** Funded completing construction of a fish screen and ladder on Butte Creek to improve fish passage for spring-run Chinook salmon and other anadromous fish.	12/31/1998	$316,500	Complete.
ERP-96-M01	**Butte Creek Siphon and Associated Improvements Project** Improved fish passage while maintaining water deliveries to Western Canal Water District customers by removing four diversion dams and construction several new facilities along Butte Creek.	12/31/1998	$3,095,873	Complete.
ERP-96-M21	**Adams Dam Fish Screen and Fish Ladder Project** This project provides funds for a feasibility study to examine the potential for construction of a fish screen and ladder at Adams Dam on Butte Creek to improve passage for anadromous fish. The final phase of this project was funded under ERP-97-M04.	12/31/1998	$70,304	Complete.
ERP-96-M22	**Gorrill Dam Fish Screen and Fish Ladder Project** Evaluated the feasibility of a fish ladder and screen on Gorrill Dam on Butte Creek to reduce entrainment and improve passage for anadromous fish.	12/31/1998	$67,990	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-97-M03	**Gorrill Dam Fish Screen and Fish Ladder Project** Funded construction of a fish ladder and fish screen at the Gorrill Dam on Butte Creek to reduce entrainment and improvement passage for anadromous fish.	12/31/1999	$369,641	Complete.
ERP-97-M04	**Adams Dam Fish Screen and Fish Ladder Project** Funded continued work on the construction of a fish ladder and fish screen at Adams Dam on Butte Creek to improve passage of anadromous fish.	6/25/1999	$216,892	Complete.
ERP-99-B02	**Lower Butte Creek Project (Phase II: Preliminary Engineering and Environmental Analysis for Butte Sink Structural Modifications and Flow-Through System)** Funded Phase II of the Lower Butte Creek Project to improve fish passage through the Butte Sink and its associated water control structures by selecting the preferred alternative for design of major structural modifications at structures throughout the Butte Sink.	6/30/2002	$900,000	Complete.
Yuba River				
ERP-96-M17	**Browns Valley Irrigation District Fish Screen Project** The purpose of this project was to reduce entrainment of important anadromous fish species by providing funds for the construction of a fish screen at the Browns Valley Irrigation District's diversion facility on the Yuba River.	12/31/1998	$114,750	Complete.
San Joaquin River				
ERP-01-N56	**Patterson Irrigation District Positive Barrier Fish Screen Study on San Joaquin River Diversion** This project was a feasibility study to design, construct, and complete a positive barrier fish screen on Patterson Irrigation District's San Joaquin River Pumping Plant. The feasibility study reviewed various ways of eliminating the impacts on the San Joaquin River Chinook salmon species.	12/31/2002	$175,000	Complete.
ERP-02-P16	**Patterson Irrigation District Fish Screen Design and Environmental Review** Project to complete the preliminary and final engineering design for a new diversion and pumping enclosure facility adjacent to the existing diversion. The existing diversion will be abandoned in place per regulatory requirements. The primary objective is to provide a positive means of preventing entrainment of migrating at-risk native fish species by the intake facility.	2/12/2007	$639,700	Ongoing.
ERP-97-M07	**Banta-Carbona Irrigation District Fish Screen Project** Project designed and constructed an improved fish screen at the BCID's water diversion facility on the San Joaquin River, in order to reduce associated mortality of out-migrating salmon. Passage effectiveness monitored by DFG.	12/31/2003	$1,168,875	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
Cosumnes River				
ERP-98-B25	**Cosumnes River Salmonid Barrier Program** This project evaluated and implemented construction of structures to improve adult salmonid passage over existing diversion structures in the Cosumnes River. Tasks included evaluation of alternatives, finalizing engineering specifications; bidding and construction.	10/31/2004	$188,255.00	Complete.
Mokelumne River				
ERP-01-N57	**Lower Mokelumne River Restoration Program - Phase 2** This project prepared the design and specifications for a proposed fish screen system along the Lower Mokelumne River.	2/28/2002	$680,000	Complete.
ERP-98-B11	**Lower Mokelumne River Restoration Plan - Phase 1** This project completed the preliminary work necessary to allow the future construction of fish passage improvements and fish screens at Woodbridge Dam on the Lower Mokelumne River.	12/31/2001	$1,920,000	Complete.
Calaveras River				
ERP-01-N59	**Stockton East Water District and Calaveras County Water District Fish Screen Facilities - Calaveras River** This project evaluated diversion structures between Bellota and New Hogan Dam on the Calaveras River.	1/31/2006	$797,920	Complete.
Sonoma Creek				
ERP-00-E04	**Sonoma Creek Watershed Conservancy** This project implemented riparian and aquatic habitat restoration activities and continued watershed stewardship and education programs in the Sonoma Creek watershed.	5/1/2004	$438,923.00	Complete.
ERP-01-N27	**Sonoma Creek Watershed Conservancy** This project expanded the Conservancy's existing efforts to inform and engage the public in watershed issues while providing critical data for adaptive management.	10/30/2005	$545,170.00	Complete.
ERP-98-E02	**Sonoma Creek Watershed Enhancement Plan - Phase II** This project assisted in implementing restoration, monitoring, and educational outreach actions in the Sonoma Creek Watershed aimed at restoring the watershed through collaboration with a combination of public and private organizations.	12/31/2000	$302,000.00	Complete.
Guadalupe River				
ERP-98-B23	**Steelhead and Chinook Salmon Fish Passage Barrier Remediation on the Guadalupe River** This project increased upstream passage of returning steelhead and Chinook salmon adults on the Guadalupe River by constructing fish passage structures past two diversion facilities.	10/31/2000	$178,200.00	Complete.
Suisun Marsh				
ERP-01-C09	**Hill Slough West Habitat Restoration Demonstration Project, Phase II** Completed the environmental documentation and permitting for a multi-phased project to restore tidal action to seasonal and permanent wetlands in the Suisun Marsh.	11/30/2006	$87,000.00	Complete.

Table 1. Water Diversion and Fish Screen Project Summary.

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-95-M07	**Suisun Marsh Fish Screen Project** This project represents Phase 1 (diversion evaluation and selection) of a larger program to construct fish screens on 5 diversions in the Suisun Marsh to reduce downstream migrant salmonid mortality and mortality of delta smelt and splittail.	12/31/1996	$450,000	Complete.
ERP-98-F08	**Hill Slough West Habitat Restoration Demonstration Project** Complete the topographic surveys, hydrological evaluation, conceptual restoration plan, and monitoring plan for a multi-phased project to restore tidal action to seasonal and permanent wetlands in the Suisun Marsh at Hill Slough.	5/30/2002	$200,000	Complete.
Delta				
ERP-97-M06	**Hastings Tract Fish Screen (Phase I: Feasibility Study)** This project was to evaluate diversion and screening alternatives to reduce the entrainment of smelt in the Cache and Lindsay Slough area in the NW Delta.	9/30/2001	$27,000	Complete.
ERP-98-B27	**Hastings Tract Fish Screen (Phase II: Construction)** Project planned and designed fish screens on its gravity intake pipes and relocated the pipes from Cache Slough to Lindsay Slough.	4/1/2004	$38,474	Complete.
Program-wide				
ERP-99-N02	**Fish Treadmill Developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes** The primary ecological/biological objective and benefit of the Fish Treadmill project is to provide the data necessary to develop the "proven technology" for protective positive barrier fish screens for priority native fishes in the Sacramento-San Joaquin watershed.	3/31/2002	$1,069,750	Complete.

Other Programs Contributing to ERP Vision

The CVPIA is a federal statute jointly implemented by the Bureau of Reclamation and USFWS. Within the CVPIA, the following programs provide funding for fish screens and other fish passage projects:

- AFSP;
- AFRP;
- The Habitat Restoration Program;
- The San Joaquin River Riparian Habitat Restoration Program.

The AFRP program funded numerous projects throughout CALFED Regions that addressed fish screens and passage issues (Table 2).

Table 2. CVPIA/AFRP Fish Screen and Water Diversion Projects.

Project Name	Location	CVPIA	Year Completed
Banta Carbona Irrigation District	San Joaquin River	$3,876,750	2004
Browns Valley Irrigation District	Yuba River	$107,037	1999
City of Redding	Sacramento River	$985,400	2006
City of Sacramento Fairbairn Diversion	American-Sacramento River	$3,685,270	2004 2005
Dayly Lee	Steamboat Slough	0	2000
Gorrill Land Company	Butte Creek	$755,948	1999
Lower Butte Creek Weir 3 - Ducks Unlimited	(Butte Creek) Sutter Bypass Lower Reach	$240,000	2003
Maxwell Irrigation District	Sacramento River 17 miles east of Maxwell	$709,214	1997
Parrott-Phelan Irrigation Systems (M&T Ranch)	Sacramento River Rivermile-192.6	$2,200,000	1997
Pelger Mutual Water Company	Sacramento River Rivermile-111.7	$139,188	1996
Princeton-Codora Glenn / Provident	Sacramento River	$5,350,000	1999
Rancho Esquon Partners (Adams Ranch)	Butte Creek	$544,812	1999
Reclamation District 1004	Sacramento River Rivermile-184 near Princeton	$1,058,459	1999
Reclamation District 108 Wilkins Slough	Sacramento River Rivermile-118 near Grimes	$6,101,037	2000
Reclamation District 999	Sacramento River	$318,000	2006
Suisun Resource Conservation District - 5 screen projects	Suisun Marsh	$621,000	1997
Sutter Mutual (Tisdale)	Sacramento River	$10,046,305	2007
Western Canal Water District	Butte Creek	$3,022,540	1998
Wilson Ranch	Sacramento River Rivermile-203 near Hamilton City	$90,000	1996
Antelope and Deer Creek fish passage improvement	Antelope Creek	$159,200	Ongoing
Big Chico Creek One Mile Pool Bypass water quality enhancement project.	Big Chico Creek	$336,000	1997
Coleman National Fish Hatchery water delivery system. Phase II: Construct interim solutions to the unscreened intakes at Coleman NFH.	Battle Creek	$138,000	2001
Replace and upgrade existing adult exclusion weir and riser at Drumheller Slough	Butte Creek	$553,410	2,002
Lower Butte Creek project Sutter Bypass-Willow Slough Weir Fish Passage Preliminary Eng. Investigation	Butte Creek	$310,000	2004
Orwick Fish Screen Improvement Project	Battle Creek	$360,000	2006
Retrofit temporary fish passage facilities at Bellota Weir on the Calaveras River	Calaveras River	$134,972	2006
Improve fish passage on the Cosumnes River	Cosumnes River	$624,952	2006
Const exclusion device to prevent Yuba River salmon from accessing the Goldfields	Yuba River	$261,668	2006
Phase II Final Engineering, Construction Design, and Cost Estimate for Iron Canyon Fish Ladder	Big Chico Creek	$396,724	2007
White Mallard Dam and Associated Diversions - Phase III Construction	Butte Creek	$2,470,213	2007
Denil-type fish ladder installation at the Cone-Kimball Diversion	Deer Creek	$76,340	Ongoing

Within CVPIA, the AFSP program has the specific program objective of protecting juvenile Chinook salmon, steelhead trout, and green and white sturgeon from entrainment at priority diversions throughout the Central Valley and Delta. Section

3406(b)(21) of the CVPIA requires the Secretary of the Interior to assist the State of California in developing and implementing measures to avoid losses of juvenile anadromous fish resulting from unscreened or inadequately screened diversions on the Sacramento and San Joaquin Rivers, their tributaries, the Delta, and Suisun Marsh.

The AFSP guidelines for prioritizing projects include consideration of biological benefits, size and location of the diversion, project cost, and availability of cost-share funding. In addition, current AFSP fish screening project priorities are coordinated with CALFED to support the goals and objectives of CALFED's ERP.

AFSP fish screen projects are consistent with Goal 3 of the CALFED ERP Draft Stage 1 Implementation Plan (CALFED 2001) "to maintain and/or enhance populations of selected species for sustainable commercial and recreational harvest, consistent with the other ERP Strategic Goals". By protecting fish from entrainment, the AFSP enhances anadromous fish out-migrant success, thereby enhancing the commercial and recreational harvest of these species. The AFSP is currently coordinating with CALFED as it develops an ERP Draft Stage 2 Implementation Plan.

A key objective of AFSP,in support of its efforts to enhance anadromous fisheries, is to obtain fish loss monitoring data at unscreened diversions. This information will be used to assess the potential benefits of fish screening and to help prioritize which unscreened diversions should be screened. This effort also supports the Stage 1 Implementation Plan (CALFED 2001, page 61) objective to "conduct studies to improve knowledge of implications of fish screens for fish populations."

In past years, the ERP Program has provided the majority of non-federal cost-share funds for the AFSP fish screen project participants. The CALFED funds contribute to the required 50 percent minimum non-federal cost share for AFSP funded fish screen projects. Pursuant to Section 3406(b) (21) of CVPIA, the AFSP can only provide up to 50% of the cost share of a fish screen project.

AFSP Status

Since 1994, the AFSP has assisted irrigation districts and water companies with fish screening projects at 23 diversions ranging from 17 cfs to 960 cfs. The AFSP has provided technical advice and cost-sharing funds for fish screen projects that have resulted in cumulatively screening over 4,200 cfs diverted from the Sacramento-San Joaquin watersheds.

The AFSP provides assistance to diverters through two primary means. First, the AFSP, comprised of experts from federal and State agencies, provides fish screen design review and technical guidance to the diverter and their consultants throughout a project. The AFSP may also provide funding support to diverters to install fish screens on their diversions.

The AFSP has provided significant funding and technical resources that are essential in implementing fish screen projects. Lack of adequate funding is often an impediment to diverters when constructing a fish screen for their unscreened diversion(s). Fish screen projects are typically complex projects that are constructed in phases over several years. The key project phases are a feasibility study, preliminary design, final design, and construction. There are also significant permitting and environmental compliance requirements that must be met. Upon completion of a project, the diverter becomes the sole owner of the new facility and is thereafter responsible for the operation and maintenance of the fish screen.

The AFSP is currently providing technical assistance (design, environmental, and permitting) for several large fish screen projects which have not yet secured funding for construction phase from federal and non-federal funding sources. These fish screen projects include Natomas Mutual (American Basin), Meridian Farms, Pleasant Grove-Verona, Patterson Irrigation, and RD 2035.

A 300 cfs fish screen and combined pumping plant funded by AFSP and CALFED ERP is currently being constructed at RD 108 and is expected to be operational in spring 2008.

Status of Topic Today

During Stage 1, the Strategic Plan (2000) directed the ERP to continue high priority actions that would reduce direct mortality to fishes including aggressively screening existing unscreened or poorly screened diversions in the Delta, on the Sacramento and San Joaquin Rivers, and their tributary streams. Projects were to be selected by following a systematic priority-based approach. In response, nearly $91 million was spent on ERP projects that researched, planned, built, or monitored fish screens throughout the Central Valley and San Francisco Bay.

The goal of screening all water diversions greater than 250 cfs in the Sacramento River Basin has been met, with the exception of the diversions at Reclamation District 2035 and Natomas Mutual Water District (none of the individual diversions exceed 250 cfs but cumulatively they add up to 630 cfs). However, the goal of screening 25% of the 903 small diversions, those with diversion rates of less than 250 cfs, in the Sacramento River Basin has fallen short of program expectations. Roughly, only 10% of these diversions have been screened to date.

Within the Suisun Marsh, screening needs and benefits must still be assessed relative to the Stage 1 Goal of screening 25% of the unscreened diversions. The ERP will work with the Interagency Fish Screen Evaluation Program and the CVPIA/AFSP to do this assessment and lay the framework for actions necessary under Stage 2 of the ERP.

Planned Projects for Implementation

There are no projects currently planned for ERP implementation funding.

Impediments to Implementation

In 2007, ERP held two one-day workshops on Central Valley fish screens to request input from State and Federal agencies and stakeholders on "lessons learned" during Stage 1. The workshops yielded several conclusions including:

- There was no systematic assessment of the magnitude of juvenile fish loss at unscreened diversions;
- No studies were performed to determine if there was a need to screen all or any proportion of small diversions (less than 100 cfs);
- The effectiveness of timing water diversions to reduce impacts upon juvenile anadromous fish was not evaluated. It is highly unlikely that a willing diverter would participate in such an evaluation;
- The relative ecosystem benefit of fish screens in conserving and restoring Central Valley fish species, compared to other habitat restoration actions, has not been evaluated;
- Although it is assumed that, based on the total amount of streamflow diverted, large diversions cause a higher number of fish mortalities than small diversions; this assumption is based on limited data. Consequently, we do not know for certain whether one large diversion poses a greater risk to fish than multiple small diversions where the same total volume of water is diverted;
- The process of project development and permitting for screen installations is time consuming and costly. Streamlining the permit process would reduce project costs, and any savings could be applied to screening additional sites;
- The costs of screen projects have increased significantly due to increases in the costs of construction materials such as steel and concrete, in addition to higher labor costs. Projects involving consolidation of diversions have proven especially susceptible to cost increases due to significant infrastructure upgrades (e.g., roadways, canals, etc.) associated with these projects. A new Reclamation Board levee encroachment permit requirement requires that existing substandard through-levee pipe crossings be upgraded or replaced as a component of any project (including modifying or adding a fish screen). These upgrade costs are expected to be incorporated into the overall project budget and could result in fewer fish screen projects being funded by ERP or AFSP;
- No pre-project monitoring was performed during Stage 1 for fish screen projects. Future projects should have pre-project monitoring, preferably for two seasons prior to construction, as well as post-project monitoring so that effectiveness can be quantitatively assessed.

- Escalating costs for construction materials is not being met with current or projected funding. Rather, funding has been reduced while project costs have increased steeply. Without commitments to meet projected future funding needs, relatively few of the over 3000 remaining unscreened diversions can be screened over the next 20 years;
- An acceptable alternative to strict screening criteria should be developed to allow variances to required permits when impacts to the environment or risk to species at a specific site are determined to be negligible.

The ERP will continue to work with the Interagency Fish Screen Evaluation Program and the CVPIA/ AFSP to address the above issues and develop further recommendations to be included in the Stage 2 Program Plan.

References

CALFED Bay-Delta Program. 2000a. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2000b. Ecosystem Restoration Program Plan - Strategic Plan for Ecosystem Restoration. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2001. Ecosystem Restoration Program - Draft Stage 1 Implementation Plan. Sacramento, CA

5. STRESSORS

5.2. Dams and Other Structures

Introduction

Dams and other structures are found throughout all of the ERP ecological management zones. Large water storage and flood control dams are present on the larger rivers and streams, as well as on many smaller streams. Dams, water storage and diversion structures impair ecological processes such as Central Valley streamflow, natural sediment supply, stream meander, natural floodplain and flood processes, and Central Valley stream temperatures. These structures also impair a variety of habitats needed to support fish, wildlife, and plant communities.

Dams and other human-made structures act as stressors on ecosystem processes, important habitats, and species in aquatic ecosystems. For example, dams and their associated reservoirs block fish migration, alter water quality, remove fish and wildlife habitat, and alter hydrological and sediment processes. Dams in any form block or hinder upstream and downstream migrations of anadromous fish and hinder downstream transport of sediment. Larger dams completely block anadromous fish migration. These large dams resulted in the loss, and in some cases extinction, of local salmon and steelhead populations (Mills et al. 1996).

Many moderately sized diversion dams, such as Red Bluff Diversion Dam (RBDD) and Anderson-Cottonwood Irrigation District (ACID) Diversion Dam, contain fish ladders to allow fish passage. Some dams, such as Capay Dam on Cache Creek and Solano Dam on Putah Creek, do not.

Small diversion dams are generally constructed to seasonally divert water for irrigation. Although many have been fitted with ladders to allow fish passage, these ladders are often technologically outdated and only marginally effective. In many cases, salmon and steelhead can negotiate the fish ladders, but other species, such as American shad, green sturgeon, white sturgeon, and lampreys cannot. In some cases, fish ladders delay adult salmon and steelhead reaching upstream spawning grounds or delay downstream migration of juvenile salmon and steelhead.

In high-flow years, water flows from the river are diverted through weirs into the bypasses and returned back into the river or Delta miles downstream. In such cases, adult salmon and steelhead may migrate upstream through the bypasses and become blocked below the weirs opposite the river. A similar situation occurs in the Sacramento Ship Channel. Blockage and delay of steelhead and winter-run Chinook salmon are of particular concern because the fish usually migrate upstream during the winter and spring high-flow periods.

In wetter years, larger irrigation returns have relatively high flows that may attract anadromous fish. Fish attracted to these returns can become lost or delayed. The Colusa Basin Drain, which enters the Sacramento River near Knights Landing, is an example of an irrigation return that is known to attract adult salmon.

Applicable ERP Vision

The vision for dams and other structures is to reduce their adverse effects by improving fish passage and enhancing downstream fish habitat.

Two Strategic Objectives relate to the effects of dams and other structures. One is to establish hydrologic regimes in regulated streams, including sufficient flow timing, magnitude, duration, and high flow frequency, to maintain channel and sediment conditions supporting the recovery and restoration of native aquatic and riparian species and biotic communities. The other is to restore coarse sediment supplies to sediment-starved rivers downstream of reservoirs to support help restore and maintain functional natural riverine, riparian, and floodplain habitats.

Stage 1 Expectations

The Stage 1 expectation for dams and other structures was to conduct studies on 5-10 regulated rivers to determine the effects of high flow releases. Natural floodplains were to be identified that could be inundated with minimal disruption of human activity. All existing non-urbanized floodplains were to have been identified and a priority list for floodplain restoration projects developed. Strategies for the restoration of natural channel and floodplain dynamics were to have been implemented in at least two large demonstration projects. Surveys to determine the status of native fishes in all regulated streams were to have been completed and flow recommendations developed. Sediment-starved channels in the Bay-Delta system were to have been identified and strategies to mitigate sediment starvation developed.

Changes Attributable to ERP

Throughout the ERP regions, there were many projects implemented that directly or indirectly addressed some of the problems caused by dams and other structures (Table 1). The projects discussed below are examples of projects that were identified as high priority mainly because they limited access to critical habitat for listed species. Additional projects associated with dams and other structures are described in chapters on Water Diversions or specific EMZs in this report.

Several high priority projects were implemented on Butte Creek in the Butte Basin Ecological Management Zone (EMZ), the project *Lower Butte Creek Project: Phase II: Preliminary Engineering and Environmental Analysis for Butte Sink Structural Modifications and Flow-Through System* (**ERP-99-B02**) improved fish passage through the Butte Sink and its associated water control structures for the benefit of anadromous fish populations, particularly spring-run Chinook salmon and steelhead. The objectives of this project were to develop a set of mutually beneficial structural modifications and operational alternatives for fisheries and water users while maintaining the viability of commercial agriculture, managed wetlands, and associated waterways. Tasks completed under Phase II were 1) completion of preliminary designs of major structural modifications at up to four sites in the Butte Sink; 2) environmental review at proposed construction sites; 3) completion of final engineering design for the upgrade to flow-through flood-up system for the Butte Sink; 4) scoping of fisheries issues for Butte Sink flow-through and structural modification upgrades; and 5) facilitation of a cooperative operations agreement of the flow-through system with Butte Sink Clubs.

The *Lower Butte Creek Project: Phase III Facilitation/Coordination and Construction of Three Fish Passage Modifications to Sutter Bypass West Side Water Control Structures* (**ERP-01-N54**) project will provide funds for the next phase of the Lower Butte Creek Project, a cooperative effort to recover and reverse the downward population trends of spring-run and winter-run Chinook salmon, steelhead, and splittail in the Sacramento River Basin. This project includes the modification of fish ladders and fish screens that will increase critical fish passage to essential spawning and rearing habitat, and decrease mortality of juvenile outmigrants. These proposed structures will modify three major water control structures within the Sutter Bypass reach of lower Butte Creek (Weir #3, Weir #5, and the East-West Diversion Weir). The objective of the project is to increase self-sustaining fish populations by significantly improving accessibility to the natal holding and spawning areas in Butte Creek. The project aims to eliminate barriers that delay, injure and increase mortality of migrating adults, and increase entrainment of juvenile outmigrants. Construction will be spread over a two year period. In addition to the above Lower Butte Creek projects, the *Butte Creek/Sanborn Slough Bifurcation Upgrade Project* (**ERP-01-N16**) provided funds for improvement of fish passage structures in Butte Creek to enhance habitat for spring-run Chinook salmon and is the result of a collaborative effort between water users and resource agencies. *White Mallard Dam and Associated Diversions* (**ERP-01-N53**) funded engineering design, permitting, and bidder's assistance to improve anadromous fish passage in Butte Creek; while maintaining the viability of agriculture and managed wetlands in the Butte Sink and surrounding area.

In the East San Joaquin EMZ, two projects were funded dealing with gravel augmentation. *Knights Ferry Gravel Replenishment, Phase I* (**ERP-97-N21**) evaluated the effects of creating new spawning habitat and increasing juvenile salmonid survival rates in the lower Stanislaus River by augmenting gravel of different sizes, from various sources, at 18 project sites between Two-Mile Bar and Oakdale. Spawning use, habitat

quality and gravel mobility were evaluated during pre-project conditions in 1998, and post-project monitoring in 1999 and 2000. Spawning salmonids preferred locations composed of (1) native gravel, (2) cleaned and sorted from ¼ inch to 5 inch in size, and (3) habitat that provided nearby refuge consisting of pools at least 4-feet deep with overhanging vegetation, surface turbulence, or instream large woody debris. Juvenile salmonids, particularly *O. mykiss*, also showed a preference for the restoration sites based on snorkeling surveys by the Fisheries Foundation. After construction, survival of juvenile Chinook salmon per redd has been at least 30% higher than before the creation of the gravel beds, based on screw trap data collected at Oakdale by S.P. Cramer and Associates. The AFRP funded Phase II monitoring for this project, conducted in fall 2004 and 2005 by KDH Environmental Services.

In another ERP-funded project, *Spawning Gravel Introduction, Tuolumne River, La Grange* (**ERP-97-C11**), 11,000 tons of gravel was added immediately below the Old La Grange Bridge in the lower Tuolumne River to increase and improve spawning habitat for Chinook salmon. The gravel augmentation site was approximately 250 feet long, 150 feet wide, and had a pre-project average depth of 4 feet. The Department of Water Resources implemented a monitoring plan to establish the baseline conditions and post construction results using topographic bed mapping, collecting bulk samples of substrate, conducting pebble counts, and placing tracer rocks in the channel.

In the Sacramento River EMZ, several projects were funded by ERP that contributed to improved fish passage. One gravel augmentation project, the *Sacramento River Spawning Gravel Restoration Project (below Keswick Dam)* (**ERP-95-M04**), restored several miles of critical winter-run Chinook salmon spawning habitat below the Keswick Dam on the Sacramento River by introducing spawning-sized gravel that was naturally redistributed by stream flow.

Four projects were funded by ERP to upgrade the fish passage facilities at the Anderson-Cottonwood Irrigation District's (ACID) main diversion dam near Redding. The *Fish Passage Improvement Project under Bay Delta Project - Category III* (**ERP-98-B03**) was the initial planning phase. Final design, environmental documentation, and permitting for the new structures were completed under the *Fish Passage and Fish Screening Improvement Project, Phase II* (**ERP-98-B24**). Phase III included construction, construction management, mitigation and monitoring tasks that were funded by two ERP grants *ACID Fish Passage Improvement Project, Phase III* (**ERP-99-N01**), which awarded 50% of the construction costs, and *Anderson-Cottonwood Irrigation District Fish Passage and Fish Screen Improvement Project* (**ERP-99-B03**).

The *Fish Passage Improvement Project at the Red Bluff Diversion Dam* (**ERP-98-B22**), provided funds to identify the best alternative for operation of the Red Bluff Diversion Dam to maximize anadromous fish passage while minimizing adverse impacts to agricultural irrigation supply. Phase II was funded by *Fish Passage Improvement at the Red Bluff Diversion Dam, Phase II* (**ERP-99-B07**), and *Fish Passage Improvement at*

the Red Bluff Diversion Dam: Balance of Phase II Funding (**ERP-01-N58**). These projects helped reduce and minimize the impacts of the Sacramento River's Red Bluff Diversion Dam on upstream and downstream migration of juvenile and adult anadromous fish, while improving agricultural water supply.

In the North Sacramento Valley EMZ, several planning projects for Battle Creek were funded. *Engineering Investigation of Anadromous Fish Passage in Upper Battle Creek Project* (**ERP-97-M02**) consisted of the planning and design phase for construction of fish ladders and fish screens to improve passage of anadromous fish along the North and South Forks of Battle Creek. This investigation collected needed field data, followed by preliminary design work for fish ladders and fish screens at three sites. The project also included reconnaissance investigation at two other sites, draft CEQA work for all five sites, and pre-reconnaissance work for some alternative fish screen sites. The *Reconnaissance Investigation and Preliminary Design for Steelhead and Winter-run and Spring-run Chinook Passage Facilities* project (**ERP-98-B16**) was a planning and design investigation of fish ladders and screens for improving fish passage on Battle Creek. The goal of the project was to develop preliminary designs and environmental work so that final design and construction can move ahead in the phased restoration program. A substantial amount of money was set aside with the *Battle Creek Salmon and Steelhead Restoration Project* (**ERP-99-B01**), which will restore 42 miles of habitat for anadromous fish and improve water quality for the Coleman National Fish Hatchery in the Battle Creek Watershed by decommissioning several PG&E diversion dams. It will provide fish ladders and screens for the dams that remain, and increase instream flows for fish. This continues to be a phased project. The *Improve Upstream Ladder and Barrier Weir at Coleman National Fish Hatchery at Battle Creek* project (**ERP-99-B08**) has and will continue to improve the fish ladder at the Coleman National Fish Hatchery and modify the barrier weir to repair existing damage. These repairs will assist hatchery management in restoring fish populations on Battle Creek. This project is an interagency agreement between the US Bureau of Reclamation (USBR) and the US Fish and Wildlife Service (USFWS), where USFWS contracted with USBR to conduct the construction work. The project is under construction and slated to be completed in February 2009.

In the Feather River/Sutter Basin EMZ, USFWS coordinated and facilitated meetings designed to gain agreement on the initial components of a study plan to evaluate the feasibility of restoring anadromous fish runs above Engelbright Dam on the Yuba River through the project titled *Conduct/Facilitate Meetings on the Upper Yuba River, Englebright Dam* (**ERP-98-C19**). Further planning efforts were funded with *Yuba Feather Work Group* (**ERP-01-N62**) to support a community-based stakeholder approach to providing input into Yuba County Water Agency's Proposition 13 Yuba Feather Flood Control Study on various non new-dam watershed management techniques to enhance flood protection while maintaining or improving natural processes, habitats and populations of high priority at risk species, including Chinook salmon and steelhead.

USGS investigated water quality, sediment transport and yield in the Yuba River watershed through the project *Technical and Scientific Services for the Upper Yuba River Studies Program* (**ERP-01-C08-D**). This project collected field data and analyzed historical data and information. The overall objective was to improve understanding of sediment supply, transport, and sediment storage in the Yuba River watershed, and to improve understanding of the current level of mercury contamination in Engelbright Lake sediments and biota. Transport of the existing sediment in the reservoir to the downstream reaches was assessed following several potential management scenarios. Nine months of continuous river discharge and temperature measurements at four gauging stations were collected from the watershed during Oct. 2001 to June 2002. The input and output of mercury and methyl mercury at Engelbright Dam will be determined. The overall objective of the Upper Yuba River Studies Program (UYRSP) was to determine whether it is biologically, environmentally, and socio-economically feasible over the long term to introduce wild Chinook salmon and steelhead trout to the Yuba River above Engelbright Dam. This was also the objective of a related project, *Upper Yuba River Studies Program: Engineering, Environmental Services, Project Management and Facilitation* (**ERP-02-C02-D**).

In the Eastside Delta Tributaries EMZ, the *Cosumnes River Salmonid Barrier Program* (**ERP-98-B25**) evaluated and implemented construction of structures to improve adult salmonid passage over existing diversion structures in the Cosumnes River. Tasks include evaluation of alternatives, finalizing engineering specifications, bidding and construction.

The Lower Mokelumne River Restoration Plan - Phase 1 (**ERP-98-B11**), and *Lower Mokelumne River Restoration Program - Phase 2* (**ERP-01-N57**) benefited fish passage at Woodbridge Dam thus improving the survival of migrating salmon and steelhead, removing the barriers to the fish passage, and improving the instream aquatic habitat. Phase 1 completed the preliminary work necessary to allow the future construction of fish passage improvements and fish screens at Woodbridge Dam on the Lower Mokelumne River. Phase 2 prepared designs and a specification for a low stage fish screen at Woodbridge Dam and a fish screen at the canal diversion point; and contemplates replacement of the existing fish screen on the Woodbridge Irrigation District's canal.

The project *Expanding California Salmon Habitat through Non-Governmental and Non-Regulatory Mechanisms to Alter Dams and Diversions* (**ERP-98-N02**) inventoried dams and diversions in the Central Valley and developed a mechanism to purchase dams and diversions from willing sellers to improve fish passage. This project also assessed opportunities to improve fish habitat as a result of reoperation of small hydroelectric facilities in California. Tasks included inventorying potential candidate facilities, developing a template for the evaluation of costs and potential, identifying cooperative strategies, and conducting community workshops.

Project Summary Table

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
CVPIA-01-F12	**Lower Calaveras River Chinook Salmon and Steelhead Life History Limiting Factors Analysis** Refined the understanding of how water management, in conjunction with other factors, limits the ability of Chinook salmon and steelhead to establish self-sustaining populations in the Calaveras River.	6/30/2006	$500,797	Complete.
CVPIA-01-F13	**Fish Treadmill-Developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes** A multi-agency, targeted research program that addresses the uncertain impacts of water diversions and fish screens on priority fish species (e.g., delta smelt, splittail, Chinook salmon, steelhead). The objective is to provide the data necessary to evaluate and improve aspects of fish protective facility design and operation at the State Water Project), Central Valley Project (CW, including the Tracy Fish Test Facility, TFTF), and other existing and proposed fish screen facilities (e.g., Hood-Mokelumne Connection).	N/A	$2,271,463	Ongoing.
ERP-00-E04	**Sonoma Creek Watershed Conservancy** Implemented riparian and aquatic habitat restoration activities and continued watershed stewardship and education programs in the Sonoma Creek watershed.	3/1/2004	$438,923	Complete. Funded 800 ft. of riparian restoration by revegetating stream banks at 3 different sites on Carriger Creek.
ERP-01-C08-D	**Technical and Scientific Services for the Upper Yuba River Studies Program** USGS investigated water quality and sediment transport and yield in the Yuba River watershed. The overall objective was to improve understanding of sediment supply, transport, and storage of sediment in the Yuba River watershed, and to improve understanding of the current level of mercury contamination of Engelbright Lake sediments and biota. An assessment of the transport of the existing sediment in the reservoir to the downstream reaches was performed following several potential management scenarios.	6/14/2005	$534,000	Complete.
ERP-01-C15	**Technical/Scientific Review of Upper Yuba River Studies Program: Hydropower Expert** Contractor was to provide technical expertise to the CALFED Bay-Delta Program Upper Yuba Rivers Studies Program. As a member of the Technical Review Panel, the Contractor reviewed materials, attended workshops, participated in discussions, responded to inquiries and presented findings and advice. A three-day workshop was held during September 2001 to discuss the technical details of the proposed work on the UYRSP.	6/30/2006	$26,000	Complete.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-N03	**Tuolumne River Restoration: Special Run Pool 10** Improved salmon spawning and rearing habitats and reduced predator habitat (bass) by filling the in-channel mining pits; preventing future connections between the River and the off-channel mining pit and restoring native riparian habitats.	6/30/2006	$652,030	Complete.
ERP-01-N16	**Butte Creek/Sanborn Slough Bifurcation Upgrade Project** Provided funds for improvement of fish passage structures in Butte Creek to enhance habitat for spring-run Chinook salmon and was the result of a collaborative effort between water users and resource agencies.	12/31/2003	$1,059,454	Complete.
ERP-01-N27	**Sonoma Creek Watershed Conservancy** Expanded on the Conservancy's existing efforts to inform and engage the public in watershed issues while providing critical data for adaptive management.	10/30/2005	$545,170	Complete.
ERP-01-N51	**Water Intake Fish Screen Replacement Project** Reduced entrainment of all runs of Chinook salmon, steelhead trout, Sacramento splittail, and green sturgeon in the lower American and Sacramento Rivers by improving fish screens at two water treatment facilities.	5/28/2004	$6,142,142	Complete.
ERP-01-N53	**White Mallard Dam and Associated Diversions** Provided funds for engineering design, permitting, and bidder's assistance to improve anadromous fish passage in Butte Creek, a tributary to the Sacramento River, while maintaining the viability of agriculture and managed wetlands in the Butte Sink and surrounding area.	4/30/2003	$84,938	Complete.
ERP-01-N54	**Lower Butte Creek Project: Phase III Facilitation/Coordination and Construction of Three Fish Passage Modifications to Sutter Bypass West Side Water Control Structures** The goal of this project is to increase self-sustaining populations of spring-run and winter-run Chinook salmon, steelhead, and splittail by significantly improving accessibility to the natal holding and spawning areas in Butte Creek through improvement/installation of fish ladders and screens at three locations along the creek.	12/31/2008	$3,047,227	Ongoing.
ERP-01-N55	**RD 2035 Fish Screen and Environmental Design Review** This project provided engineering design services for a 400-cfs landslide pump station and screened intake facility.	12/31/2003	$1,384,000	Complete.
ERP-01-N57	**Lower Mokelumne River Restoration Program - Phase 2** This project prepared designs and specifications for a proposed fish screen system along the Lower Mokelumne River.	2/28/2002	$680,000	Complete.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-N58	**Fish Passage Improvement at the Red Bluff Diversion Dam: Balance of Phase II Funding** This project helped reduce and minimize the impacts of the Sacramento River's Red Bluff Diversion Dam on upstream and downstream migration of juvenile and adult anadromous fish, while improving agricultural water supply.	9/30/2004	$734,000	Complete.
ERP-01-N59	**Stockton East Water District and Calaveras County Water District Fish Screen Facilities - Calaveras River** This project evaluated diversion structures between Bellota and New Hogan Dam on the Calaveras River.	1/31/2006	$797,920	Complete.
ERP-01-N60	**American Basin Habitat Improvement Project** This project will support the American Basin Fish Screen and Habitat Improvement Project which will improve fish passage, reduce entrainment, and improve aquatic, riverine, and riparian habitats along the Sacramento River.	12/31/2006	$1,450,000	Ongoing.
ERP-01-N62	**Yuba Feather Work Group** This project provided funds to support a community-based stakeholder approach to providing input into Yuba County Water Agency's Proposition 13 Yuba Feather Flood Control Study on various non new-dam watershed management techniques to enhance flood protection while maintaining or improving natural process, habitat and populations of high priority at risk species, including Chinooks salmon and steelhead.	8/31/2006	$297,632	Complete.
ERP-02-C02-D	**Upper Yuba River Studies Program: Engineering, Environmental Services, Project Management and Facilitation** The objective was to determine if the introduction of wild Chinook salmon and steelhead trout to the upper Yuba River watershed is feasible in the long term. CH2M Hill performed services defined by CALFED in writing, under individual task orders.	6/30/2006	$4,422,038	Complete.
ERP-02D-P55	**Physical Modeling Experiments to Guide River Restoration Projects** Supported construction of a flume at the UC Richmond's Field Station. This flume is used in experiments regarding the potential effects of river restoration projects, especially spawning gravel augmentation projects, dam removals, and channel reconstruction projects. Data from these experiments can be used to test river restoration designs and evaluate their potential effects.	9/30/2007	$2,498,453	Complete.
ERP-02-P08-D	**M & T/Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project** Protects the existing M&T/Llano Seco fish-screen facility and its beneficiaries while investigating and identifying a technically and economically feasible long-term solution to adapt the fish-friendly pumping facility to the lateral migration of the Sacramento River.	6/30/2008	$4,390,087	Ongoing.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P09-D	**American Basin Fish Screen and Habitat Improvement Project** This project is the removal of a diversion dam, consolidation of diversions and the addition of state-of-the-art fish screens to NMWC's diversion on the Sacramento River, between Verona and the American River, and on the Cross Canal.	12/31/2009	$12,600,000	Ongoing.
ERP-02-P10-D	**Reclamation District No. 108 Consolidated Pumping Facility and Fish Screen** This project involved environmental compliance, permitting, and final design for screening three of RD108's Sacramento River diversions.	8/30/2006	$690,000	Complete.
ERP-02-P12-D	**Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach (Merced River Ranch)** Designed pilot floodplain and channel restoration experiments, in their watershed context, intended to initiate the restoration of natural ecosystem function to the Dredger Tailing Reach of the Merced River and to set in place monitoring and evaluation schemes designed to contribute transferable scientific understanding that assists in reducing uncertainty in restoration design.	3/21/2007	$2,497,877	Complete.
ERP-03-C04	**Technical/Scientific Review of Upper Yuba River Studies Program: Geomorphology and Hydrology Expert** Dr. Gordon Grant of the USFS provided technical expertise to the CALFED Bay-Delta Program's Upper Yuba Rivers Studies Program.	6/30/2006	$18,000	Complete.
ERP-03-M10	**Outreach and Technical Services to Support Landowner and Watershed Resident's Participation in the Battle Creek Salmon and Steelhead Restoration Project** Provided technical resources required providing a sound scientific basis for the Conservancy's expression of local concerns to the agencies and its outreach activities related to the Battle Creek Salmon and Steelhead Restoration Project.	7/1/2008	$300,000	Complete.
ERP-04D-S09	**Estimating the Abundance of Sacramento River Juvenile Winter Chinook Salmon with Comparisons to Adult Escapement** Will obtain juvenile winter-run Chinook production indices and correlate these indices with estimated escapement from adult counts at the Red Bluff Diversion Dam and the winter-run carcass survey.	6/30/2009	$2,067,266	Ongoing.
ERP-06D-S14	**RD 108 Combined Pumping Plant/Fish Screen Project (Phase IV-Construction)** At the request of the federal and State resources agencies, the District is proposing to consolidate and screen three of its seven Sacramento River diversions to reduce the incidental take of protected fish species. The resource agencies identified these diversions as a potential threat to entrainment and mortality of fall, spring, and winter-run Chinook salmon, and splittail.	6/30/2009	$14,247,500	Ongoing.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-95-M02	**Durham Mutual Water Company Diversion Dam Fish Screen and Ladder Project** Provided funding to complete construction of a fish screen and ladder on Butte Creek to improve fish passage for spring-run Chinook salmon and other anadromous fish.	12/31/1998	$316,500	Complete.
ERP-95-M04	**Sacramento River Spawning Gravel Restoration Project (below Keswick Dam)** Restored several miles below the Keswick Dam on the Sacramento River by introducing spawning-sized gravel for natural redistribution and use by salmon as spawning habitat.	11/1/1995	$39,400	Complete.
ERP-95-M05	**M&T/Parrott Pumping Station and Fish Screen Project** Relocation of M&T Ranches' Parrot-Phelan Pumping Station and implementation of fish screens on diversion structures to reduce fish entrainment on Big Chico Creek.	12/31/1997	$1,610,000	Complete.
ERP-95-M07	**Suisun Marsh Fish Screen Project** Phase 1 (diversion evaluation and selection) of a larger program to construct fish screens on 5 diversions in the Suisun Marsh to reduce downstream migrant salmonid mortality and mortality of delta smelt and splittail.	11/31/1996	$450,000	Complete.
ERP-96-M01	**Butte Creek Siphon and Associated Improvements** Improved fish passage while maintaining water deliveries to Western Canal Water District customers by removing four diversion dams and constructing several new facilities along Butte Creek.	12/31/1998	$3,095,873	Complete.
ERP-96-M04	**Princeton Pumping Plant Fish Barriers Feasibility Study** Provided funds to design and construct a fish screen at Reclamation District 1004's Princeton Pumping Plan to prevent the entrainment of winter-run Chinook salmon on the Sacramento River.	12/31/1997	$75,000	Complete.
ERP-96-M12	**Battle Creek Chinook Salmon and Steelhead Restoration Plan** This project collected data to create a watershed plan as part of the overall watershed strategy used for implementing the Battle Creek Salmon and Steelhead Restoration Project.	10/1/1999	$306,000	Complete.
ERP-96-M13	**Yolo Bypass Fish Habitat** Examined the relationship between the Yolo Bypass and the rest of the Estuary and developed recommendations for restoration actions that would improve Bypass habitat for fisheries and other aquatic organisms.	11/3/2000	$226,000	Complete. Research and planning for <59,000 acres of agricultural land.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-96-M17	**Browns Valley Irrigation District Fish Screen Project** Reduced entrainment of important anadromous fish species by providing funds for the construction of a fish screen at the Browns Valley Irrigation District's diversion facility on the Yuba River.	12/31/1999	$114,750	Complete.
ERP-96-M19	**Feasibility Study for Intake Screen at Wilkins Slough Diversion** Phase II (feasibility study) of a five-phase project to design and construct a state-of-the-art fish screen at Reclamation District 108's Wilkins Sough diversion facility on the Yuba River to reduce entrainment of anadromous fish.	6/30/1997	$100,000	Complete.
ERP-96-M21	**Adams Dam Fish Screen and Fish Ladder Project** Provided funds for preliminary design work for constructing a fish screen, and a ladder feasibility study at Adams Dam. The project was completed and the final phase of this project was funded under ERP-97-M04.	12/31/1998	$70,304	Complete.
ERP-96-M22	**Gorrill Dam Fish Screen and Fish Ladder Project** Studied feasibility of a fish ladder and screen on Gorrill Dam on Butte Creek to reduce entrainment and improve passage for anadromous fish.	12/31/1998	$67,990	Complete.
ERP-96-M23	**Fish Screen Biological Performance Test** Demonstrated the feasibility of the application of an innovative fish screen design to smaller (< 50 cfs) unscreened diversions in the Central Valley of California.	6/30/1998	$90,000	Complete.
ERP-96-M25	**Battle Creek Watershed Management Strategy** Provided funds to form a watershed conservancy and create a "community plan" for the Battle Creek watershed that supplemented the existing "technical plan" and provided a two-tiered document for restoration activities in the watershed based on collaboration between stakeholders.	10/15/1999	$100,000	Complete.
ERP-97-C01	**Positive Barrier Fish Screen Project, Wilkins Slough Pumping Plant** Provided funding for the construction of a positive fish barrier intake screen at Reclamation District 108's diversion structure at Wilkins Slough for the protection of Chinook, splittail, and other fish species.	12/31/1999	$2,500,000	Complete.
ERP-97-C11	**Spawning Gravel Introduction, Tuolumne River, La Grange** The project added 11,000 tons of gravel between the Old La Grange Bridge and Basso Bridge in the lower Tuolumne River in 1999 to increase and improve Chinook salmon spawning habitat.	12/31/2001	$250,975	Complete.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-97-E01	**Big Chico Creek Watershed: Phase I** Provided funds for the Big Chico Creek Watershed Alliance to document the watershed's existing conditions and create a Watershed Management Strategy.	12/31/1999	$422,830	Complete.
ERP-97-M02	**Engineering Investigation of Anadromous Fish Passage in Upper Battle Creek Project** Consisted of the preliminary design phase for construction of fish screens and ladders to improve passage of anadromous fish along the North and South Forks of Battle Creek.	6/30/2002	$395,000	Complete.
ERP-97-M03	**Gorrill Dam Fish Screen and Fish Ladder Project** Provided funds to construct a fish ladder and fish screen at the Gorrill Dam on Butte Creek to reduce entrainment and improvement passage for anadromous fish.	12/31/1999	$369,641	Complete.
ERP-97-M04	**Adams Dam Fish Screen and Fish Ladder Project** Funded continued work on the construction of a fish ladder and fish screen at Adams Dam on Butte Creek to improve passage of anadromous fish.	6/25/1999	$216,892	Complete.
ERP-97-N19	**Tolay Creek Restoration Project** Restored and enhanced 435 acres of saline emergent wetlands in the Tolay Creek floodplain for the benefit of threatened and endangered species.	9/17/2001	$283,000	Complete.
ERP-97-N21	**Knights Ferry Gravel Replenishment** Evaluated the effects of adding different sizes and sources of gravel on the utilization of spawning habitat by fall-run Chinook salmon and the quality of incubation habitat at 18 project sites in the lower Stanislaus River.	3/15/2002	$561,407	Complete.
ERP-98-B02	**Boeger Family Farms Fish Screen Feasibility Study** This project conducted the required initial studies for screening of the Boeger Family Farm pumping plant on the Sacramento River near Colusa for the benefit of reducing entrainment of anadromous fish.	4/30/1999	$13,811	Complete.
ERP-98-B03	**Fish Passage Improvement Project under Bay Delta Project - Category III** Consisted of the planning phase for construction of fish passage improvement structures at the Anderson-Cottonwood Irrigation District main diversion dam for the benefit of anadromous fish.	3/31/1999	$325,000	Complete.
ERP-98-B11	**Lower Mokelumne River Restoration Plan - Phase 1** Completed the preliminary work necessary to allow the future construction of fish passage improvements and fish screens at Woodbridge Dam on the Lower Mokelumne River.	2/5/2002	$1,920,000	Complete.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-B16	**Reconnaissance Investigation and Preliminary Design for Steelhead and Winter-run and Spring-run Chinook Passage Facilities** Represented the planning and preliminary design phase for the improvement of anadromous fish passage on Battle Creek through analysis of five sites for construction of fish screens and ladders.	6/30/2001	$395,000	Complete.
ERP-98-B21	**Anadromous Fish Passage at Clough Dam on Mill Creek** This project was for the final design and construction of fish passage facilities at or near Clough Dam on Mill Creek for the benefit of salmon and steelhead.	6/30/2003	$1,013,906	Complete.
ERP-98-B22	**Fish Passage Improvement Project at the Red Bluff Diversion Dam** Provided funds for identifying the best alternative for operation of the Red Bluff Diversion Dam that maximizes fish passage for anadromous fish while minimizing adverse impacts to agricultural irrigation supply.	2/28/2000	$340,164	Complete.
ERP-98-B23	**Steelhead and Chinook Salmon Fish Passage Barrier Remediation on the Guadalupe River** Increased upstream passage of returning steelhead and Chinook salmon adults on the Guadalupe River by constructing fish passage structures past two diversion facilities.	12/31/2001	$178,200	Complete.
ERP-98-B24	**Fish Passage and Fish Screening Improvement Project, Phase II** Provided funds for completing the final design, environmental documentation, and permitting for improved fish passage structures on the Anderson-Cottonwood Irrigation District diversion dam on the Sacramento River.	8/31/1999	$840,759	Complete.
ERP-98-B25	**Cosumnes River Salmonid Barrier Program** Increased upstream passage of returning adults.	10/31/2004	$230,255	Complete.
ERP-98-B28	**The City of Sacramento Water Intake Fish Screen Replacement Projects: Sacramento River Water Treatment Plant and the E.A. Fairbairn Water Treatment Plant** Provided funds to prepare final designs for replacing fish screens at two water treatment plants, one on the Sacramento River and the other on the American, to reduce entrainment of anadromous fish.	6/30/2001	$1,964,500	Complete.
ERP-98-B29	**American Basin Fish Screen and Habitat Improvement Project** Provided funds for the feasibility study and preliminary design and environmental compliance work for the American Basin Fish Screen and Habitat Improvement Project, which will remove migration barriers and prevent straying and entrainment of anadromous fish.	6/30/2002	$450,000	Complete.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-C11	**Adult Fall-Run Chinook Salmon Movement in the Lower San Joaquin River and South Delta** Evaluated adult Chinook migration and delays through the lower San Joaquin River and South Delta to determine the effects of the South Delta Temporary Barriers, Head of Old River Barrier, and/or low DO conditions.	5/31/2001	$285,000	Complete.
ERP-98-C19	**Conduct/Facilitate Meetings on the Upper Yuba River, Engelbright Dam** FWS coordinated & facilitated meetings designed to gain agreement on the initial components of a study plan which will evaluate the feasibility of restoring anadromous fish runs above Engelbright Dam on the Yuba River.	6/30/1999	$7,333	Complete.
ERP-98-E06	**Battle Creek Watershed Stewardship** Provided funds to facilitate the activities of the Battle Creek Watershed Conservancy in development and implementation of watershed restoration activities in the Battle Creek watershed.	9/15/2002	$145,000	Complete.
ERP-98-E07	**Local Watershed Stewardship: Steelhead Trout Plan, Corte Madera Creek Watershed, Marin County, California** Developed a steelhead restoration plan for the Corte Madera Creek as part of a larger watershed management plan for the Corte Madera Creek watershed.	12/31/2000	$47,500	Complete.
ERP-98-N02	**Expanding California Salmon Habitat through Non-Governmental and Non-Regulatory Mechanisms to Alter Dams and Diversions** Inventoried dams and diversions in the Central Valley and developed a mechanism to purchase dams and diversions from willing sellers to improve fish passage.	3/15/2000	$49,000	Complete.
ERP-99-B01	**Battle Creek Salmon and Steelhead Restoration Project** Will restore 42 miles of habitat for anadromous fish and improve water quality for the Coleman National Fish Hatchery in the Battle Creek Watershed by decommissioning several PG&E diversion dams, providing fish ladders and screens for those that remain, and increasing instream flows for fish.	Unknown	$27,200,000	Ongoing.
ERP-99-B02	**Lower Butte Creek Project (Phase II: Preliminary Engineering and Environmental Analysis for Butte Sink Structural Modifications and Flow-Through System)** Phase II of the Lower Butte Creek Project to improve fish passage through the Butte Sink and its associated water control structures by selecting the preferred alternative for design of major structural modifications at structures throughout the Butte Sink.	6/30/2002	$900,000	Complete.

Table 1. Dams and Other Structures Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-B03	**Anderson-Cottonwood Irrigation District Fish Passage and Fish Screening Improvement Project, Phase III** Supported Phase III of the Anderson-Cottonwood Irrigation District (ACID) Fish Screen Project to improve fish passage and habitat for salmon and steelhead on the Sacramento River by providing funds for the construction bidding process and construction phase of the project.	12/31/2005	$4,637,278	Complete.
ERP-99-B05	**Merced River Salmon Habitat Enhancement Project Phase II- Ratzlaff Reach Construction)** Reduced entrainment and predation of out migrating fish. Isolate 45 acres of unnatural predator habitat from the river channel. Improved river and floodplains dynamics and enhanced the riparian corridor. Increased the quantity and quality of in-stream spawning habitat. Funding covered costs for part of the construction.	3/30/2000	$1,584,002	Complete. Reconstructed berms to isolate approx. 45 acres of ponds from river. 3,000 ft (0.6 miles) of channel modified, 7,000 sq ft of spawning habitat will be created.
ERP-99-B07	**Fish Passage Improvement at the Red Bluff Diversion Dam, Phase II** Provided funds for a portion of Phase II of the Tehama-Colusa Canal Fish Passage Project at Red Bluff Dam, which involved modifying the Red Bluff Diversion Dam (RBDD) to reduce or minimize the impacts of the RBDD on upstream and downstream migration of juvenile and adult anadromous fish migration. The remainder of Phase II was funded under ERP-01-N58.	3/31/2002	$1,839,888	Complete.
ERP-99-B08	**Improve Upstream Ladder and Barrier Weir at Coleman National Fish Hatchery at Battle Creek** Will improve the fish ladder at the Coleman National Fish Hatchery barrier weir and modify the barrier weir to repair existing damage that will assist management in restoring fish populations on Battle Creek.	12/31/2009	$9,326,820	Ongoing.
ERP-99-N01	**ACID Fish Passage Improvement Project, Phase III** Provided funds for construction of improved fish passage structures on the Anderson-Cottonwood Irrigation District diversion dam on the Sacramento River.	9/1/2002	$5,100,000	Complete.

Other Programs Contributing to ERP Vision

The U.S. Fish and Wildlife Service's Anadromous Fish Screen Program contributed to resolution of water diversion structure-related passage problems.

The *Saeltzer Dam Fish Passage Project, Clear Creek, Shasta County* (**ERP-97-M05**) originally provided funds to replace the existing Saeltzer Dam on Clear Creek with a

"fish-friendly" alternative consisting of a structure lower in height. The project originally included construction of a fish ladder and fish screen. However, the decision was made to remove the dam without replacing any structures. This allowed better fish passage which aids restoration of anadromous fisheries resources in Clear Creek and the upper Sacramento River. USBR decided to do the environmental work with USBR funding, so the dam removal was funded with alternate money.

Status of Topic Today

There has been much progress towards improving fish passage in Butte Creek, Battle Creek, the Sacramento River and sites in the San Joaquin basin. Numerous seasonal irrigation diversion dams have been removed or reconstructed in order to improve fish passage. Much of the effort has involved installing new fish screens or relocating the diversion to less environmentally sensitive areas. Fish screens are discussed in greater detail in the water diversion section.

The Upper Yuba River Study Investigations has looked in great detail at the ecological and economic consequences of providing fish passage in the Yuba River above Englebright Dam. The results suggest that potential benefits may not support such a large-scale effort.

Planned Projects for Implementation

Planning for Battle Creek restoration continues and numerous alternatives have been developed to improve fish passage there.

Impediments to Implementation

In 2007, ERP held two one-day workshops on Central Valley fish screens to request input from State and Federal agencies and stakeholders on “lessons-learned” during Stage 1. See the Water Diversion section for various conclusions that have come out of these workshops.

The ERP will work with the interagency Fish Screen Workgroup and the CVPIA Anadromous Fish Screen Program (AFSP) resolve the above issues, and recommendations will be included in the Stage 2 Program Plan.

References

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

Mills, T.J., D.R. McEwan, and M.R. Jennings. 1996. California salmon and steelhead: beyond the crossroads, p. 91-111. In D. Stouder, P. Bisson, and R. Naiman (eds.), Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

5. STRESSORS

5.3. Levees, Bridges and Bank Protection

Introduction

Levees, bridges, and bank protection structures inhibit overland floodflows and the processes of stream channel meander, bank erosion, and sediment deposition that contribute to floodplain creation and maintenance. Levees prevent floodflows from entering historic floodplains, stop floodplain evolution, and eliminate or alter the character of floodplain habitats. Confining floodflows to channels also increases the fluvial energy that scours or incises channel beds and reduces or prevents channel meander and oxbow formation. Bridges have a similar, though more localized, effect on channel morphology and sediment transport.

Applicable ERP Vision

The ERP vision for levees, bridges, and bank protection is to reduce the adverse effects of these structures to improve riverine and floodplain habitats and to assist in the recovery of at-risk species. Overall, the goal is to help reestablish floodplain inundation and channel-floodplain connectivity with sufficient frequency, timing, duration, and magnitude to support the restoration and maintenance of functional floodplain, riparian, and riverine habitats.

Stage 1 Expectations

The Stage 1 expectation for levees, bridges, and bank protection was to identify all unurbanized floodplains in the Central Valley (including the Feather River/Sutter Basin EMZ) and develop a priority list for floodplain restoration projects. Strategies for the restoration of natural channel and floodplain dynamics would have been developed and implemented in at least two large demonstration projects to increase understanding of channel-floodplain interactions and the potential for restoration of processes.

Changes Attributable to ERP

No projects specifically directed at levees, bridges, or bank protection have been funded. However, 37 projects have indirectly addressed the adverse influences of levees and bank protection. Most of these projects are described elsewhere, primarily in the sections on the Ecological Management Zones and Units.

Project Summary Table

Table 1. Levees, Bridges and Bank Protection Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-E01	**Last Chance Creek Watershed Restoration** Restored the Ferris-Meadowview reach of the Feather River through a collaborative effort to restore hydrologic function and meadow condition in the Last Creek watershed for the benefit of target species.	12/31/2004	$980,000	Complete. Channel restoration, using pond and plug technique to reconnect the channel/floodplain system over 9.1 miles of stream.
ERP-00-E02	**Panoche/Silver Creek Watershed Management and Action Plan** Building upon the completed Panoche/Silver Creek Watershed Assessment, this project evaluated recommended Best Management Practices (BMPs), implemented selected BMPs on feasible test sites throughout the upper watershed, and carefully monitored the test sites and the watershed in general to determine the effectiveness of BMPs for reducing loads of sediment, selenium, and other contaminants delivered during high flow events. Information gathered was used to develop the Action Plan component of the Panoche/Silver Creek Coordinated Resource Management Plan.	06/30/2005	$868,600	Complete.
ERP-00-E04	**Sonoma Creek Watershed Conservancy** Restored riparian and aquatic habitat and continued watershed stewardship and education programs in the Sonoma Creek watershed.	05/01/2004	$438,923	Complete. 100 ft long concrete box culvert fitted with Washington baffles; installed 3 boulder weirs. Opened 2 miles of stream for fish passage.
ERP-01-C05	**Feasibility Study of the Ecosystem and Water Quality Benefits Associated with the Restoration of Franks Tract, Big Break, and Lower Sherman Lake** This feasibility study evaluated the potential to create ecosystem, water quality/supply, recreational, and other benefits at Lower Sherman Lake, Big Break, and Franks Tract, by modifying remnant levees to inhibit salt trapping and restoring tidal marsh habitat.	06/30/2005	$1,218,105	Complete.
ERP-01-N08	**San Joaquin River NWR Riparian Habitat Protection & Floodplain Restoration Project - Phase II** Funded easement acquisition. Restored riparian and wetland habitat. Reintroduced riparian brush rabbits. Conducted associated monitoring. Associated project (ERP-97-B04) for Phase I.	12/31/2006	$7,968,112	Complete. Acquired 362 acres of easements and restored riparian habitat on 808 acres.
ERP-01-N27	**Sonoma Creek Watershed Conservancy** Expanded on the Conservancy's existing efforts to inform and engage the public in watershed issues while providing critical data for adaptive management.	03/16/2006	$545,170	Complete. Old concrete ford removed and boulder weir ladder constructed to improve fish passage.

Table 1. Levees, Bridges and Bank Protection Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-N28	**Sacramento River Conservation Area Program** Provided funding to continue the efforts of the Sacramento River Conservation Area Program to act as a coordinating body between local, state, and federal agencies regarding restoration activities in the Sacramento River watershed.	06/30/2007	$1,034,249	Complete.
ERP-01-N30	**Digital Soil Survey Mapping and Digital Orthophotoquad Imagery Development** Made soils information more accessible to individuals and groups engaged in ecosystem restoration projects in the Bay-Delta Region, and in doing so, improved the ability of these projects to establish habitat and support sustainable populations of valuable species.	08/15/2004	$430,390	Complete.
ERP-02D-P53	**Lower Deer Creek Restoration and Flood Management: Feasibility Study and Conceptual Design** Will evaluate the feasibility of setting back levees on Deer Creek and investigate the feasibility of allowing flood flows to access the natural floodplain in a controlled manner to improve habitat and flood control.	10/31/2008	$1,519,200	Ongoing.
ERP-02D-P54	**Restoring Ecosystem Integrity in the Northwest Delta: Phase II** Proposes to acquire conservation easements within the Cache Slough complex, along the Barker, Lindsey and Calhoun Sloughs, north Delta tidal channels located west of the Yolo Bypass.	08/31/2008	$1,781,658	Ongoing.
ERP-02D-P61	**Implementing a Collaborative Approach to Quantifying Ecosystem Flow Regime Needs for the Sacramento River** Seeks to quantify key aspects of a "naturalized' flow regime that are compatible with flood damage reduction, agriculture, diversions, storage and conveyance (was ERP-02-P15-D).	03/31/2008	$1,571,438	Ongoing.
ERP-02-P23	**Update Individual Ownership Adaptive Management Habitat Plans** Project works to update 140 "Individual Ownership Management Plans for Private Properties" within the Suisun Marsh and to provide wetland management educational information for private landowners.	10/31/2007	$214,943	Ongoing.
ERP-02-P25	**McCormack-Williamson Tract Restoration: Wildlife-Friendly Levee Management** Will re-slope 20,000 linear feet of the back slope of the levees on the McCormack-Williamson tract (MWT) to a 5:1 slope, using on-site fill to increase the strength and stability of the MWT levee system while increasing riparian habitat.	12/31/2008	$2,476,835	Ongoing.

Table 1. Levees, Bridges and Bank Protection Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P39	**Riparian Restoration Planning and Feasibility Study for the Riparian Sanctuary, Llano Seco Unit** 1) Identified feasible management options that will improve habitat and ecosystem processes on 950 acres of the Riparian Sanctuary at the Sacramento River National Wildlife Refuge, Llano Seco Unit; 2) developed and evaluate ecologically acceptable options that would improve pumping plant protection and 3) increased scientific understanding of riparian restoration projects.	02/28/2006	$289,784	Complete.
ERP-02-P45	**Geomorphic and Geologic Mapping for Restoration Planning** Mapped geomorphic landforms and geologic deposits along the lower Sacramento, San Joaquin, and Cosumnes rivers for input into ecosystem restoration planning and levee engineering. Detailed mapping (1:24,000) will be completed for portions of nine 7.5 minute quadrangles.	06/01/2005	$120,000	Complete.
ERP-05D-C01	**Hamilton City Flood Damage Reduction and Ecosystem Restoration Project** Preconstruction, engineering, and design phase to prepare final design and plans and specifications for construction.	11/30/2008	$1,020,100	Ongoing.
ERP-05D-C02	**Suisun Marsh Implementation Plan** Completed all the activities supporting the preparation of regional implementation plans in the Suisun Marsh.	06/30/2006	$110,000	Complete.
ERP-05D-S29	**Riparian Sanctuary (Phase II) – Bringing Agricultural and Ecological Interests Together for Pumping Plant Protection and Riparian Restoration (Sacramento River Mile 178) - Design Development and Environmental Compliance** Planning and design efforts to develop second phase of multi-phase process to protect PCGID-PID's pumping plant and fish screen facility and to meet Sacramento River National Wildlife Refuge habitat goals for the Riparian Sanctuary.	06/30/2010	$660,665	Ongoing.
ERP-06D-S15	**Sacramento River Conservation Area Forum (SRCAF)** Provides funding to continue the efforts of the Sacramento River Conservation Area Forum to act as a coordinating body between local, state, and federal agencies regarding restoration activities in the Sacramento River watershed.	03/31/2010	$656,277	Ongoing.
ERP-96-M13	**Yolo Bypass Fish Habitat** Examined the relationship between the Yolo Bypass and the rest of the Estuary and developed recommendations for restoration actions that would improve Bypass habitat for fisheries and other aquatic organisms.	11/03/2000	$226,000	Complete.

Table 1. Levees, Bridges and Bank Protection Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-97-B03	**Liberty Island Acquisition** Protected and restored tidally influenced wetlands, riparian corridors, and upland habitats on Liberty Island in the Yolo Bypass.	09/30/2003	$8,926,000	Complete. Acquired 4760 acres of land on Liberty Island.
ERP-97-B04	**San Joaquin River National Wildlife Refuge Riparian Habitat Protection and Floodplain Restoration Project - Phase I** Acquired and planned restoration of additional floodplain lands for USFWS San Joaquin National Wildlife Refuge.	03/31/2002	$10,947,000	Complete. 3230.56 acres of land was acquired with a combination of LWCF, NRCS, and CalFed funds
ERP-97-N12	**Franks Tract State Recreation Area Wetlands Habitat Restoration** Conducted planning and preliminary engineering for the restoration of deeply flooded habitat to 45 acres of tidal perennial aquatic, shaded riverine aquatic, and mid channel island shoal and shoal habitats in Frank's Tract State Recreation Area (SRA). The tasks included were permitting, environmental compliance, final design and other preconstruction planning.	12/31/2002	$293,052.00	Complete.
ERP-97-N13	**Tyler Island Levee Protection and Habitat Restoration Pilot Project** Evaluated alternative vegetative and biotechnical techniques for stabilizing bank erosion restoring levees, as well as riparian and shallow water habitat.	05/31/2002	$885,202	Complete.
ERP-98-A01	**Prospect Island Habitat Protection Project** Emergency repairs of levees and pumped out Prospect Island.	06/30/2000	$2,000,000	Complete.
ERP-98-B08	**Cache Slough Shaded Riverine Aquatic Habitat Enhancement Project** Planning phase of a project which will restore approximately 2,000 LF of levee bank to shaded riverine aquatic habitat.	12/31/2001	$85,000	Complete.
ERP-98-B13	**South Napa River Wetlands Acquisition** Protected and restored native marsh wetland habitat by acquiring and restoring 115 acres of land in the South Napa River Wetlands along the Napa River benefiting several federally-listed species. After acquisition, proposed restoration will modify or remove levees and other structure interventions to restore and enhance natural wetland functions. This project is related to additional restoration activities in the area under ERP-98-F14.	09/30/2000	$1,073,513	Complete.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** Implementation of monitoring and applied research that provides data and information necessary to evaluate the performance of completed CALFED program actions and ongoing programs.	12/31/1999	$800,000	Complete.

Table 1. Levees, Bridges and Bank Protection Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-E01	**Napa River Watershed Stewardship** Builds upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/31/2000	$250,000	Complete.
ERP-98-E02	**Sonoma Creek Watershed Enhancement Plan - Phase II** Assisted in implementing restoration, monitoring, and educational outreach actions in the Sonoma Creek Watershed aimed at restoring the watershed through collaboration with a combination of public and private organizations.	12/31/2000	$302,000	Complete.
ERP-98-E04	**Petaluma River Watershed Restoration Program** Provided funds to implement the restoration and monitoring projects identified in the Petaluma River Watershed Enhancement Plan with the goal of enhancing and restoring habitat and ecosystem function along the Petaluma River.	02/28/2001	$220,000	Complete.
ERP-98-F12	**Stone Lakes NWR Land Acquisition** Acquired fee title to approximately 537.35 acres of land within the boundary of the Stone Lakes National Wildlife Refuge, to protect existing aquatic, wetland, and riparian habitats and restore a mosaic of aquatic, perennial and seasonal emergent wetland, riparian, and grassland habitats.	09/30/2003	$2,626,505.00	Complete.
ERP-98-F23	**South Napa River Tidal Slough and Floodplain Restoration Project** Represents the first phase in restoring over 460 acres of wetlands in the South Napa River Tidal Slough by funding acquisition of the property, preliminary design work, an environmental feasibility study, and environmental compliance documentation and permitting.	06/30/2001	$1,480,000	Complete. Acquired 453.24 acres of land
ERP-99-B11	**South Napa River Tidal Slough and Floodplain Restoration Project** This was Phase 2 of the South Napa River Tidal Slough and Floodplain Restoration Project, which involved the restoration of tidal flow to 2.3 miles of historic slough habitat, and the restoration of nearly 483 acres of wetlands and uplands.	9/30/2005	$1,520,000	Complete.
ERP-99-F03	**Part B: The McCormack-Williamson Tract's Wildlife-Friendly Levee Management Project** On the purchased McCormack-Williamson Tract (99-F04), The Nature Conservancy initiated startup stewardship, coordinated with agencies for restoration planning, and implemented a wildlife-friendly levee program.	12/31/2004	$860,778	Complete.
ERP-99-N03	**East Delta Habitat Corridor, Tidal Marsh and Riparian Habitat Restoration** This tidal marsh and riparian restoration project improved habitat conditions along 14 miles of Georgiana Slough.	11/02/2003	$1,100,000	Complete.

Table 1. Levees, Bridges and Bank Protection Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-N10	**Assessing Ecological and Economic Impacts of the Chinese Mitten Crab** Used experimental field and laboratory studies, combined with continuous monitoring data, to examine the biology, population dynamics and impacts of a recently introduced species, the Chinese mitten crab on freshwater and estuarine habitats of the San Francisco Bay ecosystem.	07/07/2003	$113,033	Complete.

Other Programs Contributing to ERP Vision

Numerous private organizations participate in efforts to reduce the adverse impacts of bank protection. The Nature Conservancy is one organization that has participated, through CALFED, with the Sacramento River Area Conservation Forum to acquire land along the Sacramento River for restoration, including the removal of bank protection in specific areas. The Nature Conservancy is also responsible for management of the McCormick-Williamson Tract in the Delta which is being managed for sustainable agriculture and ecosystem restoration.

Status of Topic Today

Levee and bank protection continue to be a priority for the Delta. In many cases, restrictions to flow and floodplain inundation due to these structures is a barrier to habitat restoration and species recovery. In 2007, the USACE issued interim guidance for control of vegetation on levees. This memorandum created a stir among conservation entities due to the ramifications of stripping levees of vegetation in the unique setting of California's Delta.

Planned Projects for Implementation

A few projects would benefit levee and bank protection if implemented beyond the planning phase. The *Cache Slough Shaded Riverine Aquatic Habitat Enhancement Project* (**ERP-98-B08**) was the planning phase of a project to restore approximately 2,000 linear feet of levee bank to shaded riverine aquatic habitat. This project closed in 2001 and has not moved into the implementation phase. The *Lower Deer Creek Restoration and Flood Management* project (**ERP-02D-P53**) is evaluating the feasibility of setting back levees on Deer Creek. The *Geomorphic and Geologic Mapping for Restoration Planning* project (**ERP-02-P45**) mapped geomorphic landforms and geologic deposits along the lower Sacramento, San Joaquin, and Cosumnes rivers. This

detailed mapping exercise will provide input into ecosystem restoration planning and levee engineering. The *Tyler Island Levee Protection and Habitat Restoration Pilot Project* (**ERP-97-N13**) evaluated alternative vegetative and biotechnical techniques for stabilizing bank erosion restoring levees, as well as riparian and shallow water habitat.

Impediments to Implementation

The infrastructure of the Delta is dependent on structures such as levees, banks, and bridges. Removal of these structures directly affects adjacent landowners and is highly political. In addition, structure removal projects and the mitigation of flood damage attributed to structure removal are likely to be very expensive.

References

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIRTechnical Appendix. Sacramento, CA.

5. STRESSORS

5.4. Dredging and Sediment Disposal

Introduction

Maintenance dredging and sediment disposal in the Sacramento-San Joaquin Delta are used to maintain or deepen navigation channels, harbors, and marinas, and are often required to maintain or increase flood control and water conveyance capacity. Dredged sediments are commonly used as material for levee maintenance and repair (CALFED 2000a).

Delta sediments contain numerous contaminants that originate from upstream and in-Delta sources which can be re-suspended during dredging operations and can also enter the food web via consumption by aquatic organisms. Dredging operations also increase turbidity and fine sediments causing adverse effects on fish behaviors including modified feeding patterns, foraging efficiency, habitat choice, and predator/prey relationships.

However, dredging is considered necessary to maintain shipping channels and channel capacity during flood flow events. Dredging operations can be conducted in an environmentally benign manner and clean uncontaminated dredge spoils can be used for levee reconstruction, wetland restoration, reversal of subsidence, creation of shallow water habitats, and other environmental benefits (CALFED 2000a).

In an attempt to reduce the environmental impacts, dredging in the Bay-Delta is subject to regulatory "work windows" that limit dredging to several months each year during which impacts to aquatic species are likely to be minimized.

Applicable ERP Vision

The vision for dredging and sediment disposal in the Bay-Delta is to maintain adequate channel depth for navigation, flood control, and water conveyance while reducing the adverse effects of dredging activities on the Bay-Delta ecosystem (CALFED 2000a).

The strategic objective for dredging and sediment disposal is to rehabilitate natural processes to create and maintain channel morphology, in-channel islands, and shallow water habitat in the Delta and Suisun Marsh. Long and short-term objectives are, respectively, to link dredging and spoil disposal with environmental restoration, reversal of subsidence, and levee maintenance; and to reduce adverse environmental impacts and demonstrate the beneficial reuse of dredge materials (CALFED 2000a).

Stage 1 Expectations

The expectation for Stage 1 was to develop pilot programs to demonstrate the beneficial reuse of dredged materials for ecological purposes by creating wetland and shallow water habitats in the Delta and Bay. The general target for dredging and dredge disposal was to reduce the loss and degradation of habitat and to contribute sediments for the recreation of shallow water habitats.

Changes Attributable to ERP

A series of important ERP projects, *Delta Dredging Reuse Strategy* (**ERP-98-C09 a,b,c**), were funded to reduce the adverse environmental impacts from dredging. These projects addressed the reuse of materials, dredged from Delta channels during necessary maintenance operations, to maintain levees and as fill material in habitat restoration projects. The **ERP-98-C09** series funded the Central Valley Regional Water Quality Control Board, the California Department of Fish and Game, and the Delta Protection Commission to convene a panel of experts to formulate a streamlined dredging permit process for the Delta, and offer recommendations on the reuse of dredge materials in levee maintenance and habitat restoration projects. The Delta Dredging Reuse Strategy (DDRS) coordinated actions among agencies having jurisdiction over dredging activities in the Delta, characterizing sediments and compiling information into a DREDGE database, and issuing recommendations on sediment characterization and toxicity testing to facilitate dredging and dredge material reuse in the Delta.

In addition, ERP funded the planning and environmental documentation tasks for the *Hamilton Wetlands Restoration Planning* project (**ERP-98-C03**), which ultimately resulted in the restoration of 2,500 acres of subsided, diked baylands to a mix of seasonal and tidal wetlands. Located 25 miles north of San Francisco on the outskirts of Novato, Marin County, the Hamilton Wetlands restoration project demonstrated the successful beneficial reuse of nearly 33 million cubic yards of material dredged from San Francisco Bay (Jones & Stokes 1998). The Hamilton Wetlands project, as constructed, maximized utilization of dredged materials in restoring the elevations of subsided areas to create seasonal and tidal wetlands.

With respect to dredging and beneficial reuse, the Delta Dredge Reuse Strategy planning effort included establishing a Technical Advisory Panel (TAP) of experts on dredging in the Delta and regulations associated with dredging activities. It culminated in a Delta Dredge Reuse Strategy document (DDRS), which analyzed technical and regulatory issues related to Delta dredging projects and includes recommendations for additional studies and pilot projects to fill data gaps.

Upon completion of the DDRS document in 2002, the TAP noted several priority actions, including (but not limited to):

- The need for one federal agency and one State agency to take the lead in all dredging-related issues in the Delta and to develop a simple dredging process modeled after the successful Dredge Material Management Office (DMMO) in the San Francisco Bay area.
- Delta-wide soil and sediment sampling to characterize contaminant distribution, sources, fates, and possible biological effects (in cases where Delta soils naturally exceed sediment quality guidelines, the background levels would become the new sediment quality assessment guidelines for the Delta).
- Development of an information clearinghouse/library about dredging projects and the location, characteristics, and availability for reuse of dredged material.
- Preparation by the Regional Board of an environmental document for its proposed General Orders for dredging.

Some of the more noteworthy deliverables of the DDRS project included dredging guidelines and compilation of sediment survey results for the Delta in a DREDGE database. The information developed under this project is useful to the ongoing effort to establish a DMMO in the Delta similar to the successful entity established for the San Francisco Bay area. Regulatory agencies and cooperating partners continue to work to establish this program under the Delta Long Term Management Strategy (LTMS) effort for dredge material reuse in the Delta. A Programmatic EIR/EIS is tentatively scheduled for circulation by the end of 2009, with adoption of a Delta LTMS Sediment Management Plan slated for summer of 2010. More information on the Delta LTMS, including the DDRS document, is available from www.deltaltms.com.

How the DREDGE database and other information produced by the DDRS effort is being used still requires maturation. For example, while the DREDGE has been forwarded to those involved in the current Delta LTMS effort, and those at the State and Regional Water Quality Control Boards whose programs address dredging and/or sediment characterization, the extent to which DDRS information is being incorporated into these programs is unclear. The Delta LTMS program is constructing a sedimentation database which will incorporate the DREDGE database information within the larger data collection effort (www.deltaltms.com). In addition, the TAP identified the need for Delta-wide sediment and soil testing to determine contaminant distribution, sources, fates, and effects; it is hoped that this data will be developed under the State Water Resources Control Board's ongoing Sediment Quality Objectives (SQO) program. Finally, many of the recommendations of the TAP (including coordination of State and federal agencies on dredging in the Delta, and creation of an information clearinghouse on Delta dredge projects) are occurring under the ongoing Delta LTMS program, and the benefits of these actions will become more apparent as the program is implemented over time.

With respect to dredging and beneficial reuse, dredging projects have historically been evaluated by the State and Regional Water Quality Control Boards in light of toxicity and bioaccumulation in the aquatic environment. Because dredge sediment disposal in the Delta occurs mainly on upland areas, less effort could be dedicated to regulating projects based on the potential for bioaccumulation in water, and more effort could be dedicated to developing Best Management Practices for the disposal and containment of dredge spoils in the Delta (such as allowing disposal only on the land side of levees and "capping" spoils with clean materials). Pursuing more site-specific regulations for the Delta, and including all agencies that regulate dredging projects in the development of those regulations under the Delta LTMS program, could greatly facilitate the approval of Delta dredging projects, and enable some of the pilot projects envisioned for Stage 1 to move forward (DDRS 2002).

One misguided assumption related to the DDRS project was the belief that if the regulatory agencies were given sufficient funding to undertake the project, they would use the information developed to better coordinate dredging activities in the Delta, and to investigate whether current restrictions (such as "work windows") could be revisited. For example, the TAP identified a need to simplify relatively "small" dredging projects (i.e. those projects proposing to remove less than 100,000 cubic yards of dredged material) through the development of General Orders for such projects. The Central Valley Regional Water Quality Control Board did in fact release draft General Orders for small dredge projects, but could not get an adequate CEQA document to support the proposed General Orders, so this facilitation of smaller projects has not yet been successful.

ERP funded two studies for USGS researchers to collect information on sedimentation and the availability of sediment to restore habitats and ecological processes in the Delta and Suisun Bay: *Sedimentation Movement and Availability and Monitoring in the Delta* (**ERP-97-B02**) and *Sedimentation in the Delta and Suisun Bay* (**ERP-01-C06**). The studies monitored a range of sampling sites to determine the variation of sediment transport related to flows in sensitive habitats; differentiated sedimentation between dry and normal years; documented sediment transport effects of restoration activities; and tested geomorphic hypotheses to improve the conceptual model of sedimentation in the Delta and Suisun Bay.

Numerous projects funded by ERP included a component to address the erosion, deposition, and transport of sediment. These projects ranged from planning tasks toward development of a watershed management plan to full implementation of Best Management Practices (BMPs) to control sediment erosion, deposition, and transport. These projects are covered in more detail both in the Channel Forming Processes chapter and within the appropriate Ecological Management Zone (EMZ) chapters of this report.

Project Summary Table

Table 1. Dredging and Sediment Disposal Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-97-B02	**Sedimentation in the Delta and Suisun Bay** This project described the movement and availability of sediment in the Delta, as needed for habitat restoration. Information collected during this project was used to improve the conceptual model of sedimentation in the Delta.	06/30/2001	$1,047,010	Complete. Numerous journal articles published in 2005 and 2006.
ERP-98-C03	**Hamilton Wetlands Restoration Project** This project included completion of the Hamilton Wetlands Conceptual Restoration Plan, Bel Marin Keys Feasibility Study & supplemental EIS/EIR, and Hamilton Wetlands Restoration Plan Final Design. The project as constructed utilized nearly 33 million cubic yards of material dredged from SF Bay.	06/30/2002	$1,070,030	Complete. Hamilton Wetlands EIR/EIS completed December 1998; Draft Subsequent EIR completed in June 2003.
ERP-98-C09a	**Delta Dredging Reuse Strategy** This project developed a Delta Dredging Reuse Strategy (DDRS) to assure that dredging and dredge sediment reuse options are conducted in a manner that protects water quality and fish and wildlife resources.	06/30/2002	$24,000	Complete. Final report titled "Delta Dredging Reuse Strategy" completed in 2002.
ERP-98-C09b	**Delta Dredging Reuse Strategy** This project developed a Delta Dredging Reuse Strategy (DDRS) to assure that dredging and dredge sediment reuse options are conducted in a manner that protects water quality and fish and wildlife resources.	06/30/2002	$276,000	Complete. Final report titled "Delta Dredging Reuse Strategy" completed in 2002.
ERP-98-C09c	**Delta Dredging Reuse Strategy** This project developed a Delta Dredging Reuse Strategy (DDRS) to assure that dredging and dredge sediment reuse options are conducted in a manner that protects water quality and fish and wildlife resources.	06/30/2002	$200,000	Complete. Final report titled "Delta Dredging Reuse Strategy" completed in 2002.
ERP-01-C06	**Sedimentation in the Delta and Suisun Bay** This project described the movement and availability of sediment in the Delta, as needed for habitat restoration. Information collected during this project was used to improve the conceptual model of sedimentation in the Delta.	06/14/2005	$1,630,391	Complete. Numerous journal articles published in 2005 and 2006.

Other Programs Contributing to ERP Vision

The USGS sedimentation studies funded by ERP were utilized in a subsequent study funded by the San Francisco Bay Regional Monitoring Program (RMP) for Trace Substances. These studies suggest that while sediment loads appear to be decreasing over time, there has been no recent quantification of sediment loads entering the Bay; this is partially due to the difficulty of measuring load in a tidal area in which both

advective and dispersive forces are at work, and where deposition and resuspension can occur. In the RMP study, researchers demonstrated an innovative method for quantification of sediment loads in a tidal cross-section, and estimated daily and annual sediment loads entering San Francisco Bay. This new methodology is expected to yield a significant change in the previous thinking about San Francisco Bay's sediment budget, while at the same time providing an estimation of trace contaminant loads. However, it is suggested that analysis of suspended sediment concentration data collected at Mallard Island be used to estimate sediment flux to San Francisco Bay from the Delta, in part to verify the new findings on loads from the Central Valley (McKee et al. 2006).

Results from the RMP sediment transport study demonstrate that sediment load has historically been overestimated at Mallard Island in Suisun Bay, because only the load contribution of river discharge has been considered but sediment load is also influenced by the correlation between fluctuations of velocity and concentration. Previously, sediment loads from the Central Valley had been reported to account for about 90% of the San Francisco Bay's sediment budget; this study suggests that only 57% of the total sediment load to the Bay comes from the Central Valley (McKee et al. 2006).

The USGS and RMP studies imply that given the decreasing mass of sediment entering San Francisco Bay from the Central Valley and Delta, less sediment will be available for restoration of wetlands that require either dredged material reuse or natural sedimentation, and furthermore that restoration of the connectivity of near-channel floodplain to stream channels (e.g. tidal restoration of salt ponds) will capture even more sediment, greatly reducing sediment deposition elsewhere in the Bay. It is expected that sediment demand for new marsh restoration can be diminished by initiating projects where sediment is abundant and subsidence is moderate, by sizing projects to fit local sediment supplies, and by implementing projects carefully over time (McKee et al. 2006).

The USGS research indicates that tidal effects on sedimentation are greater in the San Joaquin River than in the Sacramento River, and that natural sediment supply for restoration projects in the Delta is greatest along the Sacramento River and during the wet season (Wright and Schoellhamer 2004). The USGS studies also cite the need to address anthropogenic effects within the watershed when considering management decisions in downstream depositional areas such as estuaries. For example, if anthropogenic barriers such as agriculture, urbanization, or the construction of dikes and levees are eliminated, areas that were historically tidal will not necessarily return to their pre-disturbance geomorphic forms due to the significant reduction in sediment supply from the Central Valley (Wright and Schoellhamer 2004).

With respect to sedimentation, sediment transport and deposition, USGS researchers found that from 1999-2002, a net amount of 4.4 million metric tons of sediment was deposited in the Delta, corresponding to 2 cm of deposition (or .5 cm/year). Nearly

85% of the suspended sediment came from the Sacramento River, 13% from the San Joaquin River, and 2% from other sources. A total of 82% of the sediment supply, and 85% of the total deposition, were attributable to the annual four-month wet season.

USGS researchers also found that during the period 1957-2001, the delivery of suspended sediment from the Sacramento River to San Francisco Bay decreased by about half, due to factors such as the depletion of erodible sediment from hydraulic mining, trapping of sediment in reservoirs, and riverbank protection. The researchers found that there is likely to be a decreasing trend in suspended-sediment discharge for a given flow, and warns that it may not be appropriate, for CALFED restoration planning purposes, to assume that sediment yield to the Delta will be the same in the future as it is today (Wright and Schoellhamer May 2004).

San Francisco Bay LTMS is a cooperative effort of EPA, the US Army Corps of Engineers, the San Francisco Regional Water Quality Control Board, the San Francisco Bay Conservation and Development Commission, and stakeholders to develop a new approach to dredging and dredged material disposal in the San Francisco Bay area. To facilitate the dredging process, the LTMS agencies established an interagency Dredge Material Management Office, which serves as a "one-stop shop" for Bay Area dredging permit applications (www.epa.gov/region09/water/dredging/ltms/index.html). The Hamilton Wetlands Restoration project successfully reused millions of cubic yards of material dredged from the Bay, in accordance with the San Francisco Bay LTMS program.

In accordance with the recommendations of the TAP, it is expected that the State Board's Sediment Quality Objectives (SQO) Program will yield a useful risk-based methodology for evaluating Delta soils and sediments in terms of the potential impacts of beneficial reuse of dredge material in the Delta.

Finally, the San Francisco Bay Regional Monitoring Program (RMP) for Trace Substances provided funding to build upon information generated by the ERP-funded USGS studies of sedimentation in the Delta and Suisun Bay. This yielded new information on San Francisco Bay's sediment budget and availability of sediment for restoration in the Bay (McKee et al. 2006).

Status of Topic Today

The RMP-funded study implies that, given the decreasing mass of sediment entering San Francisco Bay from the Central Valley and Delta, less sediment will be available for restoration of wetlands that require either dredged material reuse or natural sedimentation, and furthermore that restoration of the connectivity of near-channel floodplain to stream channels (e.g. tidal restoration of salt ponds) will capture even

more sediment, greatly reducing sediment deposition elsewhere in the Bay (McKee et al. 2006).

The Delta LTMS is studying the best options for the reuse of dredged material for beneficial purposes, and is largely built upon the successes of the DMMO established for San Francisco Bay. Five areas the Delta LTMS is focusing on include:

- Compile a 20-year projection for sediment generation in the Delta.
- Identify and prioritize projects suitable for use of dredged material (with priority given to levee reconstruction and ecosystem restoration projects).
- Document economic impacts.
- Refine cost estimates for dredging, placement, storage, and treatment.
- Establish a standardized testing and treatment protocol for dredged material (Guillen 2007).

According to the projected timeline for the Delta LTMS effort, a programmatic EIS/EIR is expected to be certified by late summer 2009, and adoption of a Delta LTMS sediment management plan is slated for the end of 2009 (DLTMS website 2007).

Planned Projects for Implementation

Data needs that have been identified are being pursued as the Delta LTMS effort moves forward. As of February 28, 2007, all members of the Executive Committee (a board of representatives from agencies that regulate dredging in the Delta) had signed the Delta LTMS Charter, and the Management Committee and numerous Technical Work Groups are meeting regularly.

The State Board's Sediment Quality Objectives process will include the development of appropriate chemistry and bioassay testing protocols, and a risk-based approach to classification of Delta sediments. This information will be very useful to the Delta LTMS effort, as a foundation upon which "work windows" can be evaluated, the dredging permit process clarified and streamlined, and sediment disposal options can be evaluated.

The overall objective of the Delta LTMS effort is to develop a dredging and reuse program for the Delta, modeled after the successful LTMS program and DMMO established for the San Francisco Bay Area. To the extent that the Delta LTMS effort is successful in achieving the levels of commitment and coordination that regulatory agencies are employing in implementation of the Bay LTMS through their established DMMO, there should be no impediments to implementation of the aforementioned activities.

With respect to sedimentation, the RMP-funded study suggests that analysis of suspended sediment concentration data collected at Mallard Island be used to estimate sediment flux to San Francisco Bay from the Delta; partially to verify new findings on loads from the Central Valley, but more importantly to expand data collection and analysis to address contaminants of concern (particularly those that bind to sediment) (McKee et al. 2006).

Impediments to Implementation

Formation of a DMMO is a large logistical issue requiring significant input and cooperation from entities that regulate dredging in the Delta, especially the Corps and USEPA. The Delta LTMS process is promoting early coordination and formation of the DMMO to allow time for resolution of staffing, funding, and other logistical issues (www.deltaltms.com).

References

CALFED Bay-Delta Program. 2000a. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

Central Valley Regional Water Quality Control Board, California Department of Fish and Game, and Delta Protection Commission. 2002. Delta Dredging and Reuse Strategy. Volume I. June. 2002. Sacramento, CA.

Delta Long-Term Management Strategy (DLTMS) website: www.deltaltms.com Accessed on 6/28/07.

Guillen, S. Flooding and Delta Levees. Delta Blue Ribbon Task Force Context Memo. April 27, 2007.

Jones & Stokes, Inc. 1998. Hamilton Wetlands Restoration Project, Final EIR/EIS. ERP-98-C03. Dec. 1998.

McKee, L. J., N. K. Ganju and D. H. Schoellhamer. 2006. Estimates of Suspended Sediment Entering San Francisco Bay from the Sacramento and San Joaquin Delta, San Francisco Bay, California. Journal of Hydrology 323:335-352

Wright, S. A. and D. H. Schoellhamer. 2004. Suspended-Sediment Transport Where Rivers Become an Estuary: Sacramento-San Joaquin Delta, Water Years 1999-2002. CALFED 2004 Science Conference Abstract.

Wright, S. A. and D. H. Schoellhamer. May 2004. Trends in the Sediment Yield of the Sacramento River, California, 1957-2001. San Francisco Estuary and Watershed Science. 2(2):Article 2.

5. STRESSORS

5.5. Gravel Mining

Introduction

The natural sediment supply of Central Valley rivers and streams is composed of mineral and organic fines, sands, gravel, cobble, woody debris (e.g. tree branches and root wads), and sediments that naturally enter, transport and erode through the system. Sediment is one of the natural building blocks of the ecosystem on which many other ecological processes, functions, habitats and species depend. Gravel, for example, is important for maintaining spawning habitat of salmon and steelhead, and supports many invertebrates on which young fish prey. Finer sediments and fluvial (flowing water) processes create the conditions necessary to establish new riparian forests and wetlands.

Human activities have had significant adverse effects on natural sediment processes in the Bay-Delta watershed. Removal of sand and gravel from active stream channels is one of the most prominent of these activities. Both abandoned and active mining sites exist on virtually every stream or streamside alluvial deposit throughout the ERP study area (Reynolds et al. 1993).

Sand and gravel mining has affected channel-floodplain function and aquatic and riparian habitats along the San Joaquin River, Sacramento River and their tributary streams. Gravel mining impairs sediment transport, gravel recruitment, and stream channel meander processes.

Riparian communities are affected by mining in several ways. Riparian vegetation can be directly removed or destroyed during construction of access roads, mine areas, and storage areas. Riparian vegetation can also be lost by degradation and streambank undermining. Degradation and reductions in the groundwater table destroy shallow-rooted riparian forest in large areas surrounding gravel mines.

Fish are directly affected by gravel removal. Anadromous fish use gravel for spawning, and mining can affect the quality and quantity of spawning gravel. Various factors are affected by changes in stream morphology (e.g. stranding, higher water temperatures) and can affect fish passage and survival in an area.

Applicable ERP Vision

The vision for gravel mining is to improve instream gravel transport and cleansing by reducing the adverse effects of instream gravel mining. Reducing or moving intensive mining operations off of the active stream channel, and relocating them to alluvial deposits outside the active channel, will allow stream restoration efforts, flood management, and erosion control to continue (CALFED 2000a).

The Strategic Objective is to restore coarse sediment supplies to sediment-starved rivers downstream of reservoirs to support the restoration and maintenance of functional natural riverine, riparian, and floodplain habitats.

Stage 1 Expectations

Stage 1 Expectations included: the identification of sediment-starved channels in the Bay-Delta system; development of strategies to mitigate sediment starvation, such as shifting the mining of gravel from river channels to alternate sources, adding gravel below dams, and removing nonessential dams; and the implementation (and monitoring) of demonstration projects to mitigate sediment starvation in at least six rivers. Most gravel work was expected to be implemented in subsequent ERP stages with designs and plans for ecosystem reclamation of gravel mining sites (CALFED 2000b). There are also specific expectations for gravel mining in various EMZs and EMUs.

Changes Attributable to ERP

A number of ERP projects, classified as river channel restoration projects, were planned and implemented to mitigate for the negative impacts that historic gravel mining practices had on instream and riparian habitats. In addition to the projects mentioned below, other "restoration" projects are covered in their respective EMZ/EMU chapters.

Several river restoration projects along the Tuolumne, Merced, and Consumes Rivers in the San Joaquin drainage, and tributaries to the Sacramento River including Clear Creek, were funded by ERP to repair degraded stream channels and riparian habitat, and to restore ecological processes impaired by historic aggregate mining practices.

The Tuolumne River Channel Restoration (Pool 9) (**ERP-97-M08**) was one of several large-scale salmon habitat restoration projects. Project goals were to reduce losses to out migrating salmon fry and smolts due to predation by non-native species, improve rearing conditions for out migrating fry and smolts, and replace lost riparian forest. The project consisted of filling in an inchannel mining pit left from when such activities were allowed in the river channel. The pit created a large lake-like environment that was

providing prime habitat for largemouth bass, which are primary predators on outmigrating juvenile salmonids. Pool 9 was 500 feet wide by 1,200 feet long and 19 feet deep. The project temporarily diverted the Tuolumne River while filling the pit area with 144,000 cubic yards of river aggregate mixed with topsoil to create a narrow low flow channel and a new 4.5-acre floodplain.

Two projects, *Tuolumne River Setback: Dikes and Channel Restoration, Mining Reach 7/11 Segment* (**ERP-97-M09**) and *Tuolumne River Floodway Emergency Repair and Long-Term Habitat Restoration Project (7/11)* (**ERP-98-F06**), filled mining pits, removed dredger tailings, constructed setback levees, and restored the channel and floodplain in a section of the Tuolumne River extensively mined for aggregate material. The Mining Reach was divided into four segments. The segment farthest upstream (the 7/11 Materials Project) removed dredger tailings at the upstream end of the 2.6 mile reach; partially filled mine pits and settling ponds; constructed two high flow scour channels on the south bank floodplain; constructed and upgraded dikes along the entire south bank; reconstructed the channel downstream from the Roberts Ferry Bridge; and revegetated the 21.8 acres of reconstructed floodplain with native riparian vegetation. Approximately 420,000 cubic yards of aggregate and topsoil were needed to complete this segment. Most of the fill material was obtained from on-site dredge tailings and pit-run aggregate from the 7/11 Materials Plant. Construction was completed in March 2003 and revegetation was completed in December 2004.

A levee separating a gravel extraction pit from the Tuolumne River was damaged during the 1997 floods connecting the deepwater habitat with the Tuolumne River. The *Tuolumne River Special Run Pool 10 (Levee Repair and Monitoring) Project* (**ERP-99-F01**) reduced habitat for predators of juvenile salmonids by repairing the levee and isolating the mining pit from the Tuolumne River. This project also collected a second year of pre-project monitoring to better establish baseline conditions for the full SRP 10 restoration project. The levee breach repair was completed in 2001 and the pre-project monitoring was completed in early 2002.

Lower Clear Creek Floodway Restoration Project (Phase II) (**ERP-98-F15**) restored 2.9 miles of floodplain and riverine aquatic habitats in two locations on lower Clear Creek. The objective of the project was to reverse channel degradation caused by historic aggregate extraction in the mined reach.

Two ERP projects on the Merced River restored the river to near-original channel salmon redd production, after floods in 1997 re-routed the channel through a maze of deep, predator-bearing ponds created during historic gravel mining operations. The *Merced River Salmon Habitat Enhancement Project Phase II- Ratzlaff Reach* (**ERP-99-B05**) and *Merced River Salmon Habitat Enhancement Project Phase III- Robinson Reach* (**ERP-98-F11**) is characterized by 3.5 miles of gravel pits created over the last thirty years. The mining pits were excavated during the 1970's to a depth of fifteen to twenty feet, or about 10 feet below the low water level. The berms which once

separated the gravel pits from the river have been reduced over the years to low islands along the river channel. The reach still had one functioning berm at the upstream end of the project until early 1997, but it failed that year due to sustained high flows during January floods. The failure of the berms in the project area allowed the river to change course and flow through a large abandoned gravel pit. This created prime habitat for non-native predatory fish species, i.e. largemouth and smallmouth bass. The predatory fish could then prey on outmigrating juvenile salmonids as they became disoriented and stressed in the warm, deep, slow moving water passing through the ponds. The reconstructed berms isolated approximately 45 acres of ponds from river. In addition to restoring the berms, 3000 ft of channel was modified by recreating meander in the main channel, providing 7000 sq ft of spawning habitat, and replanting the riparian zone along the restored channel with native riparian plants.

Project Summary Table

Table 1. Gravel Mining Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
CVPIA-01-F14	**Tuolumne River Mining Reach Restoration No 3 - Warner-Deardorff Segment** Completed the design engineering started under the MJ Ruddy Project, engineering for the ROW acquisition, and the pre-project monitoring for the Warner-Deardorff segment of the Tuolumne River Mining Reach project.	12/31/2005	$518,670	Complete.
ERP-00-E03	**Cottonwood Creek Watershed Monitoring and Assessment** Continued management of the Cottonwood Creek Watershed Group to oversee the implementation of a watershed plan. This phase would assess current conditions in the watershed, both as to the land and stream conditions, and to give a baseline for future projects.	12/31/2003	$350,000	Complete.
ERP-00-E05	**Merced River Corridor Restoration Project - Phase III** Developed a publicly supported, technically sound, and implementable restoration plan for the Merced River corridor from Crocker-Huffman Dam downstream to the San Joaquin River.	11/1/2002	$341,271	Complete.
ERP-01-N30	**Digital Soil Survey Mapping and Digital Orthophotoquad Imagery Development** Made soils information more accessible to individuals and groups engaged in ecosystem restoration projects in the Bay-Delta Region, and in doing so, improved the responsiveness of these projects to established habitat and supported sustainable populations of valuable species.	8/15/2004	$430,390	Complete.
ERP-05D-S18	**Lower Clear Creek Floodway Rehabilitation Project (Phase 3B)** Will reconstruct the bankfull channel, monitor project implementation, and stabilize a headcut.	1/31/2010	$3,482,451	Ongoing.

Table 1. Gravel Mining Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-95-M04	**Sacramento River Spawning Gravel Restoration Project (below Keswick Dam)** Restored several miles below the Keswick Dam on the Sacramento River by introducing spawning-sized gravel for natural redistribution and use by salmon as spawning habitat.	11/1/1995	$39,400	Complete.
ERP-97-M08	**Tuolumne River Channel Restoration (Pool 9)** Filled mining pits and constructed setback levees in the Tuolumne River at river mile 25.9 to remove predator habitat and enhance riverine processes and salmonid habitats.	2/28/1999	$2,253,100	Complete.
ERP-97-M09	**Tuolumne River Setback: Dikes and Channel Restoration, Mining Reach 7/11 Segment** Filled mining pits, removed dredger tailings, constructed setback levees, and restored the channel and floodplain in a 2.6 mile section of the Tuolumne River extensively mined for aggregate material. Other project funding is associated with ERP-98-F06.	12/31/2004	$2,801,000	Complete.
ERP-97-N06	**Butte Creek Riparian Protection and Restoration Project** Provided a portion of the funds for the acquisition of the McAmis Property, development of a management plan for the Ecological Preserve, and incorporation of the site into the Butte Creek Education Project.	12/31/2001	$187,128	Complete. Acquired 93.40 acres of riparian habitat.
ERP-98-F06	**Tuolumne River Floodway Emergency Repair and Long-Term Habitat Restoration Project (7/11)** Filled mining pits, removed dredger tailings, constructed setback levees, and restored the channel and floodplain in a 2.6 mile section of the Tuolumne River extensively mined for aggregate material.	6/30/2004	$1,358,846	Complete.
ERP-98-F11	**Merced River Salmon Habitat Enhancement Project Phase III- Robinson Reach** Worked to restore natural conditions to Merced River habitat at river miles 42 to 43.5. Restoration efforts included filling/isolating deep pools, reconfiguring channel and floodplain characteristics, and increasing riparian habitat. These actions helped eliminate predator habitat, improve spawning and rearing habitat, and vegetate riparian areas.	9/30/2002	$2,433,000	Complete.
ERP-98-F15	**Lower Clear Creek Floodway Restoration Project (Phase II)** Restored 2.9 miles of floodplain and riverine aquatic habitats on lower Clear Creek. Objectives of the project were to reverse channel degradation caused by historic aggregate extraction in the mined reach.	6/30/2006	$4,561,940	Complete.

Table 1. Gravel Mining Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-B05	**Merced River Salmon Habitat Enhancement Project Phase II- Ratzlaff Reach** Reduced entrainment and predation of out migrating fish. Isolated 45 acres of unnatural predator habitat created during gravel mining operations. Improved river and floodplains dynamics and enhanced the riparian corridor.	3/30/2000	$1,584,002	Complete.
ERP-99-F01	**Tuolumne River Special Run Pool 10 (levee repair and monitoring)** Repaired a dike at an off-channel mine pit in the lower Tuolumne River to reduce predation on juvenile Chinook salmon.	3/31/2006	$164,800	Complete.
ERP-99-F02	**Tuolumne River Mining Reach Restoration (MJ Ruddy)** Reconstructed 1.1 miles of the lower Tuolumne River channel and floodplain that was previously diked for gravel mining and then destroyed by the January 1997 floods for the primary benefit of San Joaquin fall-run Chinook salmon.	3/31/2006	$168,813	Complete. Restored a 1.1 mi reach of river to a more natural channel by creating a 500 ft wide floodplain and repaired 100 ft of berm breached in 1997 flood.

Other Programs Contributing to ERP Vision

The Central Valley Improvement Act (CVPIA) mandates federal agencies to make changes in the management of the Central Valley Project, particularly for the protection, restoration, and enhancement of fish and wildlife. CVPIA's Anadromous Fish Restoration Program (AFRP), managed by the US Fish and Wildlife Service, works diligently with diverse interest groups in funding or supporting various restoration programs, activities, and efforts beneficial to the restoration of the Sacramento and San Joaquin River systems. CVPIA/AFRP is involved with most river restoration projects in the ERP Study area and was a cost share partner for many ERP projects. Local water districts, gravel mine owners, and RCDs share the burden of restoring stream reaches affected by past gravel mining operations

Status of Topic Today

As the environmental impacts of aggregate extraction from river channels become better understood, the practice has received increased scrutiny, especially in salmon-bearing rivers and streams (Kondolf et al. 2002). Captured floodplain pits have been identified as a principal factor limiting recovery of Chinook salmon populations in the Sacramento and San Joaquin River system in California. To eliminate predation by exotic warmwater fish, the pits must be filled completely; or partially filled, with the fill portion separating the part of the pit that remains open-water. To preserve the hydraulic conductivity of the aquifer, the pit must be filled with something like gravel

and sand. This material may have to be derived from a mine elsewhere; or, as in projects along the Tuolumne and Merced Rivers and Clear Creek in California, gold dredger tailings may (and have) been used (Kondolf et al. 2002).

Increasingly, modern gravel mining operations have been moved off-channel, reducing the impacts of instream mining. Modern, environmentally sound aggregate mining operations are necessary for local economic development as well as providing a source of clean, proper sized gravel products for future channel restoration projects and gravel augmentation used to create spawning habitat in sediment starved reaches.

Planned Projects for Implementation

Tuolumne River Restoration Monitoring (**ERP-04-S04**) is "funded but not executed". This project proposes to monitor the effectiveness of four restoration projects on the Tuolumne River. Monitoring components include channel morphology, sediment transport, riparian vegetation, salmonid distribution and abundance, and salmonid habitat. Projects for which monitoring is proposed are: (1) Gravel Mining Reach Restoration (7/11 reach and M.J. Ruddy reach), (2) Special Run Pool 9 Restoration, (3) Fine Sediment Management, and (4) Coarse Sediment Management (Phases I through III, including coarse sediment augmentation at the Friends of the Tuolumne Bobcat Flat site).

Lower Clear Creek Monitoring Program (**ERP-04-S05**) and *Lower Clear Creek Floodway Rehabilitation Project (Phase 3B)* (**ERP-05D-S18**) are both "ongoing" and continue to meet ERP's goal for completing the restoration tasks and monitoring the geomorphic changes at both the project scale and on the entire watershed.

Impediments to Implementation

As populations increase and demands for new infrastructure follow, there is a growing demand for gravel products. Increased operating costs and regulatory compliance for gravel plant owners will be passed onto consumers and with new sources of gravel supply being proposed and developed, the environmental impacts of aggregate mining will be moved from instream channels to floodplains or off-channel habitats. Spawning gravel augmentation projects rely on finding sediment sources to replace the supply blocked by damming rivers and streams. Supplying these sediments from off-channel sources or from adjacent watersheds may result in new sediment starved streams.

References

CALFED Bay-Delta Program. 2000a. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2000b. Ecosystem Restoration Program Plan - Strategic Plan for Ecosystem Restoration. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

Kondolf, G. M., M. Smeltzer, and L. Kimball. 2002. Freshwater Gravel Mining and Dredging Issues. White paper prepared for Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. Center for Environmental Design Research, U.C. Berkeley, CA. April 4, 2002.

Reynolds, F.L., T.J. Mills, R. Benthin, and A. Low. 1993. Restoring Central Valley Streams: A Plan for Action. California Department of Fish and Game. 217 pg.

5. STRESSORS

5.6. Invasive Species

5.6.1. Invasive Aquatic Plants

Introduction

Weeds, or invasive plant species, are types of vegetation capable of exploiting opportunities afforded by natural or human-related disturbances in the landscape, though they can also invade relatively undisturbed habitats. Most, although not all, weeds are non-native and have been introduced from other parts of the world.

Invasive aquatic plants have become sufficiently established in some locations to threaten the health of the Bay-Delta ecosystem. The aquatic plants that pose the greatest threat to aquatic ecosystems are those that directly or indirectly affect rare native species, decrease foodweb productivity, and reduce populations of desired fish and wildlife species. The degree of influence invasive aquatic plants have on the Bay-Delta depends on site disturbance, climate, the rate of introductions of invasive plants into waterways, characteristics of the plant and animal communities, the substrate (e.g. soil) that a weed species is introduced to, and whether local water quality and hydrologic conditions favor their establishment.

Without the controls found in their native habitat (e.g. specific insects for which they are a food source, pathogens, or toxins produced by competing plants), these plants can flourish in a new landscape, gaining a competitive advantage over the native species. Many weeds have evolved characteristics that make them extraordinarily competitive in both natural and introduced environments, such as high seed production; mechanisms for effective seed dispersal; vegetative reproduction (a clone growing from stems, roots or some cases just a fragment of tissue from the parent plant); rapid growth rate; and adaptability to extremes of temperature, nutrients, and water availability.

A species is considered a problem weed if it adversely affects natural communities or human land use requirements. Introduced or native aquatic plant species are considered harmful when they reduce the biological diversity of existing natural communities by displacing native species or altering ecosystem processes such as nutrient cycling, hydrologic conditions, or water chemistry. They create problems for human society when they impair agricultural or aquacultural productivity, constrict waterways, diminish recreation and aesthetic values, or destroy structures.

Most aquatic weeds were introduced to California waterways unintentionally. They were brought in as pond ornamentals (e.g. water hyacinth), aquarium plants (e.g. *Hydrilla*), contained in the ballast water of ships, or attached or snagged on the outside of a boat. Aquatic weeds have been here for at least 100 years; water hyacinth was discovered in a Yolo County slough in 1904. *Hydrilla*, which was probably introduced through its use as an aquarium plant, has been in California for at least 20 years. *Egeria*, still a popular aquarium plant, has been in the ecosystem for over 30 years.

Most aquatic weeds pose a threat to the aquatic foodweb and rare aquatic or riparian species because they form dense mats that block sunlight or deplete oxygen supplies. The sheer mass of floating tissue can also impede navigation and the flow of water in natural waterways as well as man-made water delivery systems. Establishment of invasive aquatic plants can harm or kill rare and valued fish, native plants, and other aquatic organisms; reduce biodiversity; impede navigation; damage water control structures; and increase mosquito habitat.

Many stream and river channels in the Delta and the Sacramento and San Joaquin Rivers and their tributaries have been channelized, confined by levees, impounded, and otherwise altered from their shapes of 150 years ago. With the conversion of adjacent riparian communities to other land uses, the ecosystem processes and functions have changed substantially. These changes stress native aquatic flora and fauna, leading to changes in species composition and population densities, and perhaps making the aquatic foodweb more vulnerable to further stressors, such as infestation by aquatic weeds.

Most weeds that infest the Delta and the Sacramento and San Joaquin Rivers and their tributaries are problems in specific locations, not throughout these waterways; however, the locations of aquatic weeds have not been comprehensively mapped. The California Department of Food and Agriculture's Integrated Pest Control Branch records locations where aquatic weeds, such as *Hydrilla*, pose a threat to agriculture. Locations of weeds that threaten natural areas are not recorded. Comprehensive mapping throughout the ERPP study area is needed for all weeds that threaten aquatic habitat as a first step to monitoring and controlling infestations.

Some of the non-native aquatic weeds that pose the most serious threats and need further research, monitoring, mapping, or control are *Egeria*, *Hydrilla*, water hyacinth, water pennywort, Eurasian watermilfoil and parrot feather. These weeds flourish in a wide geographic area, sometimes in high densities, and are extremely dangerous because of their ability to displace native plant species, harm fish and wildlife, reduce foodweb productivity, or interfere with water conveyance and flood control systems.

Applicable ERP Vision

The vision for invasive aquatic plants is to reduce their adverse effects on native species and ecological processes, water quality and conveyance systems, and major rivers ant their tributaries.

One goal for non-native invasive species (NIS) as a whole is to prevent the establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-native species in the Bay-Delta estuary and its watershed.

The strategic objective is to halt the introduction of non-native invasive aquatic and terrestrial plants into the Bay-Delta estuary and its watershed, and other central California waters, and to limit the spread or, when possible and appropriate, eradicate populations of non-native invasive species through focused management efforts.

The long-term objective is to halt the release and spread of aquarium organisms, exotic plants and aquatic pets in the Bay-Delta Watershed, and eliminate, or control to a level of little significance, all undesirable non-native species, where feasible.

The short-term objective is to develop and institute strategies for working with the aquarium industry and interests representing the environment and other sectors that may be affected by such introductions, to halt the introduction and spread of non-native species and exotic plants from the aquarium and pet trades. This would begin with eradicating or containing those species for which this can most readily be done, thereby gaining the largest benefit with the least economic and environmental cost. It is also important to monitor for the arrival of new invasive species and, where feasible, respond quickly to eradicate them.

Stage 1 Expectations

Stage 1 expectations included targeting the aquarium and pet trades to identify and evaluate their contribution to establishing populations of invasive aquatic plants in the Bay-Delta system. With the cooperation of the aquarium/pet industry and affected interests, a plan was to be developed and instituted to greatly reduce, and eventually eliminate, the introduction of unwanted aquatic organisms from these sources into natural waters.

In addition, an assessment of existing introductions was to be completed to identify areas with the greatest potential for containment or eradication, and consider this in prioritizing control efforts. A program was to be developed and implemented to monitor for new invasions; as well as develop a mechanism whereby new invasions can be dealt with quickly and effectively, whenever possible.

Changes Attributable to ERP

In addition to the outreach and education projects listed in other sections of this report, projects such as the *Non-native Invasive Species Advisory Council (NISAC)* (**ERP-99-F05**), *Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education* (**ERP-99-F06**), *Reducing the Introduction and Damage of Aquatic Nonindigenous Species through Outreach and Education, Phase 2* (**ERP-02-P37**), and *CALFED NIS Program* (**ERP-06D-S17**), also provided outreach and education by holding and attending workshops, producing publications, and designing and hosting websites.

NISAC (**ERP-99-F05**) was developed and maintained to be responsible for the coordination and implementation of activities and projects that address NIS in the CALFED area of concern. In late 2007, the NISAC recommended that the Ecosystem Restoration Program review the Habitat Analysis and Critical Control Point planning process (http://www.haccp-nrm.org/) and consider incorporating HACCP plans into field work conducted under the auspices of CALFED, both by staff and by contractors. The *CALFED NIS Program* (**ERP-06D-S17**) implements NIS management coordination and prevention, including continued coordination of the NISAC. The *CALFED NIS Program* implements NIS management coordination and prevention.

The *Water Hyacinth Education Program* (**ERP-98-B38**) distributed educational materials to Delta residents, which encourages waterway users to help achieve long-term control of hyacinth in the Delta region. The project *Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education* (**ERP-99-F06**) developed a series of directed educational products and services that that brought together experts in NIS biology with members and representatives of a wide range of industries that may potentially be involved in the importation, sales, or distribution of NIS. The project *Practical Guidebook to Prevent and Control Non-native Invasive Plants in Shallow Water Habitats of the Bay-Delta Ecosystem* (**ERP-99-F10**) developed a guidebook that provides practical information for local control of the highest priority species of non-native invasive plants in shallow water habitats of the landscape of the Bay-Delta watershed.

Reducing the Introduction and Damage of Aquatic Nonindigenous Species through Outreach and Education, Phase 2 (**ERP-02-P37**) worked to prevent future invasions by educating industries involved in the sales and distribution of non-native species including the aquaria and pet trade, seafood importers, landscape contractors, nurseries and aquatic plant dealers, seafood importers, bait dealers, and others, about the costs and consequences of unwanted introductions. The project provided: 1) a series of outreach workshops, 2) the development of best management practices manuals for industries that sell non-native invasive species, 3) creation of an educational poster for

broad distribution, 4) industry magazine and websites ads and articles, 5) a short video segment for display on commercial airplanes, local cable channels and other low cost, high exposure venues, 6) maintenance of a project website that will serve as an online source of information, and 7) project management.

Life History of Egeria Densa in the Delta: Factors Controlling Production and Fragment Viability (**ERP-02-P18**) researched the life history patterns and competitive strategies of *E. densa* growing in the Delta. Growth rates, photosynthetic responses and nutrient content of *E. densa* were measured monthly for 18 months from plants collected in Disappointment Slough in the Delta. The establishment success of *E. densa* fragments (its sole method of spread outside its native range) and its photosynthetic responses under controlled greenhouse conditions were also evaluated. Plants did not senesce during the study period (Dec. 2003 to June 2005). *E. densa* stem fragments were floated above sediment-filled pots and, after 11 weeks, 100% of the stems survived and 50% successfully rooted. Compared to other submersed aquatic plants, *E. densa* efficiently saturates at low light intensity, partially explaining its success in the turbid waters of Disappointment Slough. *Egeria* growing in the Delta does not appear to be limited by nitrogen, which is usually the limiting nutrient for aquatic plants. Water temperature throughout the study did not exceed 25ºC, thus *E. densa* did not senesce as observed in other areas where water temperature can exceed 30ºC. Lastly, the survival and success of *E. densa* stem fragments reinforces the need to remove fragments after harvesting.

Project Summary Table

Table 1. Invasive Aquatic Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02D-P54	**Restoring Ecosystem Integrity in the Northwest Delta: Phase II** This project proposes to acquire conservation easements within the Cache Slough complex, along the Barker, Lindsey and Calhoun Sloughs, north Delta tidal channels located west of the Yolo Bypass.	8/31/2008	$1,781,658	Ongoing. Acquired conservation easements on 1,100 acres of existing riparian, wetland and/or agricultural lands. Currently no willing sellers.
ERP-02D-P56	**West Coast Ballast Outreach Project** The goal is to reduce the number of aquatic nuisance species (ANS) that are introduced to the west coast of the U.S.A. via ballast water discharges from merchant vessels. This training includes the distribution of educational materials, a website, and ballast water management practices. Was ERP-02-P20-D.	12/31/2008	$478,395	Ongoing. Education on ballast water discharge issues.

Table 1. Invasive Aquatic Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P18	**Life History *of Egeria densa* in the Delta: Factors Controlling Production and Fragment Viability** The purpose of this project was to develop a mechanistic understanding of the life history of a highly invasive aquatic plant, *Egeria densa* (Brazilian elodea), in order to improve management and restoration efforts in the Delta.	12/31/2006	$327,937	Complete.
ERP-02-P21	**Restoring Ecosystem Integrity in the Northwest Delta: PHASE II** The project's goal is to manage and restore up to 1300 acres of perennial grassland/vernal pool complex in Solano County, CA, and develop a management plan for the Pembco property or other acquisition within the JPP Island Corridor.	8/31/2008	$246,370	Ongoing. Planning, outreach, experimental treatment plots, to determine restoration methods.
ERP-02-P37	**Reducing the Introduction and Damage of Aquatic Nonindigenous Species through Outreach and Education, Phase 2** The project used workshops, industry magazine ads and articles, best management practices manuals, and enhancement of an existing website to educate industries, such as landscapers or hobby aquarium suppliers, that sell or distribute non-native species about the costs and consequences of unwanted introductions.	2/28/2006	$156,951	Complete.
ERP-06D-S17	**CALFED NIS Program** Non-Native Invasive Species (NIS), Zebra Mussel Prevention, Zebra Mussel Rapid Response.	6/30/2009	$750,000	Ongoing. USFWS will continue to work with the NIS Agency and Stakeholder Teams to implement and administer the NIS program, as developed and documented in the NIS Strategic and Implementation Plans. Develop Zebra Mussel Response Plan.
ERP-97-N11	**Demonstration Project for the Protection and Enhancement of Delta In-Channel Islands** Demonstrated effective biotechnical methods to reduce erosion of in-channel islands and adjacent delta island banks.	5/29/2000	$270,270	Complete. Demonstration project for organizational, administrative, pre-evaluation of sites, and permitting.
ERP-98-B38	**Water Hyacinth Education Program** The project involved the distribution of educational materials to Delta residents, which encourages waterway users to help achieve long-term control of hyacinth in the Delta region.	12/31/2001	$9,598	Complete. An educational project that informed people of the problems associated with invasive plants.

Table 1. Invasive Aquatic Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** CMARP is an adaptive management strategy for implementing proposed changes and ongoing activities to many aspects of the Bay-Delta/Central Valley environment and water management system. CMARP was to provide information and scientific interpretations necessary for program implementation and to judge the Program's success. CMARP providds information on all of the CALFED program elements and contributes to the mitigation design.	12/31/1999	$800,000	Complete.
ERP-98-E11	**Watershed Restoration Strategy for the Yolo Bypass** Facilitated a broad-based local stakeholder group in development of watershed plan.	3/31/2002	$287,353	Complete. Developed an ecosystem restoration strategy.
ERP-99-B27	**Watershed Educational Training (WET) Program** This project increased public awareness of watershed issues through implementation of the Colusa County Resource Conservation District's (CCRCD) Watershed Educational Training (WET) project, which linked community watershed health with the ecological objectives and goals identified by the CBDA. The project was completed successfully and according to the final project summary, the educational projects reached approximately 61,365 people.	6/30/2003	$12,887	Complete.
ERP-99-F05	**Non-native Invasive Species Advisory Council** Developed and maintained Non-native Invasive Species Advisory Council, an organization which is responsible for the coordination and implementation of activities and projects that address the issues of NIS in the CALFED area of concern.	11/30/2004	$50,000	Complete. Establishment of the Non-native Invasive Species Advisory Council (NISAC).
ERP-99-F06	**Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education** Developed a comprehensive program of outreach and education that will result in reducing the probability of the introduction of new Non-native Invasive Species (NIS) and minimize the spread of existing NIS in the San Francisco Bay-Delta region.	5/31/2003	$105,466	Complete.
ERP-99-F10	**Practical Guidebook to Prevent and Control Non-native Invasive Plants in Shallow Water Habitats of the Bay-Delta Ecosystem** Developed guidebook that provides practical information for local control of the highest priority species of non-native invasive plants of shallow water habitats of the landscape of the Bay-Delta watershed. The guidebook is available online, and is an effective educational tool for increasing knowledgeable local efforts to prevent and control shallow water invasions by non-native plants.	7/31/2002	$76,725	Complete.

Other Programs Contributing to ERP Vision

In 2006 CDFG released a draft of the "California Aquatic Invasive Species Management Plan." Following public review and input from other agencies, constituent groups, NGO's and academia, the plan was finalized and signed by the governor in January of 2008. The main purpose of the plan is to coordinate efforts by state agencies to minimize the harmful ecological, economic and human health impacts of aquatic invasive species. The plan proposes management actions and a rapid response process for addressing aquatic invasive species (AIS) threats to California. The plan also recognizes monitoring efforts by CSLC, DFG/OSPR, and CDFA, and identifies gaps in the current programs.

The DBW's *Egeria densa* Control Program (EDCP) treated 19 sites in the Delta, with the largest treatment acreages being at Franks Tract, Rhode Island, Big Break Wetlands, Venice Cut, and Little Venice Island. The EDCP's annual treatment acreage averaged 466 acres per year, with a maximum of 622 acres in 2005 (DBW 2006).

Status of Topic Today

Mapping of invasive plants is necessary for monitoring their spread and to direct treatment. The California Department of Boating and Waterways (CDBW) is the lead agency for the survey and control of Egeria (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*) in the Sacramento/San Joaquin Delta. *E. densa* now covers approximately 12,000 acres or 24% of the Delta (Newman 2006). It has been growing at a rate of approximately 1,000 acres per year. Water hyacinth covers approximately 5,000 acres or 10% of the Delta and grows exponentially during the hot summer months (Newman 2006). The DBW *Egeria* and water hyacinth programs use two tools to determine the coverage and bio-mass of these invasive species: hyperspectral analysis and hydroacoustic measurements. The UC Davis Calspace Center of Excellence, in cooperation with CDBW and the CDFA, investigated the use of hyperspectral imagery at two spatial scales. Spectral mixture analysis was used to classify *Egeria* and water hyacinth (Underwood et al. 2006). They found that at a relatively fine spatial scale for five sites within the Delta (average size 51 ha) average classification accuracies were 93% for Egeria and 73% for water hyacinth. However, at the coarser scale, Delta-wide scale (177,000 ha) these accuracy results were 29% for *Egeria* and 65% for water hyacinth. Underwood et al. (2006) suggested that the difference in accuracy was likely accounted for by the broad range in water turbidity and tide heights encountered across the Delta. Hydroacoustic plant mapping technology has aided in the assessment of Brazilian waterweed coverage and biovolume which has proven instrumental in evaluating efficacy of treatment by CDBW (Ruch and Kurt 2006). A key asset of the technology is that it yields a very rapid, verifiable characterization of the entire water column beneath the transducer (Ruch and Kurt 2006). Efficacy is determined by comparing the aggregation of acoustic-based plant-

coverage and biovolume models, photographs, and physical data at each treated site with control sites (Ruch and Kurt 2006).

Also see the Invasive Aquatic Organisms chapter for additional actions taken in regards to NIS (which include invasive aquatic plants) by the California State Lands Commission (CSLC), the California Department of Fish and Game (CDFG), the State Water Resources Control Board (SWRCB), California Department of Food and Agriculture (CDFA), U.S. Fish and Wildlife Service (USFWS), and the Non-native Invasive Species Advisory Council (NISAC). Due to the significant contribution that *Egeria* makes to shallow water habitat (submerged aquatic vegetation), see also the Delta Sloughs chapter.

Planned Projects for Implementation

The implementation of the "California Aquatic Invasive Species Management Plan," and the continued funding for monitoring by CSLC, DFG/OSPR, CDFA, and DBW, will help ERP meet its Stage 1 commitments.

Impediments to Implementation

EDCP efforts may not result in successful and complete vegetation restoration of in waterways due to the presence of other non-native invasive aquatic weeds (CDBW 2006). Other non-native species that could fill in, and grow to replace *Egeria densa* as it is controlled by the EDCP include, among others, *Myriophyllum spicatum* (Eurasian Watermilfoil) and *P. crispus* (Curlyleaf Pondweed). These other, non-*Egeria*, nonnative species have different growth properties that may require other control approaches and techniques than those used by the EDCP (CDBW 2006).

Successful long-term Delta restoration efforts will ultimately need to address these other non-native invasive aquatic weeds (CDBW 2006). Long-term successful Delta restoration will be dependent on an as yet to be defined Delta-wide Integrated Vegetation Management Strategy (IVMS) (CDBW 2006).

References

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIRTechnical Appendix. Sacramento, CA.

California Department of Boating and Waterways (CDBW). 2006. *Egeria densa* Control Program (EDCP): Second Addendum to 2001 Environmental Impact Report, with Five-Year Program Review and Future Operations Plan.

Newman, G. H. 2006. Efforts to Control Egeria Densa and Water Hyacinth in the Sacramento/San Joaquin Delta. *In* 4th Biennial CALFED Science Conference 2006 Abstracts. Sacramento, CA.

Ruch, S. A. and S. A. Kurt. 2006. Assessing Progress in Brazilian Waterweed Management in the Sacramento-San Joaquin Delta: an Example from Frank's Tract. *In* 4th Biennial CALFED Science Conference 2006 Abstracts. Sacramento, CA.

Underwood, E., M. J. Mulitsch, J. A. Greenberg, M. L. Whiting, S. L. Ustin and S. C. Kefauver. 2006. Large Scale Mapping of Invasive Aquatic Vegetation in the Sacramento-San Joaquin Delta Using Hyperspectral Imagery. Environmental Monitoring and Assessment. 121(1-3):47-64.

5. STRESSORS

5.6. Invasive Species

5.6.2. Invasive Aquatic Organisms (Including Invasive Mussels)

Introduction

Note: Because of the extensive attention given to zebra/quagga mussels, they will be specifically addressed where appropriate.

Invasive aquatic organisms are those non-native fish and invertebrates that have invaded the Bay-Delta at the expense of native species. Non-native aquatic invertebrates of the Bay-Delta include a wide variety of sponges, coelenterates, worms, mollusks, and crustaceans. Most are benthic organisms as adults, but some planktonic forms have also become well established. Most were introduced accidentally from the hulls of ships passing through, or that were abandoned or sunk in the Bay-Delta; from the release of ship ballast water; or from oysters (which usually contain dozens of nestling, symbiotic and parasitic invertebrates) brought in from Japan and the Atlantic coast for aquaculture purposes.

The Bay-Delta estuary historically had relatively low native species diversity; thought to be a result of its relatively young age and isolation from other Pacific Coast estuarine systems. As non-native species arrived, there were important environmental changes that most likely decreased native species' ability to compete with non-native species. These included changes in Bay-Delta morphometry, vegetation, hydraulics, and the amount and timing of Delta outflow.

It is not clear to what extent the decline in abundance of some native species is a result of environmental changes, interactions with non-native species, or (most likely) a combination of those factors. Some non-native species now figure prominently in the diets of fish, shorebirds, and invertebrate-eating waterfowl, and other wildlife species. Certain species, however, have become more abundant in some areas or have been shown to exert a negative effect on ecosystem.

Zebra/Quagga Mussel

While the term zebra mussel has been applied to the genus *Dreissena* as a whole, this is not the case in the US. In the US, Zebra mussel has been used to refer to *Dreissena polymorpha*. When a second species, *Dreissena bugensis*, was later identified from the Great Lakes, it was given the common name of quagga mussel by US researchers.

However, owing to their similarity both in physical appearance and threat posed to the Bay-Delta ecosystem, quagga mussels will be discussed here along with zebra mussels.

Zebra mussels are a highly invasive exotic bivalve first discovered in the Great Lakes region in 1988. Since its introduction, the zebra mussel has caused widespread disruption of important foodweb processes in that region, altered fish species abundances, and impaired water export facilities used for municipal, industrial, and power generation purposes. The zebra mussel was not known to occur in California until just recently, when it was found in San Justo Reservoir in southern California. Quagga mussels were found in a number of locations in southern California along the Colorado River. The introduction of zebra or quagga mussels into California's Bay-Delta watershed would be an environmental and economic catastrophe.

Zebra and quagga mussels are small mollusks marked by alternating light and dark bands. They are typically 2 inches or less in size. Zebra mussels are native to the drainage basins of the Black, Caspian, and Aral seas of Eastern Europe. It is believed that ships originating from European ports carried the mussels in freshwater ballast which was discharged into the Great Lakes. The first North American zebra mussel was discovered in Lake St. Clair, Michigan in June 1988. By September 1991, the mussel was found in all five of the Great Lakes, the St. Lawrence River, the Finger Lakes region of New York, and throughout the Mississippi River basin. The mussel is expected to infest most areas of North America within the next few years (New Hampshire Department of Natural Resources 1998).

Zebra mussels are the only freshwater mussel that can secrete durable elastic strands, called byssal threads, by which they can securely attach to nearly any surface, forming barnacle-like encrustations. Through this mechanism zebra mussels can attach to stone, wood, concrete, iron, steel, aluminum, plastic, fiberglass, and PVC. Zebra mussels typically colonize at densities greater than 30,000 individuals per square meter. They frequently settle in massive colonies that can block water intake and threaten municipal water supply, agricultural irrigation and power plant operations.

Applicable ERP Vision

The vision for invasive aquatic organisms is to reduce their adverse effects on the foodweb and on native species resulting from competition for food and habitat, and direct predation.

Zebra Mussel

The vision was to establish procedures to prevent or delay their introduction and to set up protocols to swiftly treat and eliminate any introduction.

Stage 1 Expectations

The expectations for Stage 1 were to develop and institute strategies - working with the bait industry, the fishing community, and interests representing the environment and other sectors that may be affected by such introductions - to halt the introduction and spread of organisms used as bait in fresh and brackish water. In addition, better mechanisms to treat ballast water to eliminate unwanted organisms were to be developed. Baseline monitoring of the organisms released in ballast water were be initiated to assess progress and monitor compliance. Studies were to be completed to investigate the ecological and economic impacts of introductions into the Bay-Delta system to demonstrate that strong action is warranted.

An aggressive public information program was to be developed in regard to species introductions.

An independent assessment of the pathways, risks and needed management of aquaculture introductions was to be completed; management measures to eliminate by-product introductions will have been adopted and implemented. Species in the aquarium and pet trades were to be identified and evaluated for their ability to establish populations in the Bay-Delta system. With the cooperation of the aquarium/pet industry and affected interests, a plan was to be developed and instituted to greatly reduce, and eventually eliminate, introduction of unwanted aquatic organisms from these sources into natural waters.

An assessment was to be completed of existing introductions to identify those with the greatest potential for containment or eradication, and consider this in prioritizing control efforts. A program was to be implemented to monitor for, and respond quickly to new invasions in order to contain and eradicate these organisms whenever possible. A mechanism whereby new invasions can be dealt with quickly and effectively was to be developed an implemented.

Zebra Mussel

A determination was to be made as to which waters which are most likely to serve as an initial site of invasion for zebra mussels (taking into account both water quality and other environmental factors and the mechanisms likely to transport zebra mussels). A zebra mussel monitoring program for these waters was to be developed, and a rapid response strategy was to be developed to contain and eradicate an incipient zebra mussel invasion.

Changes Attributable to ERP

ERP provided funding for educational outreach and research programs to prevent ballast water exotic species introductions such as *Preventing Exotic Introductions from Ballast Water* (**ERP-97-C07**) and *West Coast Ballast Outreach Project* (**ERP-02D-P56**). Theses projects provided education and outreach to promote practices aimed at preventing the introduction of new aquatic nuisance species (ANS) into the Bay-Delta Estuary and to ensure compliance with the National Invasive Species Act of 1996. The goals were achieved via the following six components: 1) formation of an advisory group representing various involved parties; 2) development and distribution of ANS publications; 3) development and hosting of forums on ballast practices; 4) newsletter initiation; 5) website development and maintenance; and 6) the creation of presentations for participation in other forums. The California Sea Grant Extension Program's West Coast Ballast Outreach Project (WCBOP) coordinates information exchange about ballast water, vessel fouling, and associated Aquatic Invasive Species (AIS) issues along the West Coast of the United States. WCBOP facilitates communication amongst stakeholders in industry, government, academia and research, non-governmental organizations and the public. WCBOP outreach efforts not only provide stakeholders with up to date information on ballast water, vessel fouling and AIS, but also ensure that regulators have access to timely and accurate information when making science-based policy and management decisions.

Determining the Biological, Physical and Chemical Characteristics of Ballast Water Arriving in San Francisco Bay (**ERP-00-F10**) analyzed the data on ballast biota arriving in the San Francisco Bay Estuary to assess the risk of exotic introductions, determine treatment standards, and provided baseline data to assess management or treatment efforts and conduct critical comparative analyses between estuaries. Since 2000, ships entering California have been required to exchange ballast water with oceanic water during the voyage to decrease the number of organisms discharged into the Estuary that had previously been taken aboard at foreign ports. Choi et al. (2005) examined abundance of zooplankton in ballast water of 18 container ships and 48 bulk carriers. Asia dominated the sources of ballast water, which contained multiple non-native zooplankton including species that have invaded and since become common residents in the Estuary. They found that the abundance of zooplankton was significantly lower in ballast water that had been emptied and refilled with oceanic water than those that had continuously been flushed with oceanic water (about three times the volume of ballast water), suggesting that empty–refill is more effective in removing exotic zooplankton.

The U.S. Fish and Wildlife Service (USFWS), Region 8 (formerly California-Nevada Operations), Non-native Invasive Species Program is involved with numerous activities and many diverse partnerships that apply resources to management actions related to the prevention, management, and control of aquatic invasive species. One of its collaborative efforts is the *Non-native Invasive Species Advisory Council* (NISAC) (**ERP-**

99-F05). NISAC is a group of resource agencies' representatives that gathers quarterly to discuss ongoing efforts and opportunities to collaborate on invasive species issues. The NISAC recommends an invasive species prevention approach known as Hazard Analysis and Critical Control Points planning or HACCP. HACCP for natural resources managers is a planning tool that identifies and evaluates potential risks for introducing "non-targets," such as invasive species, chemicals, disease, and other undesirables, during routine activities. It also facilitates the development of methods to reduce those risks. Time is not spent on the analysis of the numerous specific threats, since the goal of HACCP is to identify and address the key management practices that have risk of non-target introductions associated with them. To achieve a sound HACCP plan, the process emphasizes team work, science-based decisions, and monitoring practices so that adjustments can be made as necessary. A written plan also provides continuity as staff turn-over occurs. NISAC could help ERP with developing an overall implementation strategy, provide invasive species expertise, review drafted plans, and assist with raising awareness of the need for natural resource managers to do no harm while implementing restoration work or other projects.

Several projects provided outreach and education through holding and attending workshops, producing publications, and designing and hosting websites, etc. The *Non-native Invasive Species Advisory Council* (**ERP-99-F05**) developed and maintained NISAC, an organization which is responsible for the coordination and implementation of activities and projects that address the issues of NIS in the CALFED area of concern. *Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education* (**ERP-99-F06**) developed a series of directed educational products and services that that brought together experts in NIS biology with members and representatives of a wide range of industries that may potentially be involved in the importation, sales, or distribution of NIS. The *Zebra Mussel Detection & Outreach Program* (**ERP-99-F07**) implemented a combination of public outreach and monitoring first, to provide information to educate the public about zebra mussels and the means by which they spread, and second, to set up and operate an early detection system in the Central Valley, Bay/Delta and water storage and delivery systems throughout the system. *Reducing the Introduction and Damage of Aquatic Nonindigenous Species through Outreach and Education, Phase 2* (**ERP-02-P37**) worked to prevent future invasions by educating industries involved in the sales and distribution of non-native species including the aquaria and pet trade, seafood importers, landscape contractors, nurseries and aquatic plant dealers, seafood importers, bait dealers, and others, about the costs and consequences of unwanted introductions. *Reducing the Introduction and Damage of Aquatic Nonindigenous Species through Outreach and Education, Phase 2* (**ERP-02-P37**) provided: 1) a series of outreach workshops, 2) the development of best management practices manuals for industries that sell non-native invasive species, 3) creation of an educational poster for broad distribution, 4) industry magazine and website ads and articles, 5) a short video segment for display on commercial airplanes, local cable channels and other low cost, high exposure venues, 6) maintenance of a project website that will serve as an online

source of information, and 7) project management. *CALFED NIS Program* (**ERP-06D-S17**) implemented three priority elements of NIS management coordination and prevention as follows: 1) NIS Program Coordination, 2) Zebra Mussel Prevention, and 3) Zebra Mussel Rapid Response.

In September 2007, CDFG completed the eradication of Northern Pike (*Esox lucius*) from Lake Davis, on the Feather River, with ERP funds (*Lake Davis Pike Eradication Project; Planning Feasibility Phase* (**ERP-05D-S03**), *Northern Pike Containment System at Lake Davis* (**ERP-05D-S21**), and *Lake Davis Pike Eradication Project - Implementation Phase* (**ERP-07D-S02**)). If the northern pike had escaped Lake Davis, they would likely have had a great effect on Central Valley fish including a number of species whose populations have already declined significantly (Chinook salmon, steelhead, delta smelt, and splittail).

Assessing Ecological and Economic Impacts of the Chinese Mitten Crab (**ERP-99-N10**) examined the distribution, population dynamics, and life history attributes of the Chinese mitten crab (*Eriocheir sinensis)* in the San Francisco Bay and its tributaries. Burrow densities increased from a mean of 6 burrows/m^2 in 1995 to >30 burrows/ m^2 in 1999 in tidal portions of South Bay tributaries. Mitten crabs are associated with: tidally influenced portions of Bay tributaries as young juveniles; with freshwater streams (250 km from their confluence with the Bay) as older, migrating juveniles; and with the open waters of the Bay as reproductive adults after migrating from fresh water to reproduce between late fall and early spring (Rudnick et al. 2003b). Population size peaked in 1998 and has steadily declined since 2001.

Schroeter and Moyle (2007) are currently investigating the ecology of alien invasive jellyfish, (*Maeotias marginata*, *Moerisia* sp., *Blackfordia virginica*, *Cordylophora caspia*), all of which are now commonly captured in the upper San Francisco Estuary. Data used in this study are from a 2 year (2004 to 2006) CALFED-ERP monitoring project, *Distribution and abundance of shrimp, plankton and benthos in Suisun Marsh* (**ERP-02-P32**), investigating the monthly occurrence of aquatic invertebrates in and around Suisun Marsh. Preliminary results reveal a high seasonal catch of *Moerisia* sp., a moderate catch of *M. marginata*, and a low catch of *B. virginica* medusae (Schroeter and Moyle 2007). Invasive hydrozoan jellyfish are potentially contributing to the decline and/or recovery failure of plankivorous fishes in the upper San Francisco Estuary (Wintzer and Moyle 2007). Schroeter and Moyle (2006) have presented the following conclusions/questions for further research:

- *Maeotias* are increasing in abundance in the San Francisco Estuary, especially in the last 5 years.
- Salinities ranging between 2–10 ppt and temperatures >19 °C are facilitating large blooms.

- Late summer water export and reduced outflow is a strong catalyst for a bloom to occur upstream of the Carquinez Straits (Grizzly Bay and Suisun Bay and Marsh).
- Diet suggests potential for competition through resource overlap with other pelagic organisms such as fishes given Summer and Fall prey resources are limited in the San Francisco Estuary.

➢ Predation on native fishes is limited due to a temporal mismatch. Non-natives may be vulnerable, especially gobies.
➢ Are *M. marginata* increasing in abundance due to decline in other pelagic predators and greater prey availability or are other things going on?
➢ Further analyses are necessary.
  - True abundance in various habitats? Need targeted net / sampling.
  - Feeding rates, digestion rates and more predation capabilities?
  - Polyps? What are they eating?

Effects of Introduced Species of Zooplankton and Clams on the Bay-Delta Food Web (**ERP-99-N09**) examined the impacts of the Asian copepod *Tortanus dextrilobatus*, now broadly distributed in San Francisco Bay, at times reaching extremely high abundances (>1000/m^3), which is especially noteworthy for a carnivore. This large, predatory copepod seems to select larger, native copepods (*Acartiura* sp.) over smaller, non-native copepods (e.g. *Oithona davisae*). *Tortanus dextrilobatus* is one of several non-native copepods that have resulted in a dramatic change in the composition of the zooplankton community in San Francisco Bay over the last 20 years, which raises the question of whether successfully established NIS may facilitate invasions by future NIS (Bollens et al. 2002). Predatory impact of *T. dextrilobatus* in the San Francisco Estuary was estimated (% population consumed/d). Greater than 1% occurred on a regular basis when *T. dextrilobatus* was abundant, with maxima exceeding 20, 65, and 25% for *O. davisae*, *Acartia* (*Acartiura*) sp. and all Copepoda, respectively (Hooff and Bollens 2004).

Effects of Introduced Clams on the Food Supply of Bay-Delta Fishes (**ERP-99-F11**) stated that there is little likelihood that the Asian clam (*Corbula amurensis*) abundance will decrease any time soon.

Zebra/Quagga Mussel

After the March 2007 discovery of quagga mussels in the Colorado River Aqueduct, and more recently in several locations in San Diego County including San Vicente Reservoir, Lake Murray Reservoir, Lower Otay Reservoir and Lake Dixon, and in Riverside County in Lake Skinner and Lake Mathews, California set up an Incident Command system with representatives from CDWR, CDFG, USFWS, CDFA, CDBW, and USBR, and appointed a Science Advisory Panel to plan its response to the invasion. The Incident Command System was demobilized in mid-March; however, representatives from state and federal agencies who were involved in the incident continue to meet on a bi-weekly basis under

the *CALFED NIS Program* (**ERP-06D-S17**). The Metropolitan Water District of Southern California (MWD) and the City of San Diego Water Department are not formally part of the State/Federal Quagga Mussel Response organization; however, CDFG and CDWR coordinate with them and track their results. MWD has been treating infestations and the City of San Diego Water Department has implemented prevention and outreach actions, but has not yet implemented eradication efforts. In January 2008, the first population of zebra mussels in California waters was found in the San Justo Reservoir in San Benito County.

Project Summary Table

Table 1. Invasive Aquatic Organisms Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-F10	**Determining the Biological, Physical and Chemical Characteristics of Ballast Water Arriving in San Francisco Bay** This project analyzed the data on ballast biota arriving in the San Francisco Bay Estuary to assess the risk of exotic introductions, determined treatment standards, and provided baseline data to assess management or treatment efforts and conduct critical comparative analyses between estuaries.	3/31/2007	$583,739	Complete. Compiled and analyzed shipping data, and sampled and analyzed ballast water from arriving ships in Bay-Delta region.
ERP-01-C04	**Suisun Marsh Property Acquisition & Habitat Restoration** This project planned to acquire property in the Suisun Marsh, along Hill Slough, currently managed as seasonal wetland and restore the area to a fully functioning self-sustaining tidal wetland ecosystem which includes low-marsh, high-marsh, and upland transition zones, increasing the area and contiguity of saline emergent wetlands thereby assisting in the recovery of at-risk species.	6/30/2006	$536,750	Complete. Acquisition of Blacklock parcel (69 acres); to be restored to full tidal action and natural hydrology. There will be invasive species monitoring.
ERP-01-N50	**Food Resources for Zooplankton in the Sacramento-San Joaquin River Delta** This project assessed the quantity and quality of food resources for copepods in various habitats of the Sacramento-San Joaquin River Delta.	3/31/2005	$576,422	Complete. Monitored the ecology of *Pseudodiaptomus forbesi* and *Eurytemora affinis* in the Sacramento-San Joaquin River Delta.
ERP-02D-P56	**West Coast Ballast Outreach Project** The goal is to reduce the number of aquatic nuisance species (ANS) that are introduced to the west coast of the U.S.A. via ballast water discharges from merchant vessels. This training includes the distribution of educational materials, a website, and ballast water management practices. Was ERP-02-P20-D.	12/31/2008	$478,395	Ongoing. Education on ballast water discharge issues.

Table 1. Invasive Aquatic Organisms Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P22	**Shallow Open Water Habitats: Hydrodynamics and Benthic Grazing** The objective of this project was to develop, via field observation and modeling, a detailed view of how tides and wind-generated waves determine the physical structure and hydrodynamics of shallow estuarine waters, and how these physical processes can act to constrain net primary production through their effects on grazing and light. Field experiments were carried out in the shallows of Grizzly Bay and in Franks Tract.	5/31/2007	$616,605	Complete.
ERP-02-P32	**Distribution and abundance of shrimp, plankton and benthos in Suisun Marsh** The project objectives are: 1) to evaluate the relationships between presence of alien species, on the local community structure and 2) to investigate the influence that habitat type and environmental conditions have on the type and abundance of species present in the tidal marsh community. Tasks include sampling site location selections, benthos sampling, mysid sampling, zooplankton sampling and a draft and final report on methodology, data summary and analyses and conclusions.	10/31/2007	$377,549	Ongoing. Waiting for final reports from UCD due by 08/31/2008.
ERP-02-P37	**Reducing the Introduction and Damage of Aquatic Nonindigenous Species through Outreach and Education, Phase 2** The project used workshops, industry magazine ads and articles, best management practices manuals, and enhancement of an existing website to educate industries, such as landscapers or hobby aquarium suppliers, that sell or distribute non-native species about the costs and consequences of unwanted introductions.	2/28/2006	$156,951	Complete.
ERP-05D-S03	**Lake Davis Pike Eradication Project; Planning Feasibility Phase** The goal of the Planning Feasibility Phase is to plan and prepare for a project to eradicate northern pike from Lake Davis and its tributaries thus preventing their downstream spread and reducing the chances of northern pike being relocated to other California waters.	2007	$5,800,000	Ongoing. Final EIR / EIS, January 23, 2007.
ERP-05D-S21	**Northern Pike Containment System at Lake Davis** Northern pike (Esox lucius) are a non-native invasive fish species that has had a significant impact on the sport trout fishery at Lake Davis and that, if they escape from Lake Davis, could have irreversible negative impacts on California aquatic ecosystems. The project was designed to confine northern pike within Lake Davis. In addition, DWR continued to conduct reservoir operations in a way that minimized the potential of unregulated spill. Both of these measures decreased the risk of pike escapement until the Department of Fish and Game could successfully eradicate pike from the reservoir.	6/30/2008	$2,000,000	Complete.

Table 1. Invasive Aquatic Organisms Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-06D-S17	**CALFED NIS Program** Non-Native Invasive Species (NIS), Zebra Mussel Prevention, Zebra Mussel Rapid Response	6/30/2009	$750,000	Ongoing. USFWS will continue to work with the NIS Agency and Stakeholder Teams to implement and administer the NIS program, as developed and documented in the NIS Strategic and Implementation Plans. Develop Zebra Mussel Response Plan.
ERP-07D-S02	**Lake Davis Pike Eradication Project - Implementation Phase** The project is designed to eradicate northern pike (*Esox lucius*) from Lake Davis and its tributaries, minimizing the chance of further expansion downstream of Lake Davis or to other watersheds.	2007	$11,691,762	Ongoing. Eradication of Pike from Lake Davis Pike - Implementation Phase Completed
ERP-96-M15	**Invasions of the Bay-Delta Estuary: Developing a Research Program to Address the Introduction of Nonindigenous Aquatic Species** This project prepared five reports which serve as the basis to begin an overall monitoring and research program of nonindigenous species in the Bay-Delta estuary.	5/31/1999	$197,000	Complete.
ERP-97-C07	**Preventing Exotic Introductions from Ballast Water** This project increased maritime industry members' awareness of ballast water release issues and alternative practices in order to reduce the introduction of non-native species into the Delta.	8/31/2001	$222,830	Complete.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** Implementation of monitoring and applied research that provides data and information necessary to evaluate the performance of completed CALFED program actions and ongoing programs.	12/31/1999	$800,000	Complete.
ERP-99-B18	**An Evaluation of the Potential Impacts of the Chinese Mitten crab on the Benthic Communities in the Sacramento-San Joaquin Delta and Suisun Bay** Provided information regarding the relationship between the Chinese mitten crab (Eriocheir sinensis) and the benthic invertebrate community within the Sacramento-San Joaquin Delta and Suisun Bay.	3/31/2003	$178,764	Complete.

Table 1. Invasive Aquatic Organisms Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-F05	**Non-native Invasive Species Advisory Council** Developed and maintained Non-native Invasive Species Advisory Council, an organization which is responsible for the coordination and implementation of activities and projects that address the issues of NIS in the CALFED area of concern.	11/30/2004	$50,000	Complete.
ERP-99-F06	**Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education** Developed a comprehensive program of outreach and education that will result in reducing the probability of the introduction of new Non-native Invasive Species (NIS) and minimize the spread of existing NIS in the San Francisco Bay-Delta region.	5/31/2003	$105,466	Complete.
ERP-99-F07	**Zebra Mussel Detection & Outreach Program** Implemented a combination of public outreach and monitoring to, first provide information to educate the public about zebra mussels and the means by which they spread and, second to set up and operate an early detection system in the Central Valley, Bay/Delta and water storage and delivery systems.	2/23/2006	$160,000	Complete.
ERP-99-F11	**Effects of Introduced Clams on the Food Supply of Bay-Delta Fishes** This research project analyzed existing data on the co-occurrence of fish and their prey, and on the inputs of various sources of organic matter to the estuarine ecosystem. Use relatively simple models to examine the effects of the introduced clam *Potamocorbula amurensis* on foodwebs supporting longfin, delta smelt, and striped bass with the intent to fill key knowledge gaps to improve conditions for these fish species.	5/2/2004	$100,490	Complete.
ERP-99-N09	**Effects of Introduced Species of Zooplankton and Clams on the Bay-Delta Food Web** This research project studied the effects of introduced species on the food web of the San Francisco Bay-Delta, with particular emphasis placed on fish species of concern; delta smelt, longfin smelt, and striped bass. Research emphasis was the clam *Potamocorbula amurensis*, and several introduced species of zooplankton, in altering the foodweb of the three selected fish species.	7/19/2006	$653,384	Complete.
ERP-99-N10	**Assessing Ecological and Economic Impacts of the Chinese Mitten Crab** This project used experimental field and laboratory studies, combined with continuous monitoring data, to examine the biology, population dynamics and impacts of a recently introduced species, the Chinese mitten crab on freshwater and estuarine habitats of the San Francisco Bay ecosystem.	5/1/2003	$113,033	Complete.

Other Programs Contributing to ERP Vision

There is a myriad of agencies, organizations, and projects conducting research and/or outreach regarding the issue of preventing the introduction of exotic species arriving in ballast water. To get a more in-depth understanding of the current status of research and management of ballast water and ship fouling see "2007 Biennial Report on the California Marine Invasive Species Program" by Falkner et al. (2007).

The 1999 Ballast Water Management for Control of Non-indigenous Species (NIS) Act (AB 703) established a multi-agency program to prevent the introduction and spread of non-indigenous aquatic species (NAS). The California State Lands Commission (CSLC) provides oversight. Initially the CSLC Marine Invasive Species Program focused on ballast water management of vessels arriving from foreign regions. In 2003, the Marine Invasive Species Act (MISA) expanded the program, directing it to examine several emerging issues, including the spread of aquatic invasive species from domestic areas, the advancement of technologies to treat ballast water, and invasions through commercial vessel hull fouling. Based on input gained through workshops held between 2002 and 2006, regulations were approved in 2006 requiring vessels arriving to California from within the Pacific Coast Region to also manage ballast water. Passed in 2006, the Coastal Ecosystems Protection Act directed the CSLC to adopt the standards through the state rulemaking process, and to review the availability, efficacy and environmental impacts of available treatment technologies. Finally, MISA directed the CSLC to evaluate, analyze and recommend action to preventing introductions through commercial vessel fouling. Assembly Bill 740 (chaptered 10/10/2007) incorporated several of the recommendations. Compliance rates with ballast water management requirements in California are extremely high. During the period covered by this report, 99% of all vessel-reported ballast water carried into state waters complied with management requirements, either through complete retention of ballast onboard or undergoing a legal exchange prior to discharge (Falkner et al. 2007).

In 2006, CDFG released a draft version of the "California Aquatic Invasive Species Management Plan (CAISMP)." The plan proposes management actions and a rapid response process for addressing aquatic invasive species (AIS) threats to California. It focuses on the non-native algae, crabs, clams, fish, plants and other species that continue to invade California's creeks, wetlands, rivers, bays, and coastal waters (CDFG 2006). It provides a framework to respond to AIS in California, and protect the biological integrity of native plant and animal communities. The Objectives for the Plan identified during stakeholder meetings are as follows: Coordination and Collaboration, Prevention, Early Detection and Monitoring, Rapid Response and Eradication, Long-term Control and Management, Education and Outreach, Research and Laws and Regulations. The Plan identifies lead and cooperating agencies for each action within these objectives and sets up a timeline for completion actions and for revisions to the plan. The Plan also includes a draft Rapid Response Plan that provides generic guidance for agencies responding to suspect infestations. The recent quagga mussel

incident will be used as a case study on how aspects of the plan have been implemented. As of November 2007 a final version of the CAISMP had been produced. Aquatic Nuisance Species Task Force (ANSTF) conditionally approved the CAISMP, which is pending Governor Schwarzenegger's signature. The ANSTF is an intergovernmental organization dedicated to preventing and controlling aquatic nuisance species, and implementing the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990.

In addition to the actions mentioned above, the San Francisco Regional Water Quality Control Board determined that ballast discharge is a form of pollution (biological pollution) under the CWA. A 2005 federal court ruling defined non-indigenous species as "pollutants" present in discharges from vessels and found that such discharges are not exempt from permitting requirements (NPDES). Some regional boards placed specific water bodies within their regions on the CWA 303(d) list as impaired by exotics. San Francisco Bay was listed in 1998. In 2006, the State Water Resources Control Board (SWRCB) considered listing proposals for the Delta, the upper San Joaquin River, and the Cosumnes River. Once on the 303(d) list, the regional boards must develop programs for managing pollutant loads, but it has been difficult to establish TMDLs for exotic species (Resource Agency 2007).

Ballast water exchange is an interim solution to reducing the risk of invasion through ballast water release. Ultimately, ballast water treatment technologies are necessary to eliminate this vector as a source of invasive species. Treatment systems must be capable of killing interior "biofilms", microorganisms, and diapausing eggs within ships' ballast tanks. Biofilms are organic matrices of bacteria, microalgae, and protozoans found on the interior walls of ballast tanks. Biofilms may harbor pathogens and may present a risk of microbial invasion if cells are released into the water or if biofilms slough off during ballasting operations (Drake et al. 2005). Dinoflagellate cysts may also be found in ballast water, sediments and biofilms. Toxic dinoflagellates are responsible for outbreaks of paralytic shellfish poisoning and similar diseases in coastal waters; however, the International Maritime Organization (IMO) discharge standards do not address small cysts (<50 micrometers). Vessels full of small cysts would be considered compliant with IMO standards. At this time, researchers are unsure if treatments will even be able to remove larger dinoflagellate cysts as required by the discharge standards (Doblin and Dobbs 2006). Additional research suggests that treatments should be applied to ballast water as close as possible to the time of discharge because many of the aforementioned taxa can reproduce asexually in tanks and this could influence predictions of risk and control (Wonham et al. 2005). More research and development will be necessary before treatment technologies that can address these issues will be ready for commercial use.

Under the West Coast Regional Applied Ballast Management Research and Demonstration Project, Matson Navigation Company (Matson) in partnership with CSLC and Ecochlor, Inc. demonstrated Ecochlor's chlorine dioxide ballast water treatment

system on the bulk carrier Moku Pahu. Chlorine dioxide does not form unwanted chlorinated by-products even in heavily contaminated water. Most importantly, chlorine dioxide can be safely and economically generated as a dilute solution on board commercial vessels (Swanson and Perlich 2006). Matson has submitted an application for the Moku Pahu water treatment system to the United States Coast Guard for their Shipboard Technology Evaluation Program (STEP).

In 2005, 10.5% of ship arrivals to CA declared No Ballast On Board (NOBOB) (Falkner et al 2007). NOBOBs are considered an invasion risk in the Great Lakes because of an unpumpable residual of water and sediments remaining at the bottom of ballast tanks. In one study, 32% of 39 ships sampled were found to harbor resting stages of known NIS in their ballast sediments (Bailey et al. 2005a), although in a different study, only 0.05 % of collected resting eggs from these sediments were able to hatch (Bailey et al. 2005b). Nonetheless, NOBOBs are considered a potentially small but important vector for invasive species (Falkner et al. 2007).

With respect to fouling, Falkner et al. (2007) offered the following questions as critical for the development of effective scientifically grounded management requirements. At a minimum, information is needed to address the most basic, but most important question: How many fouling organisms and how many NIS arrive to and move within California via vessel fouling? Such information is critical for a characterization of the NIS risk faced by California. When coupled with vessel maintenance and movement patterns linked to fouling accumulation, research would lay the foundation to fill additional information gaps such as which kinds of vessels harbor notably more fouling organisms than others, what criteria can be used to flag a potentially high risk vessel, and which vessels pose a negligible amount of risk. Answers to these kinds of management-based research questions can guide the formulation of preventative management actions in the future.

MISA expanded the Marine Invasive Species Program to include coastwise traffic. The CDFG was required to do a baseline survey of outer coast habitats and add that data to the baseline previously established for NIS in the state's bays and harbors. USFWS funded a literature review of NAS in the Delta, developed a database format to store, organize and present this information, and analyzed the sources, vectors, and time sequence of introductions of both estuarine and freshwater NIS currently found in the Delta (Light et al. 2005). In 2005, USFWS funded a survey for NIS in San Diego Bay and in the fresh water areas of the Sacramento/San Joaquin Delta. From the samples collected during the current field surveys of the Delta, a total of 95 species were identified, of which 20 were classified as introduced, 17 were classified as cryptogenic, 6 were classified as native to California and 52 species were classified as 'status unknown' due to a lack of readily accessible information that would allow taxonomists or Moss Landing Marine Laboratory (MLML) staff to give an accurate assessment of the introduction status of those species. In addition, samples collected during the field surveys produced 89 taxa which were not identified to species level and were classified

as unresolved. Specimens were classified as 'unresolved' as a result of insufficient taxonomic resolution at the species level, which may have been due to a variety of reasons including damaged (2.4%) or juvenile specimens (2.7%), undescribed species and/or problems in the taxonomic literature for those taxa (94.8%) (Maloney et al. 2007). A relatively large percentage of the total taxa collected within each phylum were classified as unresolved, which highlights both the difficulty that scientists face when evaluating introductions throughout the world as well as the need for continued basic research on resolving taxonomic issues. The compiled database, available through MLML, gives detailed information for all samples, sampling information and all species identified, including native species.

In addition, to manage introduced species data from the aforementioned NIS survey as well as other sources, the CDFG's Office of Spill Prevention and Response (OSPR) created a database that contains the name and location of every known non-native (or suspected non-native) species on the California coast. CANOD (California Aquatic Non-native Organism Database) serves as a baseline for addressing the following questions:

- Which NAS have arrived in California via Ballast Water?
- Is the rate of new introductions increasing or not?
- Have ballast water regulations been successful in limiting introductions of new organisms?
- To what extent have humans redistributed plants and animals within California?

In October 2003 New Zealand mudsnails (*Potamopyrgus antipodarum*; NZMS) were discovered in Putah Creek and two months later in the Mokelumne. In January 2004 a well established population was discovered in an eleven mile reach of the Calaveras River. A population was found in the Napa River drainage later that summer that was possibly spread by construction equipment that had been used on the Mokelumne. NZMS were later documented in Piru Creek and by early 2006 NZMS populations were popping up in small creeks throughout Southern California. In November 2007 NZMS were discovered in the Lower American River near Sunrise Bridge and later near Lake Natomas. NZMS is a very small snail with the potential of extraordinary population densities of up to approximately a million snails per square meter. Populations in New Zealand are limited naturally by native parasites and predators. In North America, however, there are no natural predators or parasites of the snail and the populations have flourished where introduced. Currently, no method of eradication has been successfully applied to large, open river systems. To date, there has been little research on the potential impacts of New Zealand mudsnails on other aquatic resources. Impacts could be significant if nothing is done to control its spread. If the snails become very dense and comprise a large percentage of the macroinvertebrate biomass, impacts can be substantial. They can reduce food resources and populations of other macroinvertebrates, particularly mayflies, caddisflies and chironomids. They can also reduce whole-stream algal production. There is very little information on New Zealand mudsnail as a food source for fish, but it does not appear as though they are a

preferred food of trout. There is general consensus that the New Zealand mudsnail could have a significant impact on trout fisheries, including federally listed species. The CDFG has created education and outreach materials to increase awareness by anglers and others in contact NZMS infested waters. These snails can survive out of water on wading and fishing gear for extended periods (up to 25 days if they are in a moist environment). Also in 2007, ANSTF produced a National Management and Control Plan for the New Zealand Mudsnail (ANSTF 2007).

Interagency Ecological Program for the San Francisco Estuary provides status information on various species including many which are introduced. The following are from the most recent assessments:

- American shad (*Alosa sapidissima*) was introduced in 1871 and is now found throughout the estuary. The 2006 Bay Study age-0 American shad index, was well below that of 2005, however it represented the fourth highest index for the study period and 3 of the 4 highest indices have occurred since 2003 (Greiner et al. 2007).
- Threadfin shad (*Dorosoma petenense*) was introduced into reservoirs in the late 1950s and quickly became established in the delta. In the 2006 Fall Midwater Trawl Survey, threadfin shad decreased slightly from the 2005 index. Since 2001, abundance has been relatively low, averaging only 40% of the study-period mean. In contrast, the 2006 Bay Study threadfin shad index was substantially higher than the 2005 index (Greiner et al. 2007).
- Striped bass (*Morone saxatilis*) was introduced over 125 years ago, age-0 striped bass abundance has been in steady decline since the mid-1980s, with some of the lowest indices in the past 5 years. In the 2006 Summer Tow Net Survey, the striped bass 38.1-mm index was set at 0.5 in July, the lowest index in the 48-year history of the survey (Greiner et al. 2007). Striped bass survival and abundance historically responded favorably to increased outflow, though these responses have been dampened since the late 1980s invasion of the clam *Corbula amurensis* (Kimmerer 2002, Sommer et al. 2007).
- The shokihaze goby (*Tridentiger barbatus*) was introduced from Asia. The 2006 mean catch per unit effort (CPUE) was a record high for the study period, nearly double (180%) the second highest CPUE from 2005. The 2006 shokihaze goby catch far exceeded the 2006 combined catch of the 2 other introduced *Tridentiger* gobies, the shimofuri goby (*T. bifasciatus*) and the chameleon goby (*T. trigonocephalus*). For the, yellowfin goby (*Acanthogobius flavimanus*), the age-0 abundance index was 38% of the 2005 index and the lowest since 2002 (Greiner et al. 2007).

The USFWS Delta Juvenile Fish Monitoring Program (DJFMP) has conducted beach seining to monitor long term trends in juvenile fish abundance in the Sacramento-San Joaquin River Delta. Hanni and Chapman (2006) found that the number of non-native species is increasing through time while the number of native species is declining,

suggesting that non-natives are out-competing natives for common resources in the Delta.

In the winter of 2006-07, Bay and Suisun Marsh surveys did not detect any Chinese mitten crabs and only 12 were salvaged at the CVP/SWP fish facilities, the lowest total since *E. sinensis* was first detected at the CVP fish salvage facility in fall 1996. USFWS monitoring for juvenile *E. sinensis* in the delta and its tributaries again detected no crabs in 2006, and there were also no public reports of *E. sinensis*. Although the factors that control the estuary's *E. sinensis* population are not well understood, winter temperatures and outflow are hypothesized to affect larval survival and settlement time. A "boom-and-bust" cycle has been reported for some introduced species, although this may not be universally true for all introductions (Hieb 2007b).

IEP monitoring data from 2006 showed that the introduced copepod *Limnoithona tetraspina* abundance increased while another introduced copepod *L. sinensis* continued to be collected in very low numbers in 2006. The introduced freshwater calanoid copepod *Pseudodiaptomus forbesi* has remained relatively abundant in spring and summer compared to other copepods. *Acanthomysis bowmani* is an introduced mysid has been the most abundant mysid in the upper estuary since fall 1993, after reaching a low in 2005, spring abundance continued to decline in 2006 to less than half of the average annual spring abundance. *Neomysis kadiakensis* has never become common and some of the upper-estuary specimens may be a second species, *N. japonica* (Hennessy and Hieb 2007). *Palaemon macrodactylus*, the oriental shrimp, remained a minor component of the total shrimp catch. *Exopalaemon modestus*, the Siberian prawn, first collected in the lower Sacramento River in 2000, was the most common caridean shrimp in the lower Sacramento and San Joaquin rivers as of 2002, outnumbering both the native *Crangon franciscorum* and the introduced *Palaemon macrodactylus* in these areas (Hieb 2007a). A similar trend was reported for Suisun Marsh (Schroeter et al. 2006). *Exopalaemon modestus* catch peaked from October to December in the Bay Study trawls and in September and October in the Suisun Marsh trawls. Their primary reproductive areas are in freshwater upstream areas of Suisun Marsh (Hieb 2007a).

Zebra Mussel

DFG has provided training, established a website and a toll-free call in information line. Under the direction of CDFG, Portland State University Center for Lakes and Reservoirs is collecting water samples from high priority waters in California and using microscopy to determine if mussel veligers are present. The San Francisco Estuary Institute is performing a phased risk assessment of California waters in order to rank sites for further monitoring based on the likelihood that quagga or zebra mussels will establish. Phase 1 of the risk assessment includes 160 waters. A K-9 Program has been added to the CDFG as a tool against poaching and a means to detect the invasive quagga mussels, ammunitions and other odors, providing the state with an additional level of

homeland security. CDFG plans to train up to 24 dogs, all of whom will be trained in detecting quagga mussels. The first dog academy is set to begin in November and will consist of six dogs and handlers who will be trained in obedience and detection. AB 1683, was signed by the Governor on October 14, 2007. AB 1683 authorizes the Department of Fish and Game to conduct inspections, order quarantines, and take other actions necessary to prevent the spread of invasive dreissenid mussels, including quagga and zebra mussels. CDFG is developing procedures for implementation.

The CDFA operates 16 agricultural inspection stations on the major highways entering California. Until July 2003, CDFA inspectors checked all watercraft entering California through these stations for invasive aquatic species, including zebra mussel. In 2003, the program was subjected to severe budget cuts and the ability to inspect small, privately transported watercraft was lost (large watercraft, transported by commercial carriers, were still being inspected). In July 2006, CDFA began a one-year pilot project at the Needles border station on Interstate 40 that resumed private vehicle inspection. For the duration of the project, CDFA inspected private vehicles for the purpose of generating data to support future budget change proposals to resume private vehicle inspections at all 16 stations on a full-time basis (Resources Agency 2007). Since the study began at least two recreational boats with zebra mussels have been intercepted at the inspection station in Needles which normally would have passed the inspection station without being inspected (Resources Agency 2007). Currently there are only enough funds to operate six CDFA Border Protection Stations (BPS) (Blythe, Needles, Truckee, Vidal, Winterhaven, and Yermo) 24 hours per day, 7 days per week, and to check all watercraft. As of November 18, 2007, approximately 80,664 trailered boats have been checked. About 8,669 boats contained water that needed to be drained. Over ninety vessels have been quarantined at the BPS.

Status of Topic Today

Moyle and Marchetti (2006) found no set of characters that predicted success for all fish invasions, although some characters increase the probability of success. The factors that best predict invasion success are a) a history of successful establishment outside the species' native range; b) characters that promote success at multiple stages of the invasion process (e.g. high physiological tolerance); c) invaded habitat that more or less matches the alien's native habitat; d) high fish species richness, including other alien fishes; and e) propagule size exceeding 100 individuals. Finally, they suggest that the difficulty of predicting the invasion success of alien species points to the need to allow only introductions that have proved to be non-harmful and to take quick action to prevent the spread of new invaders.

According to Lund et al. (2007) the key to restoring desirable pelagic species is to recreate habitats that have a high variability in abiotic factors such as salinity, channel flows, depth, and water clarity (Nobriga et al. 2005, Lopez et al. 2006). This is the kind

of estuarine habitat that once dominated many Delta channels and Suisun Bay: open-water areas that varied sufficiently in salinity from fresh to moderately salty seasonally, or across years, and often had strong tidal currents and low water clarity (Lund et al. 2007).

In areas where such conditions return, it is unlikely that the overbite clam, Brazilian waterweed, or the Asiatic clam will be able to persist (Lund et al. 2007). The overbite clam is highly stressed when exposed to fresh water (Werner 2004) and has not colonized areas in the estuary that are fresh for extended periods of time, despite being physically able to do so (Lund et al. 2007). This suggests that annual exposure to fresh water for three to six months may limit its ability to invade some areas (Lund et al. 2007).

Lund et al. (2007) provided the following comparison between new assumptions and old assumptions relevant to NIS:

- New assumption: Striped bass are only one part of the estuary ecosystem and conditions that benefit them do not necessarily benefit native organisms. Old assumption: If the estuary is managed for striped bass (an East Coast species), all other organisms, but especially other fish, will benefit.
- New assumption: Creating more shallow freshwater habitat benefits mainly alien species in the Delta. Development of dendritic channel patterns with residence time diversity might be a key to restoration. Old assumption: Creating more shallow freshwater habitat is the key to making the Delta friendlier to native species.
- New assumption: Some alien species have major effects on ecosystem structure and function, with negative effects on highly valued species. Old assumption: Alien species mainly increase biotic diversity and harm mainly low-value native species.

A great amount of progress has been made toward the five Stage 1 Expectations: 1) Ballast Impacts monitoring, management, and treatment; 2) outreach regarding live bait industry; 3) public information programs regarding species introductions; 3) assessment of the pathways, risks to reduce, and eventually eliminate, introduction of unwanted aquatic organisms from these sources into natural waters; 5) assessment of existing introductions to identify those with the greatest potential for containment or eradication, and consider this in prioritizing control efforts.

Despite these efforts the problem is getting worse. Lund et al. (2007) points out that the old paradigm was “alien (non-native) species are a minor problem or provide more benefits than problems,” and that the new paradigm is that “alien species are a major and growing problem that significantly inhibits our ability to manage in support of desirable species.” ERP, the implementing agencies, other Federal, State, and Local

Agencies, and the private sector need to do more to face the threat that invasive species pose.

It has been documented that the most likely source for introducing zebra mussels is boats carried by trailer from areas where zebra mussels are abundant. California already has an agricultural inspection program, and this program now includes inspection of boats for mussels.

Planned Projects for Implementation

Currently there is no way to assess trends in invasions, rates of invasions or whether populations are increasing or declining. Conducting a sampling program similar to the current survey on a regular interval (possibly every 3-5 years), using standardized methods, would offer the opportunity to observe the changes in the communities sampled over time (Maloney et al. 2007). Also, it would be worthwhile for future Delta surveys to incorporate into the sampling protocol a method of collecting measurements of physical environmental conditions from each sample site, including but not limited to salinity and water temperature. Using that information, researchers would be able to look for correlations between the habitats of the Delta, the large variety of environmental conditions available across the Delta, and the distribution of species collected and identified in the surveys (Maloney et al. 2007).

The Pelagic Fish Action Plan suggested the following next steps to address invasive aquatic species:

- Support CSLC's work to control ballast water by assisting with studies related to the Estuary. CDFG is charged with oversight of studies to determine the location and geographic range of NIS in CA estuaries and coastal areas, and to assess the effectiveness of ballast water controls.
- Assist CSLC, CDFG, and other agencies with the development of regulations or control measures for hull-fouling.
- Support the implementation of the California Aquatic Invasive Species (AIS) Management Plan.

Finally, the higher-cost of control and eradication programs will not be needed if species that are potentially invasive are kept out of the state. To prevent more aquatic invasive species from entering the state, agricultural inspection stations should be operated on a 24/7 basis and inspect all boats and watercraft entering the state.

Impediments to Implementation

None.

References

Aquatic Nuisance Species Task Force (ANSTF). 2007. National Management and Control Plan for the New Zealand Mudsnail (Potamopyrgus antipodarum). Prepared for the New Zealand Mudsnail Management and Control Plan Working Group.

Bailey, S. A., I. C. Duggan, P. T. Jenkins and H. J. MacIsaac. 2005a. Invertebrate Resting Stages in Residual Ballast Sediment of Transoceanic Ships. Canadian Journal of Fisheries and Aquatic Sciences. 62:1090-1103.

Bailey, S. A., K. Nandakumar, I. C. Duggan, C. D. A. van Overdijk, T. H. Johengen, D. F. Reid and H. J. MacIsaac. 2005b. In Situ Hatching of Invertebrate Diapausing Eggs From Ships' Ballast Sediment. Diversity and Distributions. 11:453-460.

Bollens, S. M., J. R. Cordell, S. Avent and R. Hooff. 2002. Zooplankton Invasions: A Brief Review, Plus Two Case Studies from the Northeast Pacific Ocean. Hydrobiologia. 480:87–110.

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIRTechnical Appendix. Sacramento, CA.

California Department of Fish and Game (CDFG). 2006. California Aquatic Invasive Species Management Plan (Draft). Sacramento, CA.

Choi, K-H., W. Kimmerer, G. Smith, G. M. Ruiz and K. Lion. 2005. Post-exchange Zooplankton in Ships Ballast Water Coming to the San Francisco Estuary. Journal of Plankton Research. 27(7):707-714.

Doblin, M. A. and F. C. Dobbs. 2006. Setting a Size-exclusion Limit to Remove Toxic Dinoflagellate Cysts from Ships' Ballast Water. Marine Pollution Bulletin. 52:259-263.

Drake, L. A., A. E. Meyer, R. L. Forsberg, R. E. Baier, M. A. Doblin, S. Heinemann, W. P. Johnson, M. Koch, P. A. Rublee and F. C. Dobbs. 2005. Potential Invasion of Microorganisms and Pathogens via 'Interior Hull Fouling': Biofilms Inside Ballast Water Tanks. Biological Invasions. 7:969-982.

Falkner, M., L. Takata, S. Gilmore and N. Dobroski. 2007. 2007 Biennial Report on the California Marine Invasive Species Program. Produced for the California State Legislature. California State Lands Commission, Marine Facilities Division. Sacramento, CA.

Greiner, T., M. Fish, S. Slater, K. Hieb, J. Budrick, J. DuBois and D. Contreras. 2007. 2006 Fishes Annual Status and Trends Report for the San Francisco Estuary. IEP Newsletter. 20(2):22-40.

Hanni, J. R., and E. D. Chapman. 2006. Long Term Trends in Species Richness of Native and Non-Native Fish in the Nearshore Communities of the Sacramento and San Joaquin River Delta. *In* 4th Biennial CALFED Science Conference 2006 Abstracts. Sacramento, CA.

Hennessy, A. and K. Hieb. 2007. Zooplankton Monitoring. IEP Newsletter. 20(2):10-14.

Hieb, K. 2007a. Common Shrimp of the San Francisco Estuary. IEP Newsletter. 20(2):14-19.

Hieb, K. 2007b. Common Crabs of the San Francisco Estuary. IEP Newsletter. 20(2):19-21.

Hooff, R. C. and S. M. Bollens. 2004. Functional Response and Potential Predatory Impact of *Tortanus Dextrilobatus*, a Carnivorous Copepod Recently Introduced to the San Francisco Estuary. Marine Ecology Progress Series. 277:167–179.

Kimmerer, W. 2002. Effects of Freshwater Flow on Abundance of Estuarine Organisms: Physical Effects or Trophic Linkages. Marine Ecology Progress Series. 243:39-55.

Light, T., E. D. Grosholz and P. B. Moyle. 2005. Delta Ecological Survey (Phase I): Nonindigenous Aquatic Species in the Sacramento–San Joaquin Delta, a Literature Review. Final report for agreement DCN 1113322J011. U.S. Fish and Wildlife Service. Stockton, CA.

Lopez, C. B., J. E. Cloern, T. A. Schraga, A. J. Little, L. V. Lucas, J. K. Thompson and J. R. Burau. 2006. Ecological Values of Shallow-Water Habitats: Implications for the Restoration of Disturbed Ecosystems. Ecosystem. 9(3):422–444.

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

Maloney, E., R. Fairey, A. Lyman, K. Reynolds and M. Sigala. 2007. Introduced Aquatic Species in San Diego Bay and the Sacramento-San Joaquin Delta. U.S. Fish and Wildlife Service. Stockton, CA.

Moyle, P. B. and M. P. Marchetti. 2006. Predicting Invasion Success: Freshwater Fishes in California as a Model. Bioscience. 56(6):515-524.

New Hampshire Department of Natural Resources. 1998. Zebra Mussels. Technical bulletin WD-BB-17.

Nobriga, M. L., F. Feyrer, R. D. Baxter and M. Chothowski. 2005. Fish Community Ecology in an Altered River Delta: Spatial Patterns in Species Composition, Life History Strategies, and Biomass. Estuaries. 28(5):776–785.

Peterson, H. 1997. Clam-stuffed Sturgeon. Newsletter of the Interagency Ecological Program for the Sacramento-San Joaquin Estuary. 10(1). CA Department of Water Resources. Sacramento, CA.

Resources Agency. 2007. Pelagic Fish Action Plan. March, 2007.

Rudnick, D.A., Hieb, K, Grimmer, K. F., and Resh, V.H. 2003. Patterns and processes of biological invasion: The Chinese mitten crab in San Francisco Bay. Basic and Applied Ecology 4(3)249-262.

Schroeter, R. E. and P. B. Moyle. 2006. Aquatic Community Structure and Productivity of a Large Brackish Tidal Marsh in the Upper San Francisco Estuary. *In* 4th Biennial CALFED Science Conference 2006 Abstracts. Sacramento, CA.

Schroeter, R. E., A. Stover and P. B. Moyle. 2006. Trends in Fish Populations of Suisun Marsh, January 2005-December 2005. *For the* Annual report for Contract SAP 4600001965, CA Department of Water Resources, Central Division, Sacramento, CA. U.C. Davis, Department of Wildlife, Fish and Conservation Biology Davis, CA.

Schroeter, R. E., and P. B. Moyle. 2007. The Ecology and Potential Impacts of a Trio of Alien Invasive Jellyfish in the Brackish Upper San Francisco Estuary. *In* 8th Biennial State of the San Francisco Estuary Conference Abstracts. San Francisco Estuary Project. Oakland, CA.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga and K. Souza. 2007. The Collapse of Pelagic Fishes in the Upper San Francisco Estuary. Fisheries. 32(6):270-277.

Swanson, L. M. and T. Perlich. 2006. Shipboard Demonstrations of Ballast Water Treatment to Control AIS. *In* 4th Biennial CALFED Science Conference 2006 Abstracts. Sacramento, CA.

Werner, L. 2004. The Influence of Salinity on the Heat-Shock Protein Response of Potamocorbula amurensis (Bivalva). Marine Environmental Research. 58(2-5):803-807.

Wintzer, A. P. and P. B. Moyle. 2007. Interactions Between Fishes and Invasive Jellyfish in the Upper San Francisco Estuary, CA. *In* 8th Biennial State of the San Francisco Estuary Conference Abstracts. San Francisco Estuary Project. Oakland, CA.

Wonham, M. J., S. A. Bailey, H. J. MacIsaac and M. A. Lewis. 2005. Modeling the Invasion Risk of Diapausing Organisms Transported in Ballast Sediments. Canadian Journal of Fisheries and Aquatic Sciences. 62:2386-2398.

5. STRESSORS

5.6. Invasive Species

5.6.3. Invasive Riparian and Salt Marsh Plants

Introduction

Invasive riparian and marsh plants have become sufficiently established in some locations to threaten the health of the Bay-Delta ecosystem. The invasive plants that pose the greatest threats to aquatic ecosystems are those that directly or indirectly cause reductions in the populations of desired fish, wildlife and native plant populations. This is particularly true if populations of rare native species are reduced as a result of invasive plant infestations.

The degree of influence invasive riparian and salt marsh plants have on the Bay-Delta is affected by site disturbance, climate, the rate of introductions of invasive plants into riparian and salt marsh habitats, characteristics of the plant and animal communities and the substrate (e.g. soil) into which the weed species are introduced, local water quality and hydrologic conditions.

Weeds, or invasive plant species, tend to out-compete native species in habitats that have been disturbed by natural or human-caused events. They are also typically capable of infesting relatively undisturbed habitats and exploiting subsequent opportunities provided by natural or human-related disturbances in the landscape. Although not all weeds are non-native, most have been introduced from other parts of the world. In the absence of the natural biological controls found in their native habitats, such as herbivory by specific insects, weeds can flourish with fewer constraints in a new landscape, quickly gaining a competitive advantage over the native species. Many weeds have also evolved characteristics that make them extraordinarily competitive in both native and nonnative environments. These specialized traits may include high seed production, both sexual and asexual reproduction, several methods of dispersal, a fast growth rate, and tolerance of a wide range of environmental conditions such as extremes in temperature, nutrients, and water availability.

A plant species becomes a weed problem when it adversely affects natural communities or land uses. Whether non-native or native, plant species are considered harmful when they reduce the biological diversity of existing natural communities by displacing native species or altering ecosystem processes such as nutrient cycling, hydrologic conditions, or the frequency of fires. They are problems to human society when they impair agricultural productivity, present fire hazards, constrict waterways, diminish recreation and aesthetic value, or destroy structures.

Weeds have been introduced to California since the arrival of the first non-native settlers, and many have become established. According to Barbour et al. (1993), there were at least 16 non-native plant species established by 1869, 292 by 1925, 797 by 1968, and 1,023 by 1993. Undoubtedly, non-native species introductions will continue; adding pressure on the native plant communities and the wildlife that depend on them.

More than 90% of the State's historic riparian habitat has been lost, primarily as a consequence of land being converted for agricultural uses (Barbour et al. 1993). What remains continues to be threatened, not only by further habitat conversions, but also by weeds. It is particularly important for the many endangered and threatened species that depend on riparian habitat that weeds be controlled.

Many weed infestations are from non-native ornamental species that spread from gardens. Ornamental plants that are major invaders of riparian habitats include tamarisk, pampas grass, vinca, black locust, German ivy, edible fig, and various species of broom. Others were planted intentionally along engineered or altered waterways for erosion control or in the belief that native vegetation would be too vigorous and would clog waterways. Weed infestations in riparian and salt marsh systems are magnified by both alterations to the landscape and current land use patterns. Clearing land encourages weeds because they typically establish and spread in disturbed, bare ground at a much faster rate than native plant species. Once established on disturbed sites, weed species tend to spread into adjacent natural habitats. Overgrazing in riparian areas can diminish recruitment of new native trees and shrubs both directly through feeding and indirectly by livestock behavior. Supplemental feed and associated equipment and vehicles that introduce weeds, in addition to the disturbance caused by grazing, can promote the establishment of weeds. Grass species introduced for livestock pasture improvement have displaced native species in the understory of some riparian habitats. Some orchards may also be a source of riparian weed infestations. This may have happened with the establishment of California black walnut outside of its natural range when used as rootstock in English walnut orchards.

Increases in summer ground and surface water from irrigation can harm some riparian vegetation, altering the species composition. It can create conditions leading to a higher rate of invasion by urban area weeds such as Bermuda grass that can out-compete with native riparian forest seedlings. Left alone, many weeds can take over part or all of established riparian or salt marsh communities, displacing native vegetation and becoming new climax successional species. Examples include *Arundo* and tamarisk. Both were intentionally introduced and now are widespread weeds that have displaced extensive areas of native riparian vegetation throughout the western United States.

Most Central Valley and Delta riparian communities are confined to lower floodplain and river channel areas, compared to a much wider distribution over vast floodplains 150

years ago. With the conversion of riparian communities to other land uses, broad outer bands of riparian vegetation, like those dominated by sycamores or valley oaks, were lost or their extent greatly diminished.

Today, most watercourses are confined to narrower channels with little room for changing patterns of braiding and migration. Inundation and sedimentation rates are altered from historical times in river channels and are substantially reduced in floodplain areas. In the Delta, sedimentation is also altered with the erosion of islands.

Habitat losses or alterations have resulted in a pattern of habitat fragmentation. Riparian communities are often disconnected patches along river channels, and salt marshes are either newly developed from sediment deposition or smaller patches of formerly great expanses. The alteration of ecosystem processes like sedimentation, nutrient flow, fire, and hydrologic conditions, along with the reduction in cover and native plant community diversity, has resulted in degraded riparian or salt marsh habitat conditions. The riparian or salt marsh community is then vulnerable to invasions by non-native species that are better adapted to the altered conditions than the native vegetation.

Species such as *Arundo* and tamarisk are able to quickly exploit disturbed riparian sites. They, in turn, alter the ecosystem processes further, changing the frequency of fires, increasing shade and sediment capture, armoring the streambed and banks, altering soil salinity (tamarisk), and modifying the hydrologic patterns. The native species are not adapted to the new ecosystem processes, and the introduced weeds dominate the successional community.

Weeds that pose the greatest threats to riparian and salt marsh areas are those that out compete and exclude native vegetation, and diminish habitat value to wildlife and reduce biodiversity of native species. All the weeds listed in the following section have this potential.

Numerous weeds threaten the establishment and succession of native riparian and salt marsh vegetation in the Delta, and along the Sacramento and San Joaquin Rivers and their tributaries. The most detrimental plants listed below are widespread in California and can dominate large amounts of the riparian or salt marsh communities that they infest, altering many functions and characteristics of the ecosystems. Examples of plants these include tamarisk, *Arundo* and perennial pepperweed. Other invaders are trees or shrubs that now dominate portions of riparian forests and can invade larger areas if not controlled (*Ailanthus*, edible fig, northern California black walnut, eucalyptus, black locust, and Russian olive). Additional examples include some weeds that are primarily a problem in a more restricted range or ecological zone type (German ivy, cordgrass, and purple loosestrife).

Applicable ERP Vision

The vision is to reduce their adverse effects on native species and ecological processes, water quality and water conveyance systems, and major rivers and their tributaries. One goal is to prevent the establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-native species in the Bay-Delta estuary and its watershed.

The strategic objective is to halt the introduction of non-native invasive aquatic and terrestrial plants into the Bay-Delta estuary, its watershed, and other central California waters. Limit the spread or, when possible and appropriate, eradicate populations of non-native invasive species through focused and management efforts.

The long-term objective is to halt the importation, sale, and use of aquatic and terrestrial plants that can have potentially harmful impacts on ecosystems in the Bay-Delta watershed. Also, the objective is to eliminate, or control to a level of little significance, all undesirable non-native species, where feasible.

The short-term objective is to develop and institute strategies, working with the horticulture industry and interests representing the environment and other sectors that may be affected by such introductions, to halt the introduction and spread of invasive plant species. Eradicate or contain those species for which this can readily be done, gaining thereby the largest benefit for the least economic and environmental cost; and to monitor for the arrival of new invasive species and, where feasible, respond quickly to eradicate them.

Stage 1 Expectations

Plants sold in California by the horticulture industry that pose a threat to ecosystems in the Bay-Delta watershed were to be identified and evaluated for invasive potential. Special attention was to be paid to plants imported into the region from other areas. Working with the horticulture industry and affected interests, a plan was to be developed and instituted to greatly reduce, and eventually eliminate, the introduction of additional invasive plant species into natural environments.

An assessment was to be completed of existing introductions to identify those with the greatest potential for containment or eradication, and consider this in prioritizing control efforts. A program was to be implemented to monitor for, and respond quickly to contain and eradicate new invasions, where this is possible. A mechanism whereby new invasions can be dealt with quickly and effectively was to be developed an implemented.

Changes Attributable to ERP

See Invasive Aquatic Organisms Section for actions taken in regards to NIS by the California State Lands Commission (CSLC), the California Department of Fish and Game (CDFG), the State Water Resources Control Board (SWRCB), California Department of Food and Agriculture (CDFA), U.S. Fish and Wildlife Service (USFWS), and the Non-native Invasive Species Advisory Council (NISAC).

The majority of work by ERP in regards to invasive riparian marsh plants focused on five weeds *Arundo donax*, tamarisk (*Tamarix spp.*), perennial pepperweed (*Lepidium latifolium*), cordgrass (*Spartina spp.*[introduced and hybrid species]), and purple loosestrife (*Lythrum salicaria*).

Arundo

Arundo Donax Eradication and Coordination (**ERP-00-F11**) supported three years of effort by the *Arundo donax* Eradication and Coordination Program (ACEP) which is administered for Team Arundo del Norte (TAdN) by the Sonoma Ecology Center (SEC). The purpose of the program is to coordinate and assist in the planning and implementation of *Arundo* eradiation projects in the Sacramento-San Joaquin River and Bay-Delta region. Tasks performed were eradication and monitoring, data collection and repository, coordination, training, development of a regional strategy and recommendations providing technical expertise, technical coordination and planning of future eradication work, the development of an online information clearing house, and organization and dissemination of *Arundo*-related information. This project directed funds to six watersheds (Putah Creek, Big Chico Creek, Sonoma Creek, Walnut Creek, Napa River, and San Francisquito Creek) to carry out Arundo eradication. *Arundo Eradication and Coordination, Phase II* (**ERP-02D-P68**) extended the arundo eradication to 5 new sites: Gray Lodge Wildlife Area, Lindo Creek, Lower American River, San Joaquin River, and Upper Cache Creek. *Arundo donax Eradication and Coordination Program: Monitoring and Evaluation* (**ERP-04-S14**) when funded will implement the monitoring of *Arundo* eradication sites for restoration success.

California State University, Chico Research Foundation, identified and initiated eradication of areas infested by *Arundo* and tamarisk on Red Bank Creek, and Reed's Creek (*Arundo Donax: Survey and Eradication* (**ERP-01-N04**). The project area encompassed approximately 630 acres of stream bed and banks and more than 10 miles of stream channel. Eradication efforts on Red Bank Creek focused on tamarisk while eradication efforts on Reed's Creek focused on *Arundo*.

The Riparian Invasives Research Laboratory, Marine Science Institute, U.C. Santa Barbara recently found an herbivorous wasp (*Tetramesa romana*) feeding in *Arundo* stems in Santa Barbara and Ventura Counties. This wasp is the same species being evaluated by the USDA, but has been unintentionally introduced into southern

California. They are currently evaluating *T. romana* distribution and population densities in *Arundo* stands in California, determining how long the wasps have been here, and potential loss in biomass caused by larval feeding.

Tamarisk

No ERP projects were funded to directly deal with tamarisk. See "Other Program Contributions to ERP Vision" below for more information on the tamarisk biocontrol program.

Spartina

The Introduced Spartina Eradication Project (ISEP) (**ERP-99-F09**) and the *Invasive Spartina Project* (**ERP-01-C01**) create a regionally coordinated program with the primary objectives of preventing further spread of introduced *Spartina* species to the North Bay and Delta, preventing its introduction to new restoration projects and halting the degradation of CALFED priority habitat. The ISEP significantly reduced introduced *Spartina* in the San Francisco Bay estuary. More than 3,380 acres were treated from 2004 to 2006, with a 60%-80% success rate. *Monitoring for Invasive Spartina Control in the San Francisco Estuary* (**ERP-04-S02**) will provide timely, high quality data regarding the location and extent of invasive *Spartina* to the ISEP, so that it may plan and rapidly implement cost-effective weed control measures and determine when site-specific and regional control objectives have been met. In addition, the Monitoring Program will provide accurate data on the status of he endangered California Clapper Rail at the *Spartina* treatment sites, to allow *Spartina* control to be implemented with minimum adverse effects on rails as well as to document the benefits of the project.

Perennial Pepperweed

Environmental Science Associates researched the distribution of perennial pepperweed in the Bay-Delta and developed a GIS map of this region-wide inventory (*Distribution and Ecology of Lepidium Latifolium in Bay-Delta Wetlands* (**ERP-02-P09**). This study, and the GIS mapping that accompanies it, are now housed in the CDFG BIOS program. As such, it is in the public domain, and is available for use in performing further analyses, as well as adding additional or updated site data to the catalog. The risk perennial pepperweed poses to the San Francisco Bay landscape appears to be restricted largely to tidal marsh and riparian habitat. Areas predicted to be at high risk include the north part of Suisun Bay and around Grizzly Bay, the Petaluma River, the Napa-Sonoma Marshes and the marshes of Don Edwards Wildlife Refuge. Within this habitat it rarely dominates the entire marsh area. Possible limitations due to competition, salinity levels or water inundation all need further exploration. Subtle relationships to elevation, distance to levees, roads and other habitat characteristics may become important in local landscapes.

UC Davis researchers, funded by *Invasion Dynamics of Perennial Pepperweed, Lepidium latifolium, and Their Consequences for Protection of Natural and Restored Wetlands in the San Francisco Estuary* (**ERP-02D-P58**), examined the invasion dynamics of perennial pepperweed, and their consequences for the protection of wetlands in the San Francisco Estuary. The research done under this grant has revealed the major interactions affecting perennial pepperweed colonization and should help define nuanced programs of control that may minimize pepperweed without destroying the native vegetation.

Results showed that perennial pepperweed density was significantly reduced by increased levels of salinity and soil moisture. Increased salinities decrease the reproductive potential during seed production and reduce the germination success and viability of the seed. Seeds collected from the fresh and brackish sites, exhibited high rates of germination in low salinity treatments, but when salinities exceeded 15‰ germination was suppressed. Furthermore, results showed that recruitment was generally negatively correlated with increasing salinity at the defined developmental stages (i.e. cotyledon, two-leaf, four-leaf, small rosette, large rosette, and stem).
Within the salinity-induced decreased recruitment response, bare ground and infrequent flooding provided the most suitable conditions for recruitment. At all sites, perennial pepperweed played an important role in displacing other native wetland species in tidal marshes, and may facilitate future colonization by other nonnative species.

Glyphosate has been routinely used to control perennial pepperweed in the San Francisco Estuary, but it is uncertain how effective control treatments have been in tidal marshes. The least control was obtained at the freshwater site, and treatment efficacy generally improved with increased salinity. Experimental plots at the fresh and saline extremes were more likely to be colonized by non-natives. Therefore the efficacy of the spray program was dependent on salinity, flooding, and the species pool present at the site. Finally, it is clear that perennial pepperweed responds to different combinations of factors, which means control decisions must be dynamically matched to the situation at hand.

The CDFG, in conjunction with CSU Sacramento, is conducting field studies in Suisun Marsh examining the recovery of native brackish tidal marsh vegetation following application of the herbicide chlorsulfuron and removal of the thatch layer of dead *Lepidium*. One study, completed in 2007, explored the efficacy and safety of chlorsulfuron application to a tidal marsh. CDFG collected species and cover data in test plots before and after herbicide application for three consecutive years. Label instructions for chlorsulfuron (Telar® DF) require application above the mean high water mark in tidal areas, and no application over water or where the chemical could enter water. One year later, the average reductions in *Lepidium* were 99.5% for a 2% Telar® DF concentration and 98.5% for a 1% concentration (Estrella 2007). *Apium graveolens* (a nonnative) also decreased in all sprayed plots. The natives *Potentilla anserina*, *Triglochin maritima*, and *Calystegia sepium* decreased in most sprayed plots.

Natives *Schoenoplectus americanus* and *Typha* sp. increased in most sprayed plots. Natives *Distichlis spicata*, *Jaumea carnosa*, and *Juncus balticus* increased only in sprayed plots where 1% Telar® DF was applied (Estrella 2007).

Purple Loosestrife

The CDFA Purple Loosestrife Control Project continues to implement prevention, detection, and control of purple loosestrife in the CALFED Bay-Delta Watershed (*Purple Loosestrife Prevention, Detection & Control in the Sac/SJ Delta & Associated Hydrologic Units* (**ERP-99-F08, -N11-N11b**) and *Expanded Prevention, Detection, and Control of Purple Loosestrife in the California Bay-Delta Authority Watershed* (**ERP-02D-P64**). Current efforts target the elimination of infestations on White Slough, Ryer Island, Old, Middle, Calaveras, and San Joaquin Rivers, and will continue to work on the eradication of the Tuolumne River infestation. They are currently accomplishing this by spraying with Glyphosate herbicide twice per year.

Phragmites

Phragmites australis is considered the most invasive plant in marsh and wetland communities in the United States. *Phragmites* is a cryptic invader. Because of the difficulty in detecting them, cryptic invaders are a largely unrecognized type of biological invasion that lead to underestimation of the total numbers and impacts of the invaders. The distribution and abundance of *Phragmites* in North America has increased dramatically over the past 150 years. Saltonstall (2002) showed that a non-native strain of *Phragmites* is responsible for the observed spread, including in California.

No ERP projects were funded to directly deal with phragmites. See "Other Program Contributions to ERP Vision" below for more information on recent research.

Project Summary Table

Table 1. Invasive Riparian and Salt Marsh Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-E03	**Cottonwood Creek Watershed Monitoring and Assessment** Continued management of the Cottonwood Creek Watershed Group to oversee the implementation of a watershed plan. This phase assessed current land and stream conditions in the watershed to use as a baseline for future projects.	12/31/2003	$350,000	Complete.
ERP-00-F11	***Arundo donax* eradication and coordination** This project directed eradication and monitoring funds for on-the-ground eradication of *Arundo*, the state's most invasive riparian weed, to eradication partners in six watersheds. In addition, this project coordinated data collection, establishing standardized eradication and monitoring protocols and creating an online clearing house.	3/26/2006	$1,063,595	Complete.
ERP-01-C01	**Invasive *Spartina* Project** This project was an expanded effort to plan and implement control measures for *Spartina alterniflora*, contribute to the overall scientific understanding of the species, and build a bay-wide infrastructure to detect and prevent its future invasions.	10/31/2006	$1,793,661	Complete. Mapped ecological risks and priority control sites and distribution of invasive spartina species throughout the Bay.
ERP-01-N04	***Arundo donax*: Survey and Eradication** The primary objective of this project is to identify and eradicate areas infested by *Arundo donax* and *Tamarix* on Red Bank Creek, Reed's Creek and to finish eradication efforts on Deer Creek.	12/31/2006	$539,836	Ongoing. Waiting for some final report appendices. No work was done on Deer Creek.
ERP-01-N11	**Habitat Acquisition for Riparian Brush Rabbit and Riparian Woodrat** Acquired fee title or conservation easements on 400 acres of riparian habitat to provide secure sites for release of captive-bred riparian brush rabbits.	12/31/2006	$2,720,085	Complete.
ERP-01-N31	**Willow Slough Watershed Rangeland Stewardship Program** This project built on restoration efforts in the Willow Slough watershed to enhance and restore riparian and grassland habitats, improve forage quality, improve water quality, and reduce erosion. www.plantbiology.msu.edu/malmstrom/Audubon/index.htm	12/31/2005	$1,800,668	Complete. Enhanced/restored 843 acres of grassland, Enhanced 98 acres/ 5.95 miles of riparian.
ERP-01-N33	**Watershed Education, Headwaters to Ocean** This project provided funding for five different education outreach programs conducted by the Sacramento River Discovery Center aimed at educating citizens about natural systems.	2/28/2005	$321,816	Complete.

Table 1. Invasive Riparian and Salt Marsh Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02D-P54	**Restoring Ecosystem Integrity in the Northwest Delta: Phase II** This project proposes to acquire conservation easements within the Cache Slough complex, along the Barker, Lindsey and Calhoun Sloughs, north Delta tidal channels located west of the Yolo Bypass.	8/31/2008	$1,781,658	Ongoing. Acquisition of conservation easements on 1,100 acres of existing riparian, wetland and/or agricultural lands. Currently in the process of acquiring an agricultural easement on 292 acres.
ERP-02D-P58	**Invasion Dynamics of Perennial Pepperweed, Lepidium latifolium, and Their Consequences for Protection of Natural and Restored Wetlands in the San Francisco Estuary** This project proposes to perform research to improve eradication and control programs for pepperweed. The research will improve the understanding of the plant's life history so that better strategies, such as increasing salinity, extending flooding, or applying herbicides, can be developed to exclude or control the species.	10/31/2007	$178,701	Ongoing.
ERP-02D-P64	**Expanded Prevention, Detection, and Control of Purple Loosestrife in the California Bay-Delta Authority Watershed** This project is an expansion and continuation of efforts for the prevention, detection, and control of purple loosestrife.	3/31/2008	$328,136	Ongoing. Surveys of extent of invasion will be available on web site.
ERP-02D-P66	**Cosumnes River Preserve Perennial Pepperweed Control Project** Based on inventory and continued monitoring of existing *Lepidium* populations at the Cosumnes River Preserve, this project will develop targeted research about control of *Lepidium* focused on physical and chemical aspects of the soil and on the response of surrounding vegetation to *Lepidium* populations.	12/31/2007	$481,634	Ongoing.
ERP-02D-P68	***Arundo* Eradication and Coordination, Phase II** This is Phase II of the *Arundo donax* eradication and coordination project. Phase II provides funding for ongoing monitoring and followup treatments for 5 Phase I projects, and adds 5 new partners. This project aims to remove approximately 273 acres of *Arundo* on over 63 miles of rivers and creeks.	3/15/2009	$2,033,859	Ongoing.
ERP-02D-P71	**Napa-Sonoma Marsh Restoration Project - Construction Phase (Ponds 3,4, and 5)** The purpose of this project was to conduct phase I of the Napa-Sonoma Marsh restoration project, a Federal USACE project which entails the restoration of three former commercial salt ponds along the Napa River, totaling approximately 3,000 acres.	6/30/2007	$3,203,000	Complete. Restored Pond 3 (1,300 ac) to tidal marsh and associated marsh habitat by lowering, grading, and breaching levees. Breached levees on ponds 4 and 5 (combined 1,700 ac) for salinity reduction in preparation for restoration.

Table 1. Invasive Riparian and Salt Marsh Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P09	**Distribution and Ecology of *Lepidium latifolium* in Bay-Delta Wetlands** The purpose of this project was to conduct research on distribution of perennial pepperweed (*Lepidium latifolium*) in the Bay-Delta and develop GIS mapping of this region-wide inventory.	7/14/2007	$223,050	Complete. Developed GIS mapping of pepperweed region-wide inventory. Project also created a spatial model of invaded habitats.
ERP-02-P12	**Sustainable Restoration Technologies for Bay/Delta Tidal Marsh and Riparian Habitat** The objective of this project was the protection of natural embankment and reconstruction through passive recruitment of new sediment to create new riparian and shaded riverine aquatic habitat in aquatic channels.	12/30/2006	$1,800,000	Complete.
ERP-02-P20	**Restoration and Monitoring of Riparian Habitat Corridors Along The Lower Mokelumne River** Restored approximately 50.45 acres of riparian habitat along two miles of Lower Mokelumne River for birds. Restore degraded riparian ecosystems through invasive species removal and native plant restoration and to monitor the response of neo-tropical migrant songbirds to the restoration.	1/31/2007	$859,405	Complete.
ERP-02-P39	**Riparian Restoration Planning and Feasibility Study for the Riparian Sanctuary, Llano Seco Unit** The project goal was to identify feasible management options that will 1) improve habitat and ecosystem processes on 950 acres of the Riparian Sanctuary at the Sacramento River National Wildlife Refuge, Llano Seco Unit; 2) develop and evaluate ecological acceptable options that would improve pumping plant protection and, 3)increase scientific understanding of riparian restoration projects	2/28/2006	$289,784	Complete.
ERP-02-P46	**At-Risk Plant Species, Habitat Restoration and Recovery, and Non-Native Invasive Species Management** This project worked to protect, manage and restore habitat quality of vernal pool wetlands, particularly for Crampton's tuctoria and alkali milk vetch, through eradication of non-native invasive species on 320 acres in Yolo County.	7/25/2006	$400,000	Complete.
ERP-04-S02	**Monitoring for Invasive Spartina Control in the San Francisco Estuary** The primary project goal is to provide timely, high quality data regarding the location and extent of invasive *Spartina* to the San Francisco Estuary Invasive *Spartina* Project, so that it may plan and rapidly implement cost-effective weed control measures and determine when site-specific and regional control objectives have been met. In addition, the Monitoring Program will provide accurate data on the status of endangered California clapper rails at the *Spartina* treatment sites, to allow *Spartina* control to be implemented with minimum adverse effects on rails.	12/31/2008	$1,234,396	Ongoing.
ERP-04-S05	**Lower Clear Creek Monitoring Program** This project will include: Avian Monitoring, Geomorphic Monitoring, and Riparian Habitat Monitoring.	1/31/2008	$1,308,449	Ongoing.

Table 1. Invasive Riparian and Salt Marsh Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-05D-S29	**Riparian Sanctuary (Phase II) – Bringing Agricultural and Ecological Interests Together for Pumping Plant Protection and Riparian Restoration (Sacramento River Mile 178) - Design Development and Environmental Compliance** Project seeks funding for planning and design efforts to develop second phase of multi-phase process to protect PCGID-PID's pumping plant and fish screen facility and to meet Sacramento River National Wildlife Refuge habitat goals for the Riparian Sanctuary.	6/30/2010	$660,665	Ongoing.
ERP-06D-S15	**Sacramento River Conservation Area Forum (SRCAF)** This project will provide funding to continue the efforts of the Sacramento River Conservation Area Forum to act as a coordinating body between local, state, and federal agencies regarding restoration activities in the Sacramento River watershed.	3/31/2010	$656,277	Ongoing.
ERP-06D-S17	**CALFED NIS Program** Non-Native Invasive Species (NIS), Zebra Mussel Prevention, Zebra Mussel Rapid Response.	6/30/2009	$750,000	Ongoing.
ERP-97-N10	**Restoring Ecosystem Integrity in the Northwestern Delta - Jepson Prairie Restoration and Habitat Conservation Plan** Restored habitat along two northwest Delta sloughs and adjacent perennial grasslands at Jepson Prairie.	9/30/2002	$292,801	Complete. Converted 507 acres of agricultural grazing land to perennial grassland. Removal of eucalyptus trees and prescribed burning of weeds. Fenced 500 ft along the bank of Calhoun Cut and planted native plants to restore riparian and enhancing Delta Sloughs.
ERP-98-B33	**Expand Bird Monitoring, Develop a Native Grass Plot, and Enhance Public Involvement with Access to Native Plant Garden Surrounding the Discovery Center** This project provided a public information/education component of CALFED work to ensure that the improvements on the river and the maintenance of a sustainable, balanced, healthy river system are understood and supported by the general public.	9/30/2001	$49,640	Complete.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** Implementation of monitoring and applied research that provided data and information necessary to evaluate the performance of completed CALFED program actions and ongoing programs. CMARP is an adaptive management strategy as a process for implementing proposed changes and ongoing activities to many aspects of the Bay-Delta/Central Valley environment and water management system. CMARP provides information on all of the CALFED program elements and contributes to the mitigation design.	12/31/1999	$800,000	Complete.

Table 1. Invasive Riparian and Salt Marsh Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-C17	**Assist in Developing Appraisal & Planning with TNC for the McCormack-Williamson Property** The California Department of Water Resources provided services and support for the acquisition and initial site planning for the McCormack-Williamson Tract, including an appraisal, a legal transaction review, and initial planning activities.	11/30/2001	$24,000	Complete.
ERP-98-E01	**Napa River Watershed Stewardship** This project built upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/31/2000	$250,000	Complete.
ERP-98-E16	**Lower Putah Creek Watershed Stewardship Program** Developed a community-based watershed stewardship program from the lower Putah Creek through a collaborative process involving stakeholders, landowners, state and federal resources agencies, and local groups.	3/31/2002	$100,500	Complete.
ERP-99-B20	**Expand Bird Monitoring, Develop a Native Grass Plot, and Enhance Public Involvement with Access to Native Plant Garden Surrounding the Discovery Center** This project provided funds to support on-going educational programs at the Sacramento River Discovery Center that teach students about the complexities of watersheds and the importance of building partnerships to best manage these resources.	9/30/2001	$38,400	Complete.
ERP-99-B27	**Watershed Educational Training (WET) Program** This project increased public awareness of watershed issues through implementation of the Colusa County Resource Conservation District's (CCRCD) Watershed Educational Training (WET) project, which linked community watershed health with the ecological objectives and goals identified by the CBDA. The project was completed successfully and according to the final project summary, the educational projects reached approximately 61,365 people.	6/30/2003	$12,887	Complete.
ERP-99-F05	**Non-native Invasive Species Advisory Council** Developed and maintained Non-native Invasive Species Advisory Council, an organization which is responsible for the coordination and implementation of activities and projects that address the issues of NIS in the CALFED area of concern.	11/30/2004	$50,000	Complete.
ERP-99-F06	**Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education** Developed a comprehensive program of outreach and education that will result in reducing the probability of the introduction of new Non-native Invasive Species (NIS) and minimize the spread of existing NIS in the San Francisco Bay-Delta region.	5/31/2003	$105,466	Complete.

Table 1. Invasive Riparian and Salt Marsh Plants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-F08	**Purple Loosestrife Prevention, Detection & Control in the Sac/SJ Delta & Associated Hydrologic Units** Over a 3 year period, the Integrated Pest Control Branch of the CA Dept of Food & Ag carried out a series of tasks which resulted in: 1. exhaustive survey of the Sacramento-San Joaquin Delta; 2. local eradication of loosestrife in Phase I and II areas; 3. focused delimitation and survey of all loosestrife infestations in the CALFED focus area; 4. training of agency personnel, working in and near the Delta, to recognize purple loosestrife and other aquatic non-native invasive species; and 5. education of the boating, water fowl hunting, and similar public citizenry. Project is tied to ERP-99-N11 and ERP-99-N11b.	5/31/2003	$221,306	Complete.
ERP-99-F09	**Introduced *Spartina* Eradication Project** The Introduced *Spartina* Eradication Project (ISEP) is a regionally coordinated program with the primary objectives of preventing further spread of introduced *Spartina* species to the North Bay and Delta, preventing its introduction to new restoration projects and halting the degradation of CALFED priority habitat. The ISEP significantly reduced introduced *Spartina* in the San Francisco Bay estuary. More than 3,380 acres were treated from 2004 to 2006, with a 60%-80% success rate. Includes work from ERP-99-F09 and ERP-01-C01.	9/30/2006	$325,000	Complete. Significantly reduced or eliminated an estimated 1,930 acres of introduced *Spartina* in the San Francisco Bay estuary.
ERP-99-N04	**Lake Red Bluff Riparian Area Restoration and Education Support Project** This project restored 2 acres of riparian habitat in the Lake Red Bluff Riparian Area on the mainstem of the Sacramento River by removing invasive exotic plant species, reintroducing native species, and reducing erosion.	3/27/2003	$29,114	Complete. Planted 1,000 native shrubs and grasses in restored area.
ERP-99-N11	**Purple Loosestrife Prevention, Detection and Control Actions for the Sacramento - San Joaquin River Delta System and Associated Hydrological Units** This project surveyed and mapped the non-native invasive plant species, purple loosestrife. This project developed a site specific adaptive management plan and comprehensive local eradication and control efforts.	1/10/2003	$139,473	Complete. Created GIS layers and available on website.
ERP-99-N11b	**Purple Loosestrife Prevention, Detection and Control Actions for the Sacramento - San Joaquin River Delta System and Associated Hydrological Units** This project continued early detection, prevention and eradication/control work for purple loosestrife in the Phase I and Phase II areas (these phases were funded to ERP-99-N11 and ERP-99-F08).	12/31/2003	$49,865	Complete.
ERP-99-N14	**Colusa Basin Watershed Project** This project served as a watershed management project to assist private landowners in addressing non-point source pollution, flood control issues, exotic invasive weed abatement, and reactivating important ecological processes and functions of riparian corridors in the Colusa Basin Drain watershed.	11/6/2005	$492,500	Complete. Constructed ponds, fenced impacted areas, provided for irrigation systems, and planted grasses and shrubs to control erosion.

Other Programs Contributing to ERP Vision

Invasive riparian and salt marsh plants negatively affect other ecosystem elements such as riparian and riverine aquatic habitat, and fish, wildlife, and plant species.

There are numerous non-CALFED funded efforts to restore and maintain riparian and salt-marsh habitats by various public agencies and NGO's. DFG received $900,000 in FY 2006/2007 to conduct special weed control projects on DFG lands in addition to routine weed control activities. Twenty-one projects are currently being conducted on ecological reserves and wildlife areas throughout the state. The majority of these projects address riparian weed species. These projects, though beneficial, address merely the tip of the weed iceberg on DFG lands, let alone the other public and private lands managed for natural resource conservation.

The California Invasive Plant Council is a non-profit organization that provides a platform for professionals to exchange information about their efforts to reduce the impacts of invasive plants in California's wildlands and coordinates the CalHip program, which works with the horticultural industry to reduce the use of highly invasive plants in the garden trade (http://www.cal-ipc.org/).

An approach to mapping perennial pepperweed is being taken by Andrew and Ustin (2006) of the California Space Institute Center of Excellence, U.C. Davis. They are mapping perennial pepperweed with hyperspectral imagery in the Delta. HyMap image data was acquired over the entire Delta in June-July 2005 with a spatial resolution of 3m. A hierarchical classification scheme combining a variety of techniques was applied to the reflectance data to detect *Lepidium*. Strategies included texture indexes; physiological indexes sensitive to ecologically relevant parameters; and linear spectral unmixing, a subpixel analysis that determines the relative contribution of land cover types within each pixel. These analyses successfully detected *Lepidium* with relatively high accuracies. False positives were fairly common in the resulting maps, however. This resulted from confusion between the target species and sparse vegetation mixed with litter or soil, which shows a similar reflectance pattern in the visible spectrum.

Researchers have recently tested root-derived allelopathy in *Phragmites* (Rudrappa et al. 2007). Allelopaths are chemicals released by a plant that inhibit the growth of surrounding plants. To this end, root exudates of two *Phragmites* genotypes, one native and one exotic, were tested for phytotoxicity on different plant species. The treatment of the susceptible plants with *Phragmites* root exudates resulted in acute rhizotoxicity (Rudrappa et al. 2007). An interesting note is that the root exudates of exotic were more effective in causing root death in susceptible plants compared to the native exudates. The active ingredient in was identified as 3,4,5-trihydroxybenzoic acid (gallic acid). Most tested plants succumbed to the gallic acid treatment with the exception of phragmites itself. In addition, gallic acid demonstrated an inhibitory effect on *Spartina alterniflora*, one of the salt marsh species it successfully invades.

Tamarisk has proven extremely difficult and labor intensive to control with mechanical and chemical methods. Consequently, a tamarisk biocontrol program was initiated. One leaf hopper species, *Opsius stactogalus*, and two scale insects, *Chionaspis* spp., do occur on tamarisk in North America, but these species do not exert significant pressure on the plant (Lewis et al. 2003). The leaf beetle *Diorhabda elongata* was released into the open in 2001. The results of these releases were mixed (DeLoach et al. 2004), and the most successful establishment took place at five sites in Colorado, Nevada, Utah and Wyoming. At sites in northern Nevada, the beetles have defoliated vast stands with over 10,000 ha damaged at one site in 2004 (Geraci et al. 2006). By the 4th year of defoliation (2005), plant mortality reached 40%.

Even without plant mortality, biocontrol may provide substantial benefits. Sap-flow measurements and evapotranspiration indicated that groundwater losses were reduced by over 70% during the first year of defoliation in Nevada, with greater savings in subsequent years. In addition, recent studies suggest that both avian (Hitchcock et al., in review) and spider diversity and abundance have increased in stands where *D. elongata* is present. However, the releases of *D. elongata* have not always been successful.

There are three ecological reasons that might explain these establishment failures. First, at North American sites lower than 37-38° N, the original form of *D. elongata* (originally collected from Fukang, China, 44° N) was not successful because it responds to declining daylength by entering diapause too early in the season to successfully overwinter (DeLoach et al. 2004). In incubation studies, the Fukang beetles cease reproduction at a critical daylength of 14.5 hours, meaning that they are only reproductive for one month at mid-latitudes (e.g. 37° N) and the critical day length is never achieved at southern latitudes (Bean et al. 2001). A second factor that might influence establishment is predation, primarily by harvester-type ants which prey on both larvae and adult beetles. At one site in Oregon (43.5° N), which should have been ideal in terms of day length, the density of ant colonies was extremely high, and near total reduction of released beetles was observed over the course of two days following release. A third factor is unsuitable host plants. One of the most invasive tamarisk species is *T. parviflora* and its related hybrids, which seem to be a poor host for the Fukang ecotype. Experimental planting of similar size *T. ramosissima* and *T. parviflora* plants were affected very differently by local high densities of beetles, with the *T. parviflora* largely avoided as opposed to near complete defoliation of the *T. ramosissima* plants. It may not be surprising that a central Asian herbivore (the Fukang ecotype) is not compatible with a west Asian/eastern Mediterranean host plant (*T. parviflora*).

Status of Topic Today

There has not been a concerted effort by ERP for the Stage 1 expectation to identify all the plants sold in California by the horticulture industry that pose a threat to ecosystems in the Bay-Delta watershed. A plan needs to be developed or instituted, in cooperation with the horticulture industry and affected interests, to greatly reduce, and eventually eliminate, the introduction of additional invasive plant species into natural environments.

Planned Projects for Implementation

The implementation of the California Aquatic Invasive Species Management Plan and the continuation funding for monitoring by CSLC, DFG/OSPR, and CDFA well help ERP meet the second of the two Stage 1 expectations. The AIS Management Plan included arundo, tamarisk, cordgrass (*Spartina* spp. [introduced and hybrid species]), and purple loosestrife as AIS species. However, the management plan does not specifically address all of the invasive riparian and marsh plants that CALFED wishes to target, like perennial pepperweed.

Impediments to Implementation

None.

References

Andrew, M. E., and S. L. Ustin. 2006. Mapping Perennial Pepperweed with Hyperspectral Imagery of the Sacramento-San Joaquin Delta. *In* 4th Biennial CALFED Science Conference 2006 Abstracts. Sacramento, CA.

Bean, D., T. Chew, B. Li and R. I. Carruthers. 2001. Diapause in Relation to the Life History of *Dirohabda Elongata* (Chrysomelidae), a Eurasian Leaf Beetle Introduced as a Biocontrol Agent of Saltcedar (*Tamarix* spp.). Abstract. Entomological Society of America. San Diego, CA.

Barbour, M., B. Pavlik, F. Drysdale and S. Lindstrom. 1993. California's Changing Landscapes: Diversity and Conservation of California Vegetation. California Native Plant Society. Sacramento, CA.

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIRTechnical Appendix. Sacramento, CA.

DeLoach, C. J., R. I. Carruthers, T. D. Dudley and 18 others. 2004. First Results for Control of Saltcedar (*Tamarix* spp.) in the Open Field in the Western United States. *In* R. Cullen (ed.), XI International Symposium on Biological Control of Weeds. Canberra, Australia.

Estrella, S. 2007. Reestablishment of Native Plant Populations Following Application of the Herbicide Chlorsulfuron to *Lepidium* in a Tidal Wetland in Suisun Marsh. In 8th Biennial State of the San Francisco Estuary Conference Abstracts. San Francisco Estuary Project. Oakland, CA.

Geraci, C. C., T. Dudley, and B. Rundquist. 2006. Remote Sensing Assessment of Widespread Saltcedar Infestation and Biological Control in NW Nevada. Prairie Perspectives. In press.

Hitchcock, D., T. D. Dudley and W. Longland. In review. Influence of Biological Control Introductions on Wildlife Habitat Quality in Saltcedar Stands. Great Basin Naturalist.

Lewis, P. A., J. C. Herr, T. D. Dudley, R. I. Carruthers and C. J. DeLoach. 2003. Assessment of Risk to Native Frankenia Shrubs from an Asian Leaf Beetle, Diorhabda Elongata Deserticola (Coleoptera: Chrysomelidae), Introduced for Biological Control of Saltcedars (Tamarix spp.) in the Western U.S. Biological Control. 27:148-166.

Rudrappa, T., J. Bonsall, J. L. Gallagher, D. M. Seliskar and H. P. Bais. 2007. Root-Secreted Allelochemical in the Noxious Weed *Phragmites australis* Deploys a Reactive Oxygen Species Response and Microtubule Assembly Disruption to Execute Rhizotoxicity. Journal of Chemical Ecology. 33(10):1898-1918.

Saltonstall, K. 2002. Cryptic Invasion by a Non-native Genotype of *Phragmites australis* into North America. Proceedings of the National Academy of Sciences, USA. 99(4):2445-2449.

5. STRESSORS

5.6. Invasive Species

5.6.4. Non-native Wildlife

Introduction

One of the most serious environmental problems facing California is the explosive invasion of non-native plants and animals. Non-native plants, wildlife, fish, and aquatic invertebrates can greatly alter the ecosystem processes, functions, habitats, species diversity, and abundance of native plants, fish, and wildlife.

Many of these invasive species spread rapidly and form dense populations primarily by out-competing native species as a result of large-scale habitat changes that tend to favor non-native species, and a lack of natural controls (e.g. disease and natural predators). As populations of non-native species grow, they can disrupt the ecosystem and population dynamics of native species. In some cases, habitat changes have eliminated connectivity of habitats that harbor native predators that could help to limit populations of harmful non-native species.

The following common but harmful non-native species are found in the Bay-Delta area:

- The European red fox was brought to California to be hunted for sport and raised for fur during the late 1800s and early 1900s. The population of this fox appears to be increasing and is now widespread in the Central Valley lowlands and the coastal counties south of Sonoma County. The range of this species also appears to be increasing, and the fox is a threat to many native endangered wildlife species such as the California clapper rail.
- The Norway rat was introduced unintentionally and was established in many areas by the mid-1800s. Increases in urban development, landfills, and riprap areas have resulted in large populations of these rats living along the bay shores. They are a threat to ground-nesting wildlife.
- Feral cats a remajor predators on bird and mammal populations in the wetland areas of the Bay-Delta Estuary and wildlife areas elsewhere.
- The bullfrog is not native west of the Rockies, but has been successfully introduced throughout most of California from Oregon to Mexico. Bullfrogs can establish and thrive in most permanent aquatic habitats that support emergent vegetation. Population levels in semi-permanent aquatic habitats vary from year to year. Bullfrogs feed on most vertebrates and invertebrates that they can seize and swallow.

- The red-eared pond slider is a turtle native to the southeastern United States and sold in pet stores throughout the west. The species has become established in the wild in some locations through releases by pet owners. The range and status of sliders in the Delta are unknown but it is possible that this species is successfully reproducing. It competes with western pond turtles for basking sites and may compete with other aquatic species for resources in the Delta.

Non-native wildlife species have been sighted throughout the Sacramento and San Joaquin Valleys in a variety of habitats, including aquatic; riparian scrub, woodland, and forest habitats; valley oak woodland; grassland; and agricultural land.

Reestablishing connectivity between habitats would help to reduce non-native species. For instance, restoring the connection between Bay marshlands and upland habitats that have populations of coyotes may help to reduce populations of red fox. Nest conditions in fragmented areas of riparian habitats encourage nest predation and parasitism by nonnative species such as European starlings and brown-headed cowbirds. Restoring large blocks or broad bands of riparian habitats will eliminate or minimize these adverse effects. Larger blocks may also encourage additional nesting by native deep-forest-nesting species that have been previously excluded.

Reducing the numbers of non-native species and therefore the effects these species have on native wildlife will require a coordinated approach that includes: restoring ecosystem processes and functions where applicable and possible; restoring native habitats; reducing or eliminating other stressors that suppress native species; and making efforts to control non-native species.

Applicable ERP Vision

The vision for non-native wildlife species is to implement a program to reduce the numbers of harmful non-native wildlife species (i.e. those that threaten the diversity or abundance of native species or the ecological stability of an area).

The large-scale restoration of emergent wetlands, riparian habitat, and adjacent perennial grasslands will be the main focus of a strategy to reduce the adverse impacts of non-native wildlife on the health of the Bay-Delta ecosystem. The goal is a restored Bay-Delta and watershed where the quality, quantity, and structure of the restored habitat discourage colonization by non-native wildlife, provide a competitive advantage to native wildlife, and reduce the vulnerability of native species to nest parasitism and predation from species such as the brown-headed cowbird and European starling, and from predation by species such as the red fox and Norway rat.

Stage 1 Expectations

The expectation for Stage 1 was that an assessment of existing introductions would be completed to identify those with the greatest potential for containment or eradication; and that this assessment would be considered when prioritizing control efforts. A program was to be implemented to monitor for new invasions, and respond quickly to contain and eradicate those invasions, where possible. A mechanism to deal with new invasions quickly and effectively was to be developed and implemented.

Changes Attributable to ERP

See Invasive Aquatic Organisms Section for actions taken in regards to NIS by the California State Lands Commission (CSLC), the California Department of Fish and Game (CDFG), the State Water Resources Control Board (SWRCB), California Department of Food and Agriculture (CDFA), U.S. Fish and Wildlife Service (USFWS), and the Non-native Invasive Species Advisory Council (NISAC). None of the ERP projects listed in the project summary table focused primarily on the removal of non-native wildlife. None of the projects reported the removal of non-native wildlife.

Project Summary Table

Table 1. Non-native Wildlife Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-E05	**Merced River Corridor Restoration Project - Phase III** To develop a publicly supported, technically sound, and implementable restoration plan for the Merced River corridor from Crocker-Huffman Dam downstream to the San Joaquin River.	11/1/2002	$341,271	Complete.
ERP-01-N38	**Delta Studies Program: San Joaquin County Schools** This project increased student and teacher knowledge at sixty targeted schools in San Joaquin County. The program will develop a Delta Studies Curriculum, develop and maintain a Delta Education Resource Center, and recruit, identify, train, and support a cadre of thirty teacher leaders each per years Two and Three called Delta Educational Leaders for Teaching and Action (DELTA).	6/30/2004	$323,198	Complete. This was an educational program with lessons focused on aquatic and terrestrial habitats and ecological functions of the Delta.
ERP-01-N41	**Bay-Delta Learning Initiative** Produced and distributed educational posters, directed at boaters and anglers, to teach them about plant and pest non-native invasive species; and provided the media with an overview of current topics and provided workshops and teaching materials for teachers for greater awareness of and appreciation for the Bay-Delta ecosystem.	3/31/2004	$126,668	Complete.

Table 1. Non-native Wildlife Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-B34	**Discover the Flyway** Increased student awareness of wetlands and wildlife issues in the Yolo Basin.	12/31/2001	$49,000	Complete. Enhanced seasonal wetland planting 3,000 native sedge/grass plugs.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** CMARP is an adaptive management strategy as a process for implementing proposed changes and ongoing activities to many aspects of the Bay-Delta/Central Valley environment and water management system. CMARP provides information and scientific interpretations necessary for program implementation and to judge the Program's success. CMARP provides information on all of the CALFED program elements and contributes to the mitigation design.	12/31/1999	$800,000	Complete.
ERP-98-E01	**Napa River Watershed Stewardship** This project built upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/31/2000	$250,000	Complete.
ERP-98-E09	**Merced River Corridor Restoration Plan - Phase II** Analyzed and quantified current in-channel, riparian, and floodplain conditions in the Merced River Corridor.	5/23/2001	$345,443	Complete.
ERP-98-E12	**Lower Mokelumne River Watershed Stewardship Program (Phase I)** Facilitated broad based local stakeholder group in development of watershed plan, develop Environmental Farm plan and expand Neotropical bird monitoring for the Mokelumne River Watershed.	9/1/2000	$159,000	Complete.
ERP-99-F06	**Reducing the Risk of Importation and Distribution on Nonindigenous Invasive Species Through Outreach and Education** Developed a comprehensive program of outreach and education that results in reducing the probability of the introduction of new Non-native Invasive Species (NIS) and minimizes the spread of existing NIS in the San Francisco Bay-Delta region.	5/31/2003	$105,466	Complete.
ERP-99-F07	**Zebra Mussel Detection & Outreach Program** Implemented a combination of public outreach and monitoring to, first provide information to educate the public about zebra mussels and the means by which they spread and, second to set up and operate an early detection system in the Central Valley, Bay/Delta and water storage and delivery systems.	2/23/2006	$160,000	Complete.

Table 1. Non-native Wildlife Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-N15	**Lower Mokelumne River Watershed Stewardship Plan Program (Phase II/III)** This project was a continuation of a previously funded project by completing preparation of the Lower Mokelumne River Watershed Stewardship Plan/Watershed Owner's Manual, Action Plan, and Monitoring and Evaluation Program and implemented the Initial Watershed Stewardship Actions.	6/30/2002	$227,000	Complete.
ERP-99-N20	**Napa River Watershed Stewardship Year 2** This project built upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/30/2001	$191,100	Complete.

Other Programs Contributing to ERP Vision

Golet et al. (2007) addressed the concern that restoration may increase pest species' impacts on adjoining agricultural lands. They conducted a study of small mammal distribution and abundance at four habitat types (agricultural, young restoration, older restoration, and remnant riparian) on the middle Sacramento River. Results indicated that although certain orchard pests (especially voles) had relatively high abundances at young restoration sites, these declined as sites matured. Overall, they found relative abundance of small mammal pests was typically lower in older restoration sites and remnant habitats than in agricultural sites. They suggest that in young restoration sites, voles could be controlled by erecting barn owl nest boxes, as voles are their most common prey of the owl. However, they are still concerned with the high relative abundance of exotic black rats (*Rattus rattus*), a predator of songbird nests and roosting bats, in older restoration sites and remnant riparian forests.

Small (2007) conducted a study to examine factors affecting landbird demographics in the context of floodplain forest restoration in an agricultural valley. Using time-lapse video equipment, he identified nest predation by agriculture-associated predators as a primary source of nest mortality in the Sacramento River Valley. Nest predation rates on restoration and mature remnant forest sites did not differ, indicating that restoration sites are functioning at least as well as forest sites as breeding habitat, in terms of nest success. He also suggested that nest predation, in addition to nest parasitism, by the brown-headed cowbird (*Molothrus ater*) may be a critical limiting factor for spotted towhees (*Pipilo maculates*). Additionally, flood timing influences nest predation rates for black-headed grosbeaks (*Pheucticus melanocephalus*), possibly by driving mammalian nest predator population cycles (Small 2007).

Status of Topic Today

ERP needs to complete an assessment of existing introductions to identify those with the greatest potential for containment or eradication, and consider this in prioritizing control efforts. ERP needs to establish a program to monitor for new invasions of non-native wildlife, and respond quickly to contain and eradicate them.

Planned Projects for Implementation

None.

Impediments to Implementation

None.

References

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIRTechnical Appendix. Sacramento, CA.

Golet, G. H., J. Hunt, D. Koenig, R. J. Bogiatto and G. Werner. 2007. Do Small Mammal Pest Species' Impacts Increase on Farms when Adjoining Lands are Converted to Riparian Habitat? *In* Sacramento River Restoration Science Conference Abstracts. The Nature Conservancy and Sacramento River Conservation Area Forum. April 9-10, 2007.

Small, S. L. 2007. Conservation and Ecology of Breeding Landbirds in a Riparian Restoration Context. *In* Sacramento River Restoration Science Conference Abstracts. The Nature Conservancy and Sacramento River Conservation Area Forum. April 9-10, 2007.

5. STRESSORS

5.7. Predation and Competition

Introduction

Predation and competition are natural ecological functions whose effects can be magnified by human activities. Efforts to reduce undesirable levels of predation or competition between fish species, particularly species of concern, may be a valuable component in restoring fish populations in the Bay-Delta system.

As originally described in the Ecosystem Restoration Program Plan, predation and competition were focused on fish species, especially Chinook salmon. While predation is a natural ecosystem element, artificial structures such as dams, bridges and diversions create shadows and turbulent water that tend to attract both native and non-native predatory species and provide them with an unnatural advantage. Likewise, salmon and steelhead artificially propagated at hatcheries in the Central Valley may compete with naturally produced fish for food, or displace them from available habitats in the river or estuary.

Predation was observed during field studies at various locations, including Red Bluff Diversion Dam, Glenn-Colusa Irrigation District's Hamilton City Pumping Plant, flood bypasses, and release sites for salmon salvaged at the State and federal Delta pumping plants, areas of rip-rap bank protection, the Suisun Marsh Salinity Control Structure, and Clifton Court Forebay.

Applicable ERP Vision

The ERP vision for this set of stressors is to reduce undesirable levels of predation and competition by removing, redesigning or reoperating in-water structures and diversion dams, and by altering hatchery practices to minimize interactions between hatchery and natural stock. Although the major focus was placed on Chinook salmon; other native species of concern such as delta smelt and green sturgeon should be included.

Stage 1 Expectations

The Stage 1 expectations for predation and competition were to implement projects that would identify and reduce predation associated with the operation of the state and federal water export facilities and at other diversion sites throughout the ERPP study area.

Changes Attributable to ERP

The project summary table (Table 1) contains examples of projects that directly or indirectly reduce the undesirable effects of competition and predation. Two projects (detailed below) encompassed objectives that would directly benefit native fish by reducing predator habitat. The effects of predation have been addressed indirectly through thirteen other ERP projects. For example, projects have acquired land for floodplain restoration and rock revetment, the Glenn-Colusa Irrigation District's fish screen at its Hamilton City Pumping Plant has been replaced, and the Red Bluff Diversion Dam has been re-operated in part to reduce turbulence and reduce predation on juvenile salmon. Projects included the acquisition and restoration of floodplain lands and natural stream processes and isolation of predator habitat especially in the East San Joaquin EMZ.

The Merced River Salmon Habitat Enhancement River Miles 42 to 44 (revised Phase II) project (**ERP-01-C03**) restored a reach of the Merced River. Gravel mining throughout the 4.5 mile reach of the Merced River created areas lower than the river channel that were captured in the 1997 high flows. This caused the river to deviate from its original course, therefore creating an impediment to passage for juvenile and adult fall-run Chinook salmon; prime habitat for warm-water predators (like bass) and birds that prey upon juvenile salmon; and decreased fall-run Chinook salmon spawning habitat by 25%. Among many objectives, this project eliminated and isolated predator habitat by removing levees and berms and filling gravel ponds in the floodplain. Removal of the ponds from the main channel will decrease predators, improve river function, and improve passage and spawning habitat for salmon.

One of the primary goals of the *Tuolumne River Restoration: Special Run Pool 10* project (**ERP-01-N03**) was to improve salmon spawning and rearing habitats, and reduce predator habitat (bass) by filling the in-channel mining pits, preventing future connections between the River and the off-channel mining pit, and restoring native riparian habitats. Because of the high flows and low temperatures during the study period, predator data collected was inconclusive. The research suggests further studies should be conducted to document predation rate and assess velocity-driven and temperature-driven habitat segregation between salmon and predators at lower flows and higher water temperatures.

Project Summary Table

Table 1. Predation and Competition Project Summary

Project Number	Project Name and Description	End Date	Total Funding	Project Status
CVPIA-01-F02	**Spawning Habitat & Floodplain Restoration in the Stanislaus River, Phase I** Restored spawning and rearing habitat for salmonids in the Lover's Leap reach on the lower Stanislaus River.	Unknown	$672,610	Complete. Gravel infusion.
ERP-00-B03	**Culture of Delta Smelt Phase II & III** Developed a functional culture system for delta smelt. Continuance of phase I of ERP-98-C02.	10/31/2003	$811,380	Complete.
ERP-00-E05	**Merced River Corridor Restoration Project - Phase III** Developed a publicly supported, technically sound, and implementable restoration plan for the Merced River corridor from Crocker-Huffman Dam downstream to the San Joaquin River.	11/1/2002	$341,271	Complete.
ERP-00-F08	**McCormack-Williamson Tract Restoration Planning, Design and Monitoring Program I** Performed baseline studies necessary for project planning and design, and the development of long-term monitoring programs of the McCormack-Williamson Tract (M-W), which is a 1,600-acre Delta island.	8/1/2003	$556,200	Complete.
ERP-01-C03	**Revised Phase II - Merced River Salmon Habitat Enhancement River Miles 42 to 44 (Robinson Reach and Permit #307 sites)** (Was 01-N06) – Restoration of a reach of the Merced river: channel reconfiguration, creation of a large floodplain with native vegetation, and berm reconstruction to reduce predation of non-native fish on native species.	6/30/2004	$1,699,101	Complete.
ERP-01-N03	**Tuolumne River Restoration: Special Run Pool 10** Improved salmon spawning and rearing habitats and reduced predator habitat (bass) by filling the in-channel mining pits; preventing future connections between the River and the off-channel mining pit and restoring native riparian habitats.	6/30/2006	$652,030	Complete. Funding was for the assessment, planning and design portion of the project. Actual channel restoration has not occurred due to lack of funding.
ERP-01-N57	**Lower Mokelumne River Restoration Program - Phase 2** Prepared design and specifications for a proposed fish screen system along the Lower Mokelumne River.	2/28/2002	$680,000	Complete.
ERP-01-N58	**Fish Passage Improvement at the Red Bluff Diversion Dam: Balance of Phase II Funding** Helped reduce and minimized the impacts of the Sacramento River's Red Bluff Diversion Dam on upstream and downstream migration of juvenile and adult anadromous fish, while improving agricultural water supply.	9/30/2004	$734,000	Complete.
ERP-07D-S03	**Population Biology, Life History, Distribution, and Environmental Optima of Green Sturgeon** Conduct telemetric, physiological, reproductive, and genetic studies to provide state and federal agencies such as NMFS and the California Department of Fish and Game (CDFG) with information on the size of the population.	9/30/2009	$969,690	Ongoing.

Table 1. Predation and Competition Project Summary

Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-B22	**Fish Passage Improvement Project at the Red Bluff Diversion Dam** Provided funds for identifying the best alternative for operation of the Red Bluff Diversion Dam that maximizes fish passage for anadromous fish while minimizing adverse impacts to agricultural irrigation supply.	2/28/2000	$340,164	Complete.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** Implementation of monitoring and applied research that provides data and information necessary to evaluate the performance of completed CALFED program actions and ongoing programs.	12/31/1999	$800,000	Complete.
ERP-98-E03	**San Francisco Bay Area Wetlands Ecosystem Goals Project** Provided funds to enable the collection of data to be use in the creation of habitat goals which will be used by private, local, state, and federal entities seeking to protect and improve the San Francisco Bay Area's wetlands.	Unknown	$76,000	Complete. Visit website at www.sfei.org/sfbaygoals for more information.
ERP-98-E09	**Merced River Corridor Restoration Plan - Phase II** Analyzed and quantified current in-channel, riparian, and floodplain conditions in the Merced River Corridor.	5/31/2001	$345,443	Complete.
ERP-99-B04	**Preliminary Design and Engineering of Lower Western Stone Site, Merced River Salmon Habitat Enhancement Project (Phase IV)** Reduced entrainment of outmigrating fish. Improve river and floodplain dynamics and enhance the riparian corridor.	4/30/2003	$125,000	Complete.
ERP-99-B05	**Merced River Salmon Habitat Enhancement Project Phase II- Ratzlaff Reach Construction)** Reduced entrainment and predation of out migrating fish. Isolate 45 acres of unnatural predator habitat from the river channel. Improve river and floodplains dynamics and enhance the riparian corridor. Increase the quantity and quality of in stream spawning	3/30/2000	$1,584,002	Complete.
ERP-99-B07	**Fish Passage Improvement at the Red Bluff Diversion Dam, Phase II** Provided funds for a portion of Phase II of the Tehama-Colusa Canal Fish Passage Project at Red Bluff Dam, which involved modifying the Red Bluff Diversion Dam (RBDD) to reduce or minimize the impacts of the RBDD on upstream and downstream mi	3/31/2002	$1,839,888	Complete.

Other Programs Contributing to ERP Vision

Abundance indices for several Delta-dependent fish species, calculated by the Interagency Ecological Program (IEP) through 2007, suggested recent marked declines in four pelagic fishes in the Delta and Suisun Bay. These fishes include delta smelt and

the longfin smelt. Although several species show evidence of long-term declines, the recent low levels were unexpected given the relatively moderate winter-spring flows of the past several years. In response to these changes, the IEP formed a Pelagic Organism Decline ("POD") work team to evaluate the potential causes. The major findings through 2007 were synthesized using conceptual modeling approaches (Baxter et al. 2008).

One of the stressors examined by POD scientists was predation. The hypothesis suggested that predation effects have increased in all water year types as a result of increased populations of pelagic and inshore piscivores. In the pelagic habitat, age-1 and age-2 striped bass appear to have declined more slowly than age-0 striped bass. Adult striped bass abundance increased in the latter 1990s, so it is likely that there has been high striped bass predation pressure on smaller pelagic fishes in recent. Further, largemouth bass abundance has increased in the Delta over the past few decades. Analyses of fish salvage data show this increase occurred somewhat abruptly in the early 1990s and has been sustained since.

The increase in salvage of largemouth bass occurred during the time period when E. densa, an introduced aquatic macrophyte was expanding its range in the Delta. The habitat provided by beds of *E. densa* provide good habitat for largemouth bass and other species of centrarchids. Thus, the increased abundance of this introduced predator was likely caused by an increase in an introduced plant, which provided favorable habitat. The coverage of *E. densa* in the Delta continued to expand by more than 10% per year from 2004 to 2006, as it infested a greater portion of channels and invaded new habitat. This suggests that populations of largemouth bass and other species using submerged aquatic vegetation will continue to increase. Increases in largemouth bass may have had a particularly important effect on threadfin shad and striped bass, whose earlier life stages occur in littoral habitat (Baxter et al. 2008).

Status of Topic Today

Many researchers are investigating the roles of alien species in the Delta and Suisun Marsh and their relation to predation and competition with native species.

Planned Projects for Implementation

There are no projects planned for implementation, however studies should continue that would increase understanding on predator-prey relationships, competition, and the effects of altering operation of the state and federal water export facilities and diversion sites.

Impediments to Implementation

None.

References

Baxter, R., R. Breuer, L. Brown, M.Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, T. Sommer, and K. Souza. 2008. "Pelagic Organism Decline Progress Report: 2007 Synthesis of Results" Interagency Ecological Program.

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIRTechnical Appendix. Sacramento, CA.

5. STRESSORS

5.8. Contaminants

5.8.1 Dissolved Oxygen

Introduction

Dissolved oxygen (DO) is gaseous oxygen dissolved in water and is produced from photosynthesis, atmospheric diffusion, and wind/wave action. DO is consumed by microbial processes such as respiration and nitrification, both of which are stimulated by nutrients such as nitrogen and carbon. The amount of oxygen required to decompose organic matter is often expressed as biological oxygen demand (BOD). When oxygen consumption exceeds oxygen production, oxygen is depleted and DO levels drop.

Most aquatic life depends on DO for oxygen, and low DO levels can result in mortality to fish and other aquatic animals. The optimum range of dissolved oxygen for fish and aquatic life is from 5-9 mg/L. Low DO can affect fish behaviors such as feeding, migration and reproduction. Waters with DO concentrations approaching 2 mg/L are usually considered hypoxic. Hypoxic conditions can be a barrier to fish migration and may result in community or food web changes when fish and benthic invertebrate populations are impacted.

Oxygen depletion is exacerbated by warm water temperatures, as warm water cannot hold as much DO as cold water can. Therefore, DO concentrations typically are lowest during the summer months when river temperatures are warmest. Also, as salt concentration increases, DO decreases because fewer oxygen molecules can be dissolved.

The Stockton Deep Water Ship Channel (DWSC) is a dredged portion of the San Joaquin River beginning at the mouth of the San Joaquin River near Antioch and terminating near the City of Stockton. Large vessels use the DWSC to access to the Port of Stockton. Low DO levels occur in the DWSC between Channel Point (near Stockton) and about 13 miles downstream to Disappointment Slough. The concentration of DO in this section of the DWSC is a function of three primary factors: flow, channel geometry (depth and width), and upstream contributions of algae and oxygen-depleting constituents, such as ammonia.

Low DO levels in late summer and fall have been a problem in the DWSC for over 50 years. The primary causes of low DO in the mid-1950s were increased oxygen demand from decay of cannery wastes; reduced river flows caused by construction of Friant Dam; and pumping at the Central Valley Project (CVP) Tracy Pumping Plant. The problem was exacerbated in 1987 when the DWSC was deepened to 37 feet. Today,

the flow of the San Joaquin River through the DWSC during the summer and fall is highly regulated by upstream reservoir releases and agricultural and other water diversions. Reduced flow due to CVP pumping and the depth of the DWSC increase residence time of water within the DWSC, causing inflowing algae to settle and decay. Oxygen consumption increases as the algae respire and bacteria decompose the dead algae. Other substances, like ammonia, are discharged or generated by biogeochemical processes within the San Joaquin River and the DWSC, and these also exert oxygen demand.

When ERP implementation plans were developed, documented fish kills and low DO levels in the DWSC were well known. Biologists also suspected that fall-run Chinook salmon on their return migration to east side tributaries were being held downstream longer when DO in the DWSC was low.

In 1967, Interim Water Quality Control Plans for the Sacramento–San Joaquin Delta were adopted by the CVRWQCB, with a DO water quality objective of 5.0 mg/L established for all waters of the Delta. This objective was adopted into the first edition of the Basin Plan in 1975. In 1991, the Central Valley Regional Water Quality Control Board (CVRWQCB) raised the numeric water quality objective for DO in the DWSC to 6.0 mg/L between September 1 and November 30 to facilitate the upstream migration of fall run Chinook salmon, and maintained it at 5.0 mg/L for the rest of the year (CVRWQCB 1991). DO concentrations in the DWSC frequently drop below these water quality objectives during the summer and fall months (June to November).

Applicable ERP Vision

The ERP Vision for contaminants, including the factors leading to low DO, is to ensure that all waters of mainstem rivers and tributaries entering the Bay-Delta, and all waters of the Bay-Delta, are free of high concentrations of toxic substances.

The specific Strategic Objective for Dissolved Oxygen is to reduce loadings of oxygen-depleting substances from human activities into aquatic ecosystems in the Bay-Delta watershed to levels that do not cause adverse ecological effects.

The July 2000 CALFED Water Quality Program Plan identified priority actions to address low DO concentration and oxygen-depleting substances in the San Joaquin River near Stockton, with the following goals:

- Eliminate the occurrences of DO concentrations below 5 mg/L,
- Reduce algal blooms,
- Reduce stress to fish from low DO concentrations,
- Eliminate fish kills near Stockton, and
- Reduce impediments to fish migration caused by low DO

Stage 1 Expectations

The expectations for Stage 1 were to have identified sources or areas of problem releases of oxygen-depleting substances and to have developed incentive programs to reduce the amount of organic contamination coming from agricultural, industrial, and residential areas.

Changes Attributable to ERP

In 1999, ERP funding from Proposition 204 was used for the first large study of the causes of DO depletion in the San Joaquin River, *Determination of the Causes of Dissolved Oxygen Depletion in the San Joaquin River* (**ERP-99-B16**) (CALFED 2001).

In 2001, nearly $2 million was awarded to a team of scientists to continue studies on dissolved oxygen in the DWSC. This directed action included 10 project tasks that were later contracted as separate projects, **ERP-01-N61-01** through **ERP-01-N61-06**. The projects comprising the 2001 Directed Action Dissolved Oxygen Study are identified as such in the Project Summary Table.

These studies had two primary purposes: 1) to determine the assimilative capacity of the DWSC for oxygen-demanding materials of various types and under various conditions; and 2) to provide a technical basis for assigning load allocations to responsible contributors of oxygen-demanding substances. The study provided initial direction on potential approaches to control low DO and identified urban stormwater runoff as a potential source of oxygen demand leading to DO depletion.

A key task under this study was *San Joaquin River Dissolved Oxygen Depletion Control Project: Coordination, Integration, and Technical Administration* (**ERP-01-N61-01**) focused on the integration and coordination needed for these 10 projects. The dissolved oxygen report known as the “Synthesis Report” was also completed under this task. The Synthesis Report combined the findings of ERP-funded directed action projects conducted between 1999 and 2003, including findings from a peer review of the project’s results and recommendations on future research needs.

Temporary rock barriers are installed each year in three south Delta channels to trap incoming tides to raise in-channel water levels to assist south delta agricultural diversions. A fourth barrier improves circulation and reduces stagnant or "null zones". The installation and operation of Head of Old River barrier - between October and November is specifically requested by DFG to keep more SJR water flowing through the DWSC to improve DO for upstream migrating SJR Chinook salmon.

To determine whether it would be possible to operate the barriers in a different way to positively affect DO levels, the ERP-funded *Directed Action for Dissolved Oxygen* (**ERP-01-C61-1-D**). Using a stand-alone version of the DSM2 model for the upper San Joaquin River, this study investigated the effects of increasing San Joaquin River flow by adding auxiliary pumps over the Grant Line Canal Barrier. The study concluded that this approach would increase the flow of the San Joaquin River through the DWSC, benefiting south Delta water quality and making it easier to manage aeration in the DWSC by stabilizing San Joaquin River flows.

When the hydraulic barriers are not in place, up to 50 percent of San Joaquin River flows may be diverted for municipal and agricultural purposes. To quantify the impact of these diversions on DO levels in the DWSC, the ERP funded *San Joaquin River Diversion Data Assimilation, Drainage Estimation, and Installation of Diversion Monitoring Stations* (**ERP-01-N61-02**). This project provided data on the volume of agricultural and non-agricultural diversions and return flows in the lower San Joaquin River between Lander Avenue and the DWSC. The study found that reduced pumping/diversions between September and November (when DWSC DO depletions are problematic) allow the uninterrupted passage of algae from the upper watershed into the channel, potentially doubling the total algal load. While greater algal loads were always found to result in increased oxygen demand, the study noted the problem is worse in dry years when riparian and appropriative diversions remove a majority of SJR flow, and less severe in wet years when greater flows through the DWSC decrease residence time and the opportunity for algal loads to settle. The project also found municipal POTW discharges to the San Joaquin River during the summer months to be small in volume and significance, equivalent to about 1% of total river flow, and 2-3% of the total load of oxygen demanding substances.

The City of Stockton discharges its treated wastewater into the San Joaquin River approximately two miles upstream of where the river enters the DWSC at Channel Point. To characterize DWSC water quality patterns and evaluate relationships between wastewater effluent loads and San Joaquin River loads, the ERP funded *City of Stockton Water Quality Sampling* (**ERP-01-N61-03**)

To characterize the impact of San Joaquin River flow on DO concentrations in the DWSC, the ERP funded *Downstream Tidal Exchange and Residence Time in the Deep Water Ship Channel* (**ERP-01-N61-06**). This project investigated and quantified hydraulic residence time and net San Joaquin River flow as influenced by tidal action and Delta exports to evaluate the significance of various flow regimes and related DO sags. The project found that San Joaquin River flows below 2,000 cfs result in hydraulic residence time of waters in the DWSC that exacerbate the DO deficit by holding algae within the channel. However, this project also showed that greater San Joaquin River flows through the DWSC also increase the load of oxygen demanding algae that is transported into the channel.

To better understand the sources of algae to the DWSC and the growth of algae within the channel, the ERP funded *Directed Action for Sources and Causes of Oxygen Demand from Algal Biomass in the San Joaquin River Deep Water Ship Channel* (**ERP-01-C61-2-D**). By quantifying the current sources of oxygen demand in the DWSC during the summer and fall of 2000 and 2001, this project found that persistent low DO concentrations in the channel were not caused by channel geometry or phytoplankton respiration. Rather, the study showed that low DO levels were primarily caused by nitrification of dissolved ammonia associated with the Stockton RWCF and upstream non-point sources and, to a lesser degree, carbonaceous oxygen demand associated with phytoplankton originating upstream. The factors were interrelated as nitrate loads fueled phytoplankton growth, increasing algal respiration and eutrophication, therefore increasing the severity and extent of oxygen depletion. The study recommended more studies related to upstream sources of organic and inorganic matter.

To investigate assumptions that a significant portion of nutrient loading to the DWSC was originating from upstream sources, the ERP funded *Monitoring of Nutrients and Oxygen Depleting Substances in the San Joaquin River Basin Upstream of Vernalis* (**ERP-01-C61-4-D**). This project evaluated 1986-1988 data to determine the major sources of nutrient loads between June and November and sampled nutrients and oxygen-demanding substances at four sites in the San Joaquin River between July and October 2000. The project evaluated loading of nitrate, nitrogen, and phosphorous according to stream flows and revealed that most of the algae in the San Joaquin River was growing in the river, as opposed to being discharged into the river from adjacent tributaries. The project also showed animal waste and sewage to be significant sources of nitrate loading to the San Joaquin River.

To determine the impact of algae and other particulate matter on DO, the ERP funded *Sediment Deposition Rates and Associated Oxygen Demand* (**ERP-01-N61-04**). This project used sedimentation traps to measure the settling rates of algae, organic matter, and inorganic sediments entering the DWSC during summer and fall 2001. The project looked at particulate settling and re-suspension mechanisms, associated oxygen demand, and the rate at which oxygen is depleted. The project concluded that the settling and resuspension of particles in the DWSC results in an increase in the length of time that organic matter, including decaying algae, stays in the channel and contributes to overall oxygen demand. This project recommended additional study related to algal growth and decay in both the San Joaquin River and DWSC.

Concurrent with projects to better understand the sources of oxygen-demanding substances and the mechanisms that influence DO concentrations, the ERP funded studies related to aeration, including *Aeration Technology* (**ERP-01-N61-05**) which evaluated aeration technology from an engineering perspective, and *Aeration Technology Performance Evaluation* (**ERP-01-N61**) which described existing methods to increase DO, summarized the performance of the US Army Corps of Engineers jet-diffuser device, and evaluated the feasibility of various alternative aeration

technologies. This project included four field studies to measure the potential success of aeration, including a dye study to evaluate how well an aeration or oxygen injection system would laterally distribute aerated water across the DWSC. Each of these studies concluded that aeration is an appropriate and feasible technology for improving DO levels and recommended full-scale pilot testing of alternative devices in the DWSC.

The 2001 Directed Action Study also included a task to support the Interagency Ecological Program (IEP) database management to store data from the various directed action projects under the project *Directed Action for Dissolved Oxygen, IEP Data Management* (**ERP-01-C61-3-D**).

In 2003, The ERP Selection Panel recommended that $6.8 million in Proposition 13 funding be awarded to study upstream sources of algae in the DWSC to better understand and control nutrients that lead to algae in the upstream watershed. The study, *Monitoring and Investigations of the San Joaquin River and Tributaries Related to Dissolved Oxygen* (**ERP-02D-P63**) hypothesized that upstream sources of algae are a significant source of oxygen demand in the DWSC. In addition to algae, upstream sources of oxygen-demanding substances that contribute BOD to the San Joaquin River include ammonia and organic carbon from municipalities, dairies, wetlands, and agricultural industries. This study will help discriminate between algal BOD and other sources of BOD in the San Joaquin River watershed. This study looked at the sources and fate of oxygen-consuming materials in the San Joaquin River watershed between Channel Point and Lander Avenue to provide information on the baseline conditions of the basin against which to measure the success of any water quality management program implemented as part of the DO TMDL regulatory program.

Several models of have been developed to assist in evaluating the influence of various factors on DO depletion and to allow simulations of management alternatives for project planning and/or adaptive management. All five models are listed below to provide a comprehensive background. Two of these models were developed using ERP funding.

- The first documented application of a water quality model of the DWSC was the Resource Management Associates (RMA) Link-Node Model (Not ERP funded), a link-node (i.e., mixed volume elements) tidal model, developed by RMA for the Sacramento District of the U.S. Army Corps of Engineers (Corps).
- A second link-node model (Not ERP funded) of the DWSC was developed by Systech for the City of Stockton to assist the City of Stockton (Systech) in preparing for their National Pollutant Discharge Elimination System (NPDES) discharge permit renewal from the CVRWQCB (Philip Williams and Associates 1993).
- A third water quality model of the entire Delta (including the DWSC) is the *Delta simulation DSM2-QUAL model* (Not ERP funded) developed by the Department of Water Resources (DWR). The DSM2 model is a link-node tidal hydraulic model

and is currently used to calculate tidal hydraulics for the entire Delta and as the methodology for flow and salinity estimates in the Bay-Delta.

- A model called ECOMSED was developed by HydroQual Inc. to improve on the fully mixed link-node model results and allowing the diurnal stratification and resulting surface DO increases from aeration and algal photosynthesis to be simulated. *San Joaquin River DO Depletion Modeling HydroQual 3-D Model* (**ERP-02D-P50**) developed a technically defensible modeling framework of the DWSC and the San Joaquin River in order to accurately represent DO dynamics. It included the development of a 3D, time variable model of the DWSC tidal hydrodynamic transport and DO dynamics coupled with a new water quality model of the San Joaquin River. This model is fairly complex and not easily used by other stakeholders. It also generally provided the same results as the simpler and easily used mixed link-node model, suggesting that the link-node model may be preferable for simulating different scenarios for managing DO in the DWSC.
- *Hydrodynamics and Oxygen Modeling of the Stockton Deep Water Ship Channel* (**ERP-02D-P51**) project was designed to address data gaps in two high priority areas identified in the 2001 ERP Single Blueprint: Delta Hydrodynamics and Sediment Transport; and to augment the other modeling projects for dissolved oxygen. This model was developed to evaluate how hydrodynamic and biogeochemical processes interact to produce reductions in DO concentrations within the DWSC. Development of this 3-D hydrodynamic model included extensive data collection efforts in August 2004 and August 2005 to compose a three-dimensional water quality model to develop a clear understanding of what conditions cause oxygen deficiency and recommend potential solutions. This model may prove to be a valuable research tool to investigate extreme events or specific conditions in the DWSC. It may also prove useful as a tool for the broader Delta, as the model data sets have been used for other Delta hydrodynamic efforts.

Although development of the DWR DSM2-Qual Model and the Systech Link-Node water quality model were not ERP-funded, the ERP did fund a support services agreement with the CVRWQCB titled *Validation of Deep Water Ship Channel Models and Technical Support for the San Joaquin River Dissolved Oxygen Project* (**ERP-04-C02**) to provide independent scientific evaluation of these models, including the ability of each to predict key water quality parameters, such as DO.

ERP-funded water quality modeling studies have had mixed results. The data collected (2004 and 2005) have provided a better overall understanding of hydrodynamics in the South Delta and SJR. However, to date the modeling effort has not provided sufficient information to address ERP and CVRWQCB objectives, and the models have had limited value for the ongoing efforts to understand and solve the impairment.

In addition to modeling studies, the ERP has funded several projects to better understand the mechanisms that influence oxygen demand in the DWSC, and to characterize the contribution of various sources to the oxygen demand.

As a potential option for artificial aeration of the DWSC, the ERP funded the *Aeration Technology Performance Evaluation* (**ERP-01-N61**). The project includes research on the feasibility and cost effectiveness of various alternatives for aeration, and deployment of an actual aeration project. After a multi-year effort, including an engineering feasibility study to determine the preferred location, size, and type of aerators to be demonstrated, and planning, design, and construction of the selected demonstration aerators, a U-Tube technology was selected to add 10,000 pounds per day of oxygen to the DWSC. Oxygen-rich water will be injected into the DWSC through a submerged diffuser and mixed through natural tidal influence. The aeration demonstration project also includes an ongoing assessment of DO levels in the DWSC and vicinity and a study of potential adverse effects of oxygen on resident fish species.

Project Summary Table

Table 1. Dissolved Oxygen Project Summary

Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-N61	**Aeration Technology Performance Evaluation** Described existing methods to increase DO; summarized performance of US Army Corps of Engineers jet-diffuser device; and evaluated feasibility of alternative methods to artificially increase DWSC DO levels with various aeration technologies. Examined four field studies to test DWSC aeration, including dye study to evaluate lateral distribution.	2/28/2003	$1,645,000	Complete.
ERP-01-N61-01 (2001 Directed Action Study)	**San Joaquin River Dissolved Oxygen Depletion Control Project: Coordination, Integration, and Technical Administration** Supported work with TAC to develop synthesis report to incorporate information from new studies, including peer review and component project results.	2/28/2003	$158,000	Complete.
ERP-01-N61-02 (2001 Directed Action Study)	**San Joaquin River Dissolved Oxygen Depletion Control Project: San Joaquin River Diversion Data Assimilation, Drainage Estimation, and Installation of Diversion Monitoring Stations** Provided data on flow volume of agricultural and non-agricultural diversions and return flows in lower San Joaquin River between Lander Avenue and DWSC to assess watershed nutrient loading.	8/31/2002	$100,000	Complete.
ERP-01-N61-03 (2001 Directed Action Study)	**San Joaquin River Dissolved Oxygen Depletion Control Project: City of Stockton Water Quality Sampling** Conducted weekly sampling to characterize water quality patterns within DWSC and evaluate potential relationships between wastewater effluent loads and San Joaquin River loads.	5/31/2002	$75,000	Complete, data submitted in final report

Table 1. Dissolved Oxygen Project Summary

Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-N61-04 (2001 Directed Action Study)	**San Joaquin River Dissolved Oxygen Depletion Control Project: Sediment Deposition Rates and Associated Oxygen Demand** Investigated water and suspended sediments in San Joaquin River and DWSC to better understand settling and re-suspension mechanisms that influence DO concentrations to determine impact of algae and other particulate matter on DO and its significance relative to other sources/impacts.	8/31/2002	$112,000	Complete, final report submitted
ERP-01-N61-05 (2001 Directed Action Study)	**San Joaquin River Dissolved Oxygen Depletion Control Project: Aeration Technology** Provided an engineering evaluation of using aeration technology to eliminate the DWSC DO deficit.	12/31/2002	$125,000	Complete, final report submitted
ERP-01-N61-06 (2001 Directed Action Study)	**San Joaquin River Dissolved Oxygen Depletion Control Project: Downstream Tidal Exchange and Residence Time in the Deep Water Ship Channel** Investigated and quantified hydraulic residence time and net San Joaquin River flow as influenced by tidal action in DWSC and Delta exports through Turner Cut and Head of Old River to evaluate significance of various flow regimes and related DO sags.	8/31/2002	$74,000	Complete.
ERP-02D-P50	**San Joaquin River DO Depletion Modeling - HydroQual, Inc.** Developed modeling framework of DWSC and San Joaquin River to accurately represent DO dynamics, including development of 3D, time variable model of DWSC tidal hydrodynamic transport and DO dynamics coupled with new water quality model of San Joaquin River.	6/30/2006	$500,000	Complete, but a more simple link-node model, was developed subsequently
ERP-02D-P51	**Hydrodynamics and Oxygen Modeling of the Stockton Deep Water Ship Channel** Evaluated interaction of hydrodynamic and biogeochemical processes resulting in reductions in DO levels.	8/31/2007	$863,732	Project expired, some deliverables outstanding but will be submitted
ERP-04-C02	**Support Services Agreement - Validation of Deep Water Ship Channel Models and Technical Support for the San Joaquin River Dissolved Oxygen Project** Provided independent scientific evaluation of the Systech link-node water quality model and the DWR Delta Simulation Model (DSM2) including performance of each in predicting key water quality parameters.	3/30/2007	$370,000	Complete.
ERP-01-C61-1-D (2001 Directed Action Study)	**Directed Action for Dissolved Oxygen** Developed version of DSM2 model for upper San Joaquin River to evaluate effects of increasing San Joaquin River flow by adding auxiliary pumps over the Grant Line Canal Barrier.	6/30/2005	$120,000	Complete, reports on website sjrdotmdl.org
ERP-01-C61-2-D (2001 Directed Action Study)	**Directed Action for Sources and Causes of Oxygen Demand from Algal Biomass in the San Joaquin River Deep Water Ship Channel** Determined causes of oxygen demand in DWSC during summer and fall of 2001.	12/31/2004	$583,702	Complete, reports on website sjrdotmdl.org

Table 1. Dissolved Oxygen Project Summary

Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01-C61-3-D (2001 Directed Action Study)	**Directed Action for Dissolved Oxygen, IEP Data Management** Supported data storage in DWR's Interagency Ecological Program (IEP) database	6/30/2006	$50,000	Complete, data stored in IEP database
ERP-01-C61-4-D (2001 Directed Action Study)	**Monitoring of Nutrients and Oxygen Depleting Substances in the San Joaquin River Basin Upstream of Vernalis** Evaluated 1986-1988 data to determine major sources of nutrient loads June through November and sampled nutrients and oxygen-demanding substances at four sites in San Joaquin River July through October 2000.	12/31/2003	$276,000	Complete.
ERP-99-B16	**Determination of the Causes of Dissolved Oxygen Depletion in the San Joaquin River** Produced management action plan to eliminate oxygen depletion in the San Joaquin River during the fall.	6/30/2003	$866,408	Complete.
ERP-02D-P63	**Monitoring and Investigations of the San Joaquin River and Tributaries Related to Dissolved Oxygen** Provided comprehensive understanding of sources and fate of oxygen-consuming materials in San Joaquin River watershed between Channel Point and Lander Avenue.	6/30/2008	$6,807,428	Ongoing

Other Programs Contributing to ERP Vision

The *Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection Bond Act (Proposition 13)* under Chapter 9 provided $40 million to fund construction of facilities to control waste discharges that contribute to low DO in the lower San Joaquin River and the south Delta. A policy decision later allowed a percentage of this amount (initially authorized for the construction of implementation projects) to be used for planning and studies.

Based on the recommendations of the DO TMDL Steering Committee and information generated by ERP-funded studies, the CVRWQCB adopted a phased TMDL in 2005. The San Joaquin River Dissolved Oxygen TMDL requires more studies of the sources of oxygen-demanding substances into the DWSC and recommends specific actions to address the effect of channel geometry and low flow. Based on the results of these studies, the CVRWQCB will develop a final TMDL in 2009.

The City of Stockton discharges its treated domestic wastewater into the San Joaquin River approximately 2 miles upstream of where the river enters the DWSC. The City of Stockton is in the process of constructing and beginning operation of a nitrification facility to reduce ammonia concentrations to below the 2 mg/l effluent limitations in the RWCF discharge permit issued by the Regional Board in 2002. While the nitrification facility will help reduce the frequency of DO problems in the winter months (which

happen periodically), it is not expected to change things significantly during the worst months of the DO impairment (June through September). It should also be noted that the RWCF nitrification facility will not address the carbonaceous portion of RWCF BOD loading to the San Joaquin River.

Three temporary rock barriers are installed each year at Head of Old River to capture incoming tides to mitigate for lowered water levels that result from operation of the SWP and CVP. These barriers modify channel hydrodynamics to reduce the risk of DO blocks near Stockton and are closed between October and November and for 1 month in the spring. As part of the South Delta Improvements Program, DWR proposes to construct and operate a permanent barrier at the head of Old River. While the success of a permanent barrier in increasing dissolved DO is dependent on Delta exports, operation of the barrier in the fall could help maintain desired DO levels in the San Joaquin River by maintaining higher flows in the river.

The *CA Department of Water Resources Stockton DWSC Aeration Demonstration Dissolved Oxygen Project* has been funded to construct a pilot-scale aeration system sized to deliver approximately 10,000 pounds of oxygen per day into the DWSC. The system construction will be completed in the fall of 2007 with testing beginning shortly thereafter. The aeration system will be operated intermittently when DWSC DO levels are below water quality objectives. The on/off operation mode is intended to produce pulses of oxygen that will help quantify the oxygen inputs and response in the DWSC. The project incorporates efforts to understand the distribution of oxygen inputs within the DWSC and the impacts it will have on the long-running DWR DO meter at Rough & Ready Island. The project also includes a study of any adverse effects of oxygen on resident fish species.

In August 2004, the Port of Stockton tested an aeration device that can provide 2,500 pounds per day of DO to the DWSC at Channel Point. As part of that testing, the Port of Stockton also tested the use of pure oxygen to determine the applicability of replacing or enhancing the current system with this technology. As part of that effort, the ERP provided funding to conduct a dye study to track the tidal distribution of oxygen in the DWSC to provide information on the appropriate location and sizing of a demonstration project. In June 2007, the Port of Stockton finished construction and started operation of a bubble plume aeration system using pure oxygen that, when operated in conjunction with the existing U.S. Army Corps of Engineers jet-aerator, will dissolve approximately 4,090 lb/day of oxygen in the DWSC near Channel Point. The Port of Stockton is required to provide this aeration under the terms of Waste Discharge Requirements received from the Regional Board for a berth-deepening project at Rough & Ready Island. These aeration inputs mitigate the calculated effects of the project's further increase of DWSC geometry on the DO impairment.

Status of Topic Today

A DO TMDL Technical Working Group (TWG) was established to provide a public forum for discussing and disseminating technical information generated by the numerous ERP-funded studies focused on understanding and solving low DO impairment in the DWSC. The TWG serves to inform stakeholders involved in the DO TMDL process and to encourage collaboration among the various scientists and engineers involved in managing and executing the studies. The TWG includes nearly 200 scientists and stakeholders and has been meeting approximately five times per year since October 1999. Funding for this forum was originally provided by the City of Stockton and California Department of Water Resources (DWR) and later through ERP funding.

Research to date suggests that a large part of the organic load in the DWSC originates as algae in the upper San Joaquin River which grows during its transport downstream to the DWSC. Significant progress was made late in Stage 1 on a number of San Joaquin River watershed studies conducted to determine the feasibility and cost/benefit of an upper watershed algal control program. However, additional investigations related to algal growth dynamics and zooplankton grazing impacts on algae populations in the SJR are also necessary to better understand how algae populations transform in the San Joaquin River watershed.

While there is normally no rainfall runoff in the San Joaquin River watershed between June and September, there is a potential for municipal, commercial, industrial, and agricultural storm water runoff to be a source of oxygen demand associated with wet weather events that typically occur between October and November. While the ERP has funded studies to better understand and quantify the causes of these extreme DO deficits and to better predict DO response in the DWSC based on ammonia concentrations and flows, the conditions under which DO concentrations respond to changes in flow are still not well understood.

The Basin Plan water quality objective of 6 mg/L between September 1 and November 30 was adopted to protect fall run Chinook salmon migration through the DWSC to their upstream home waters. However, there have been no regional or local studies to validate whether the DO water quality standard is protective of fish, fish migration, and other aquatic organisms, especially since the Stockton RWCF was upgraded to comply with Clean Water Act requirements.

While the TMDL Steering Committee supported development of the Link-Node model in 2000, the CALFED Science Program recommended development of a more elaborate model, specifically the HydroQual 3-D Model and USGS/UC Davis/Stanford Model. The TMDL TWG is currently more confident in the Link-Node model than the more elaborate models developed at the direction of the CALFED Science Program. There is considerable uncertainty among TWG members as to whether these more elaborate models would be successful in making more accurate predictions than the original link-

node model that was available in 2001. It is also important that the models used in the future have open source code and are relatively simple for stakeholders to operate.

A statistical model has confirmed that temperature, hydraulic conditions, ammonia loading, algae produced in the DWSC itself (*in situ* algal production), and upstream algal production all exert significant effects on DO conditions. All of these factors can affect DO in more than one way, and none operates in isolation. However, the predicted response of the system to a variety of hypothetical management actions has indicated that some factors may not be as effective in controlling DO in the channel as previously thought, whereas others may be much more important than previously expected

The flow of the San Joaquin River through the DWSC influences the amount of upstream algal (oxygen demand) load that enters the DWSC, with greater oxygen demand loads occurring with higher flows. However, increasing net flow reduces hydraulic residence time and thus the time available for oxygen-consuming processes to occur in the channel. Higher flow also increases mean velocity, thereby increasing natural aeration. Increasing flow also increases the amount of artificial aeration required to achieve a unit increase in DO and may also increase the loading rate of algal biomass or other organic matter from upstream sources, thereby potentially reducing DO in the channel. Moreover, within a certain range, increasing flow may merely displace or shift the most DO-depleted zone of the channel a few miles downstream of its usual position near Rough and Ready Island. These disparities have a number of implications related to future modeling, monitoring, and management of the system.

Efforts to correct the low DO problem have focused on understanding the sources and causes of the impairment. While some actions such as the City of Stockton RWCF upgrades and the Port of Stockton aerators will likely improve conditions in the DWSC in the near future, monitoring programs and analytical tools have are not yet being used to assess the benefit of these improvements.

Planned Projects for Implementation

The first phase of a DO TMDL was adopted into regulation by the CVRWQCB in January 2005. This regulatory program calls for further study to identify and quantify: 1) sources of oxygen demanding substances in the SJR watershed; 2) transformation of these substances in the SJR on their way to the DWSC; and 3) the conversion of these substances into oxygen demand within the DWSC. This information is needed for the final TMDL allocation which the CVRWQCB has committed to adopting by December 2009. It will also provide watershed stakeholders with the technical understanding and analytical tools necessary to evaluate and implement measures to comply with the

TMDL. Until the TMDL is finalized, the associated ERP CALFED ROD commitments have not been satisfied.

Shortly after the adoption of the first phase of the DO TMDL in 2005, ERP funded a comprehensive 3-year study to provide the data and a computer model needed to understand where and how algae is generated in the SJR watershed (upstream studies). Upstream studies were funded by ERP to document sources and their loads, and effectively address most of the first, and part of the second TMDL study requirements (see previous paragraph). However, no plans are currently in place to gain a better understanding of the conversion of upstream oxygen demanding substances into actual oxygen demand within the DWSC. The following actions have been indicated by the CVRWQCB to be necessary/adequate for addressing the remaining TMDL study requirements:

- Update and expand the water quality model for the SJR downstream of Vernalis and into the DWSC, including some analysis of the flow split at the head of Old River.
- Water quality, algae and zooplankton dynamics studies downstream of Vernalis and into the DWSC.
- Possible continuation of upstream studies for one year due to unusual high-flow conditions experienced during the first two years of the study
- Synthesis, and final peer-review of all above work, including upstream studies

Recommendations for post-TMDL implementation studies include:

- Studies related to the impact of controlling loads of algae (plankton) on the downstream food supply;
- Flow controls and whether South Delta Improvements will improve DO concentrations;
- Applications of artificial aeration; and
- Re-evaluation of whether the CVRWQCB water quality objective of 6.0 between September 1 and November 30 is necessary to protect the return migration of fall-run Chinook salmon.

Impediments to Implementation

A major impediment to implementation is incomplete technical studies required by the TMDL. These studies are needed to satisfy the TMDL regulations and ERP CALFED ROD commitments. They would also assist watershed stakeholders by providing the technical understanding and analytical tools necessary to evaluate and implement measures to comply with the TMDL. Efforts should be made to include CVRWQCB and SWRCB input into ERP processes since the DO TMDL is an ongoing regulatory effort, but neither the CVRWQCB nor the SWRCB are implementing agencies of the ERP.

DWSC geometry and reduced flows through the DWSC are not loads of a pollutant for which mass or concentration limits can be assigned. Instead, these factors reduce the capacity of the DWSC to assimilate loads of oxygen-demanding substances (load capacity). The CVRWQCB has been charged with the development of the DO TMDL but lacks the ability to directly influence flow or channel geometry. The TMDL can only recommend that the agencies responsible for these contributing factors take action to address their impact. Through a coordinated ERP effort and the expeditious use of funding allocated for the DO impairment, it is possible to bring these other agencies to the table for a coordinated and effective solution.

References

CALFED Bay-Delta Program. 2000a. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2000b. Ecosystem Restoration Program Plan - Volume II: Ecological Management Zone Visions. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2000c. Ecosystem Restoration Program Plan - Strategic Plan for Ecosystem Restoration. Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2001. Ecosystem Restoration Program - Draft Stage 1 Implementation Plan. Sacramento, CA

Central Valley Regional Water Quality Control Board (CVRWQCB). 1998. Water Quality Control Plan (Basin Plan) for the Sacramento River Basin and San Joaquin River Basin, Fourth Edition. Sacramento, CA.

CVRWQCB. 1991. Water Quality Control Plan for Salinity for the San Francisco Bay/Sacramento–San Joaquin Delta (1991 Bay/Delta Plan); superseded by 1995 Bay/Delta Plan.

5. STRESSORS

5.8. Contaminants

5.8.2. Mercury

Introduction

Mercury is a toxic metal that has no known beneficial function in animals (Wiener et al. 2003a). Historical mercury mining in the Coast Range, and mercury use in amalgamation associated with gold mining and extraction in the Sierra Nevada, have left an environmental legacy of pervasive mercury contamination in many of the watersheds in northern California (Alpers et al. 2005). The dominant forms of mercury in mining wastes are inorganic: cinnabar (mercury sulfide, a crystalline solid) and quicksilver (elemental mercury, a liquid). Under certain environmental conditions, a small proportion of the inorganic mercury is converted by microbial activity to methylmercury, a more toxic, organic form of mercury that readily bioaccumulates in aquatic and terrestrial food webs. Because methylmercury increases in concentration with each step up the food chain, the species at greatest risk are top predators such as bass and sturgeon; fish-eating birds such as bald eagles; and humans, especially individuals consuming large amounts of sport fish from areas where methylmercury production is pronounced.

Sport fishes from San Francisco Bay as well as the Sacramento–San Joaquin Delta and several of its tributaries have been identified as being unsafe for human consumption because of elevated mercury concentrations. More than 20 fish consumption advisories for mercury have been issued in watersheds in the CALFED solution area (California Office of Environmental Health Hazard Assessment 2007), including a draft advisories for the San Joaquin River and southern Delta (Gassel et al. 2007) and for the Sacramento River and northern Delta (Gassel et al. 2008). The current regulatory environment for mercury includes Total Maximum Daily Load (TMDL) analyses for mercury and methylmercury. A TMDL-based Basin Plan Amendment was recently accepted by the SWRCB for San Francisco Bay (California Regional Water Quality Control Board – San Francisco Bay Region 2006) and a TMDL-based amendment has been proposed by RWQCB staff for the Delta (Wood et al. 2006).

Increased concentrations of methylmercury in water, sediment and/or biota might result from any of several types of ERP actions, including a) restoration of wetland and floodplain habitats in the San Francisco Bay and Delta, b) changes in the conveyance of fresh water across the Delta, and c) changes to floodplains related to flood control. Concerns for wetlands stem from previous work that identified these landscapes as

associated with the formation of methylmercury (e.g. Krabbenhoft et al. 1999 and Munthe et al. 2007).

Applicable ERP Vision

ERP's vision for contaminants, including mercury, is to ensure that all waters of mainstem rivers and tributaries entering the Bay-Delta, and all waters of the Bay-Delta, are free of high concentrations of toxic substances.

The vision includes preventing, controlling, or reducing damaging levels of high-priority contaminants by remediating mine wastes, minimizing boat discharges and dredging effects, managing flows, restoring habitat, managing watersheds, and supporting existing programs for controlling agricultural and urban point and non-point sources.

The remediation of abandoned mines will significantly contribute to reduction of heavy metals, sediments, acidified water, as well as other pollutants to tributaries and mainstem rivers, and the Bay-Delta estuary. Water degradation from mine drainage water can be reduced by controlling runoff based on water quality objectives for specific contaminants; re-grading, sealing, and reclaiming strip-mined lands by restoring physical habitat; or using biological or chemical inhibitors to reduce acid formation.

ERP specified that dredging activities should be monitored and practices developed and implemented to reduce the release and re-suspension of toxic substances in contaminated sediments and the discharge of contaminated water from dewatering operations.

Stage 1 Expectations

The understanding of mercury contamination at the beginning of Stage I was summarized by the following passage from Volume 1: "…many resident fish, wildlife and invertebrates contain high levels of heavy metals and other contaminants, resulting in warnings that their consumption may be harmful to human health. Elimination of this contamination in the short run is unlikely, but systematic reduction of sources may eventually make all harvested organisms in the estuary and watershed safe to eat. In some cases, such as mercury, reduction of loads to safe levels may be extremely difficult because of deposits in sediments and through absorption and bioaccumulation, but strategies to reduce concentrations are still needed" (CALFED 2000a).

Stage I expectations regarding mercury contamination are that, "…strategies and financial incentives will have been developed and implemented that reduce the risk of contamination of toxic materials…The monitoring of contaminants should be substantially increased, both as applied and in the environment to get a better handle

on what is going where and on the association of contaminants with declines of aquatic species…Major sources of contaminants in fish will have been identified and drainage-specific plans developed to reduce their entry into the ecosystems" (CALFED 2000a).

In Volume 2 of the ERPP (CALFED 2000b), Visions, Targets, and Programmatic Actions are specified for each of the 14 Ecological Management Zones (EMZs) in the ERP project area in the following categories: Ecological Processes, Habitats, Reducing or Eliminating Stressors, and Species. Mercury is mentioned as a Contaminant in the Stressor category in association with specific Targets in four of the 14 EMZs: 1) the Sacramento-San Joaquin Delta, 2) Suisun Marsh and North San Francisco Bay, 10) the Yolo Basin, and 12) the San Joaquin River.

Most of the Ecosystem Restoration Program (ERP) goals and objectives, as articulated in the ERP Draft Stage I Implementation Plan (CALFED 2001), have some relevance to mercury issues. With regard to Endangered and Other At-Risk Species and Native Biotic Communities (Goal 1), the main issue is that methylmercury acts as an endocrine disruptor and a neurotoxin, and therefore it may affect the reproduction of certain fish and bird species. In the context of Ecological Processes (Goal 2), an important mercury issue relates to coarse sediment that is needed to restore aquatic habitat downstream of reservoirs — most sources of coarse sediment in these watersheds are contaminated with mercury from historical gold mining. Bringing uncontaminated coarse sediment to theses areas or washing the sediment to remove mercury in fine grained particles may add significant costs to stream restoration efforts. With regard to Harvested Species (Goal 3), spawning areas for salmonids in the Central Valley are contaminated with mercury from historical mining, and the modification and/or removal of dams to enhance habitat of anadromous fish is complicated by the presence of trapped mercury-contaminated sediments. Habitat Restoration in the Delta, Suisun Bay, Suisun Marsh, and San Francisco Bay (Goal 4) may lead to an increase in formation and bioaccumulation of methylmercury; specific habitats identified as being relatively high in methylmercury exposure to wildlife include high tidal marsh, and seasonal wetlands (flood plains). With regard to Water and Sediment Quality (Goal 6), mercury and methylmercury are toxic contaminants of concern in the San Francisco Bay–Delta and many of its tributaries, as evidenced by numerous fish-consumption advisories (California Office of Environmental Health Hazard Assessment 2007) and pending regulatory actions (including TMDLs). Successful efforts to achieve other water-quality objectives such as reducing loadings of oxygen-depleting substances and of fine-grained sediment should result in lower concentrations of mercury and methylmercury in water, sediment, and biota.

In the ERP's Draft Stage I Implementation Plan (CALFED 2001) a Strategic Objective regarding contaminants including mercury is "to reduce the loadings and concentrations of toxic contaminants in all aquatic environments in the Bay-Delta estuary and watershed to levels that do not adversely affect aquatic organisms, wildlife, and human health." Each of the 19 mercury projects funded by the ERP has contributed to this

objective in one or more EMZs or throughout the entire CALFED region, as described below.

Changes Attributable to ERP

A total of 19 ERP-funded mercury projects emphasized research and monitoring, planning, and public education rather than implementation. Therefore, there are no immediately measurable benefits to water quality, such as reductions in mercury (Hg) or monomethylmercury (MMHg) concentrations or loads, or reduced concentrations of methylmercury in biota that can be attributed to these efforts.

Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (**ERP-99-B06**) and *Mercury in San Francisco Bay-Delta Birds: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction* (**ERP-02D-C12**) have addressed the issue of reproductive effects of methylmercury exposure on several bird species using a combination of field and laboratory techniques. Innovative laboratory experiments in these projects have involved injecting eggs of various bird species with known quantities of methylmercury and evaluating toxicity to embryos, a technique first perfected using mallards (Heinz 1979). An important finding from *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) is that embryos of the California clapper rail (*Rallus longirostris obsoletus*, a Federal and State endangered species) are more sensitive to mercury than those of mallards, and that the high concentrations found in fail-to-hatch rail eggs collected in the field were likely embryotoxic (Heinz 2003). Although none of the ERP-funded projects were designed to address reproductive problems or other toxic effects in fishes related to methylmercury exposure, several of the projects (most notably *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**), *Mercury in San Francisco Bay-Delta Birds: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction* (**ERP-02-C01-D**), *Evaluation of Mercury Transformations and Trophic transfer to the San Francisco Bay-Delta: Identifying Critical Processes for ERP* (**ERP-02-P40**), and *A Pilot Program for Monitoring, Stakeholder Involvement, and Risk Communication Relating to Mercury in Fish in the Bay-Delta Watershed* **(ERP-02D-P67**) have generated extensive data sets on mercury concentrations in fishes of various trophic levels (ranging from silversides to largemouth bass) from various geographic areas. These data provide a major advance in understanding regional patterns of methylmercury exposure. Once additional research is completed to determine toxic thresholds in key species of concern as well as other possible unknown effects of methylmercury exposure, the fish data can be used to estimate possible ecological effects.

The issue of mercury contamination in tailings from historical gold mining is important because of the need for coarse sediment to restore aquatic habitat downstream of reservoirs in watersheds that were extensively mined by hydraulic and/or dredging

methods. *Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach (Task 5)* (**ERP-02-P12D**), a stream restoration effort on the Merced River, addressed these concerns by determining mercury and methylmercury concentrations in biota and sediment of various grain sizes. Although mercury tends to be more concentrated in finer grained materials, the dredge tailings on the Merced River were determined to be suitable for stream restoration purposes (Stillwater Sciences 2004). A key understanding gap here is the lack of any research to determine the degree to which mercury associated with waste materials from historical gold mining wastes is available for methylation.

In the upper Yuba River watershed, *Implement Upper Yuba Studies Program Water Quality and Sediment Studies – USGS* (**ERP-02-C01-D**) characterized mercury-contaminated sediments trapped behind Englebright Dam (Alpers et al. 2006), so that planning could be done for various dam-management scenarios, including possible modification and/or removal to enable passage of anadromous fish including Central Valley Spring-run Chinook salmon ESU (*Oncorhynchus tshawytscha*, a Federal and State threatened species) and Central Valley steelhead ESU (*Oncorhynchus mykiss,* a Federal threatened species). Another important finding from *this project* was that methylmercury concentrations in invertebrates and rainbow trout (also *Oncorhynchus mykiss)* of various sizes were consistently higher by a factor of three to six in reaches of the South and Middle Yuba Rivers affected by historical gold mining compared with reaches upstream of the mining, indicating potentially significant methylmercury exposure at a sensitive life stage if these reaches were to become accessible to anadromous fish for spawning (Slotton et al. 2004a).

Several ERP-funded mercury projects (particularly *Effects of Wetland Restoration on Methyl Mercury Levels* (**ERP-97-C05**), *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**), *Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries, An Integrated Mass Balance Assessment Approach* (**ERP-02-C06-a**), *Evaluation of Mercury Transformations and Trophic transfer to the San Francisco Bay-Delta: Identifying Critical Processes for ERP* (**ERP-02-P40**), and *Mercury and Methylmercury Processes in North San Francisco Bay Tidal Wetland Ecosystems* (**ERP-02D-P62**) have addressed the issue of methylmercury production and bioaccumulation in various habitats in these areas, including Seasonal Wetland Habitat, Non-tidal and Perennial Aquatic Habitat (both shallow and deep open water), Tidal Perennial Aquatic Habitat, Saline Emergent Wetland, Fresh Emergent Wetland (non-tidal), and Tidal Sloughs.

Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (**ERP-99-B06**), completed during 1999–2003, was the first large-scale, multi-disciplinary research effort designed to improve understanding of mercury and methylmercury transport and bioaccumulation in the CALFED region. Several important

results emerged from this project. Within the Cache Creek/Clear Lake watershed, the following working hypotheses were developed (Domagalski et al. 2004):

- Mine sites and geothermal sources within the Cache Creek watershed are major sources of mercury, and potentially of methylmercury, to creeks and streams. *Supported*.
- Geothermal discharge is important in the subsequent production and accumulation of methylmercury within the Cache Creek watershed. *Supported* based on data from the Sulphur Creek subwatershed.
- Effective mine-site remediation should be based on general-site erosion-control measures. *Supported*. Measures to reduce the amount of sulfate entering waterways from thermal springs and to reduce interaction between sulfate-rich thermal-spring water and mine materials should also be considered. *Speculative*.
- Sediments of Cache Creek below the mine sites and geothermal sources are also a source of mercury and methylmercury to the aquatic ecosystem because of a greater than 100-year history of erosion from mine sites and because of continuous discharge from geothermal springs. *Supported*.
- Although much of the cinnabar-based mine site materials appears to be relatively unavailable for conversion to toxic methylmercury, these sites and the geothermal sites also discharge more labile forms of mercury. *Supported*.
- Some portion of the mercury derived from the identified point sources can be methylated within the watershed, particularly in the upper tributary environments. *Supported*.
- Clear Lake and Indian Valley Reservoir do not contribute high concentrations of bioavailable mercury to the aquatic environment. *Supported*.
- The aquatic food chain below mine sites and geothermal sources is greatly affected by accumulation of methylmercury. *Supported*.
- A predictive relation exists between unfiltered methylmercury in the water and methylmercury bioaccumulation in invertebrates and small fish. *Supported*.
- Mercury in lower-trophic-level bioindicator organisms is predictive of mercury bioaccumulation in large fish. *Supported*.

Within the Delta, the following working hypotheses were developed as part of *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) (Foe et al. 2003):

- Concentrations of mercury in sport fish from the Delta region represent a potential human health concern. *Supported*.
- Consistent multi-species methyl mercury tissue concentration patterns exist in the Bay-Delta Estuary. *Supported*.
- Mercury tissue concentrations have not changed in the last 30 years. *Supported* by data for largemouth bass.
- Methyl mercury primarily accumulates in the base of the food web in the spring and early summer. *Supported* by data on clams.

- Methylmercury tissue concentrations in biota track aqueous methyl mercury and phytoplankton concentrations in the spring and early summer. *Supported*.
- Mercury concentrations in avian eggs vary greatly within the Bay-Delta system, were highest in fish eating birds, and varied spatially with concentrations in other media. *Supported*.
- Mercury concentrations in eggs of some bird species in the Bay-Delta were above embryotoxic thresholds. *Supported*.

Several additional mercury research projects were funded by ERP during 2003–2007 to follow up on this initial work. Several of the larger, ERP-funded mercury research projects were reviewed at two workshops (held November 29 – December 1, 2005 and April 23–25, 2007) by an external panel of mercury experts, who commended the principal investigators for their excellent work. According to the review panel, 'Understanding of mercury transport, methylation, bioaccumulation, and ecotoxicology have all been greatly advanced since the beginning of mercury studies in 1999" (California Bay-Delta Authority Mercury Project Review Panel 2007).

With regard to avian exposure to methylmercury and related health effects, *Mercury in San Francisco Bay-Delta Birds: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction* (**ERP-02D-C12**) reached several important findings (Ackerman et al. 2007):

- *Definite evidence of a mercury pollution problem*. This study showed that exposure to methylmercury (via dietary uptake) could adversely affect certain aquatic birds that forage and nest in the Bay-Delta system.
- *Assessment of risk*. The species studied were at risk for MMHg toxicity, particularly for individuals foraging in North and South San Francisco Bay. In Forster's tern, 58% of the adult birds breeding in San Francisco Bay and 46% of eggs were at high risk for MMHg toxicity.
- *Mercury-selenium interactions.* In developing bird embryos, exposure to both methylmercury and selenium at certain concentrations resulted in greater effects than were seen than from exposure to either one of these alone.
- *Rapid uptake and off-site exposure.* MMHg is rapidly (few weeks) accumulated by surf scoters while over-wintering in the SF Bay area. In reproducing hens, this MMHg is transferred to eggs, increasing in ovo exposure in embryos at the breeding grounds in northern Canada.
- *Substantial variation in sensitivity to methylmercury among species.*
- *Sensitive life stages.* Avian embryos and young hatchlings were the life stages most sensitive to MMHg exposure. This demonstrates the critical importance of in ovo exposure in the life cycle of birds.
- *Hotspots.* Identification of hotspots (foraging sites) and associated trophic pathways that cause bioaccumulation of MMHg in birds to toxicologically significant concentrations. MMHg exposures for some bird species at some sites

- *Demonstrated complexity and interactions of multiple factors.* These include foraging habitat, diet and trophic ecology, species and reproductive biology, factors that strongly influence methylmercury bioaccumulation and exposure for a given species.
- *Inter-species variation in sensitivity to methylmercury.* Toxicological test results are not readily transferable among bird species.
- *Species-specific data for mercury toxicology is transferable to other ecosystems but could be confounded by other contaminants.*

The project *Evaluation of Mercury Transformations and Trophic Transfer in the San Francisco Bay/Delta: Identifying Critical Processes for the Ecosystem Restoration Program* (**ERP-02-P40**) evaluated six hypotheses with regard to mercury methylation and demethylation processes at two primary field sites: 1) the Cosumnes River and its floodplain and 2) Franks Tract, a flooded island in the Central Delta. Overall, the Cosumnes River site had much higher methylmercury in water, sediment, and biota than the Central Delta site. A working hypothesis that is consistent with the observed differences in water and sediment methylmercury concentrations and methylation potential in sediment in the two areas is that higher rates of microbial sulfate reduction in the Central Delta produced abundant hydrogen sulfide, which combined with inorganic mercury to make it less reactive, and less susceptible to re-oxidation and methylation (Marvin-DiPasquale et al. 2007). This hypothesis needs to be tested by additional research. Hypotheses analyzed were:

- Benthic conditions are more conducive for net MMHg production in Cosumnes River than in the Central Delta. *Supported* by field data.
- Physical and/or geochemical conditions mediating MMHg benthic flux to the overlying water column are more favorable in the Cosumnes River than in the Central Delta. HYP-2 is supported by calculated estimates of MMHg diffusive flux from the sediment to the overlying water. Direct measurements of benthic flux were equivocal (*neither supported or refuted*).
- The Central Delta has a higher net loss of MMHg from the water column, due to either microbial and/or photo-degradation, resulting in a lower net transfer of MMHg into the base of the food web in this region, compared to the Cosumnes River. Equivocal. The data collected are *not sufficient to either support or refute* this hypothesis, although measured MMHg degradation rates in the water column appear low.
- Regional and/or sub-habitat differences in food web dynamics, such as habitat utilization, feeding behavior, food chain length and composition, and/or species-specific Hg bioaccumulation rates at the food web base, account for the higher MMHg concentrations in Cosumnes River biota compared to the Central Delta. The data collected are sufficient to *reject this hypothesis* under current operating conditions in the Delta.

- Larval fish reared on the Cosumnes River Floodplain have higher Hg levels than those reared in the Cosumnes River proper, due to increased MMHg production and Hg exposure during seasonal inundation of the floodplain (i.e. the reservoir effect). *Sediment data support this hypothesis, but water column MMHg concentration data do not support this hypothesis*.
- Regional differences in plant-Hg interactions, such as Hg uptake and leaching rates by various plant species, gaseous elemental Hg efflux by plants, and/or plant community composition and density, lead to regional differences in Hg cycling pathways, MMHg production, and ultimately to differences in Hg levels in biota. Equivocal. The data collected to date can *neither fully support nor refute this hypothesis*, although significant regional differences in plant community characteristics and plant-Hg interactions have been identified

The project *Mercury and Methylmercury Processes in North San Francisco Bay Tidal Wetland Ecosystems* (**ERP-02-P62**) compared methylmercury production rates and concentration in a variety of tidal marsh environments including sloughs, low tidal marsh, and high tidal marsh (which is only wetted at extreme high tides, approximately 2–6 days per month). The highest concentrations of methylmercury and highest production rates in sediments occurred in the high marsh interiors (Yee et al. 2007). Significant conclusions from this project are as follows:

- High marsh interiors have higher concentrations of methylmercury and reactive divalent mercury [Hg(II)], and a higher activity of Hg(II)-methylating bacteria than slough channels and channel edges.
- Bioaccumulation in resident bird populations is correlated with sediment MMHg concentrations in their home ranges.
- Methylmercury production in sediment correlated with live root density.
- Experimental devegetation reduced rates of MMHg production.
- Hg fluxes through plant uptake and decomposition were not significantly different among habitats and were not significant pools and fluxes of Hg and MMHg relative to other more active processes.
- MMHg demethylation and Hg(II) reduction decrease ambient concentrations, but are slower in turbid slough waters.

The project *Dissolved Organic Carbon Release from Delta Wetlands: Amounts, Alterations, and Implications for Drinking Water Quality and the Delta Foodweb* (**ERP-00-G01**) was originally designed to investigate organic carbon in the Delta. An amendment in 2004, titled *Mercury Release from Delta Wetlands: Facilitation and Fluxes*, expanded the scope of the project to include investigations of the interactions between mercury and organic carbon and measurements of mercury and methylmercury fluxes from Browns Island adjacent to Suisun Bay. Many findings were contrary to expectations:

- Tidal advective and dispersive fluxes from wetlands within the Delta export significant quantities of mercury and methylmercury to Delta channels. *Hypothesis rejected*.
- Dissolved organic matter (DOM) from different environments will have significantly different rates and extents of mercury binding. *Supported*.
- DOM from different Delta environments will have significantly different capacities to solubilize mineral forms of mercury. *Supported*, but other water chemistry characteristics may be important.
- Wetlands in the Sacramento River Delta, which are known to have high concentrations of DOM, with a large proportion of highly aromatic DOM, provide highly favorable conditions for the release of Hg from sediments.
- Mercury release increased with decreasing ionic strength because of the mobilization of colloidal mercury, a very mobile mercury fraction. Preliminary results indicate that a significant fraction of the mobilized Hg is in the form of colloidal particles; however, significant work remains to complete this portion of the investigation.
- Hg-DOM stability constants were found to be consistent with measured stability constants in other regions.
- When photolyzed with simulated solar irradiation of an intensity approaching that of summer sunlight in northern California, Hg(II) reduction half-lives ranged from one and a half to five hours for the DOM isolates, depending on the nature of the added organic matter; most fell into the range of two to three hours.
- An in situ instrumentation package provided a high-frequency time series of total mercury (using turbidity) and methylmercury (using chromophoric DOM) together with a multivariate statistical model.
- The flux of the dissolved fraction of MMHg is largely driven by pressure events such as barometric and hydraulic conditions. In the spring, the fluxes of dissolved MMHg were greatest during the neap and the period of relatively high barometric pressure; in the autumn, the quiescent flow and weather conditions led to a slow and steady off-island flux of dissolved MMHg.

Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries, An Integrated Mass Balance Assessment Approach (**ERP-02-C06-a**, **ERP-02-C06b**) was focused on developing an understanding of the transport, cycling, and fate of mercury and methylmercury in the San Francisco Delta and tributary watersheds on both a temporal and spatial basis using a biogeochemical mass-balance framework as an integrating tool to assess sources, sinks and biogeochemical processes. The status of hypotheses addressed by this project are as follows:

- River-borne MMHg is a major source of MMHg introduced to the Delta, especially under high river flow conditions. *Supported*.
- Atmospheric Hg deposition is a minor source of total Hg loading to the Delta, but bioavailability may be significant. *Supported*, with uncertainty about bioavailability.

- Methylmercury concentrations in Delta sediments increase during late spring through early summer as a result of increased Hg methylation in the sediment. *Supported*.
- Mercury and methylmercury concentrations in Delta sediments are spatially variable relative to habitat type and the distribution remains relatively constant year to year. *Supported*.
- Within the Delta, wetland and marsh regions are major sites of methylmercury production and enhanced sediment-water exchange flux. *Supported*.
- Methylmercury is lost from the water column within the Delta ecosystem by an unknown removal mechanism. *Supported*: photodegradation is potentially very important, however mass balances remain highly uncertain.
- Methylmercury concentrations increase in the Sacramento and San Joaquin Rivers as they flow downstream to the Delta. *Equivocal*. Increase downstream observed in Sacramento River. Decrease downstream observed in San Joaquin River. Important role of tributaries.
- Wetlands are important sites for methylmercury production in the Central Valley. *Supported by preliminary data*.
- Upstream remediation to reduce methylmercury discharges result in downstream reductions in concentrations and loads. *Unknown*. Work in progress to test "conservative transport hypothesis" for methylmercury.

A Pilot Program for Monitoring, Stakeholder Involvement, and Risk Communication Relating to Mercury in Fish in the Bay-Delta Watershed (**ERP-02D-P67**) is a multifaceted three-year project with the goals of examining mercury in fish in the Bay-Delta watershed and increasing public awareness of fish contamination issues. The Project is closely following the recommendations of the CALFED Mercury Strategy (Wiener et al. 2003b) relating to monitoring mercury in the watershed in support of adaptive management. The overall goals of the project are to reduce mercury exposure of humans and wildlife. Major accomplishments of the project are as follows:

- Quantifies seasonal, inter-annual, and spatial differences in MMHg in fish tissue in Bay Delta system and tributaries.
- Species of high and low MMHg have been identified. Target species highest in mercury are largemouth bass and pikeminnow, followed in decreasing order by carp, sucker, channel catfish, black crappie, white catfish, bluegill, and redear sunfish.
- Some fishing locations are high in mercury, while others are low in mercury. Sacramento, San Joaquin, and Cosumnes Rivers are higher than Central Delta.
- Using biosentinels (silversides), some wetlands were found to have lower methylmercury exposure than adjacent non-vegetated habitats.
- Biosentinels showed significant seasonal trends in some areas, with dramatic spikes in small fish mercury linked primarily to episodic flooding of normally dry soils.

- Biosentinels also showed a significant inter-annual trend in the Suisun Marsh region (2006 was higher than 2005) and the reason is unexplained.

Two ERP-sponsored projects, *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) and *Mercury in San Francisco Bay-Delta Birds: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction* (**ERP-02D-C12**), addressed adverse effects threshold concentrations in key organisms, with respect to ecotoxicological risk to avian reproduction.

Several of the tasks in *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) addressed mercury issues in the Cache Creek watershed, as specified in the ERP MSCS Milestones. The following project reports from the *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) addressed the *"source*, transport, inventory, mapping and speciation of mercury":

- Mercury and methylmercury loads were determined at several locations in the Cache Creek watershed by Domagalski et al. (2004) and the loads from specific abandoned mine sites were determined by Suchanek et al. (2002).
- An inventory and evaluation of mine wastes as potential remediation targets was prepared by Churchill and Clinkenbeard (2003).
- An analysis of solid-phase mercury speciation and bioavailability was done by Bloom (2003).
- The work by Slotton et al. (2004b) determined bioaccumulation effects in Cache Creek and several of its tributaries.

All of the studies cited above addressed the milestone to "support development and implementation of TMDL for mercury." TMDL staff reports prepared by the RWQCB for Cache Creek, Bear Creek, and Harley Gulch in 2004 (Cooke et al. 2004) and for Sulphur Creek in 2007 (Cooke and Stanish 2007) cited results from several components of *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**).

Two projects in the Cache Creek watershed addressed mine site inventory and mine-related regulatory activities: *Abandoned Mine Lands Inventory & Assessment* (**ERP-02-C03-D**) and *Regulatory Activities of Inactive Mercury Mine Sites Affecting Delta Water Quality* (**ERP-03-C03**). The *Cache Creek Settling Basin Feasibility Study (Phase 3)* (**ERP-01-C07-D**) was intended to address the milestone of "remediation (drainage control) of mercury mines," however no actual remediation in this area has yet taken place. The final report for Task 5C2 of the *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) (Tetra Tech EM, Inc. 2003) consists of an engineering evaluation and cost analysis of possible remediation approaches for abandoned mines in the Sulphur Creek drainage.

Preliminary results from sampling of two species of crayfish from wetlands throughout the Bay-Delta for *Effects of Wetland Restoration on Methyl Mercury Levels* (**ERP-97-C05**) were reported by Suchanek et al. (1999). The *Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed* (**ERP-99-B06**) analyzed mercury in invertebrate and fish species at different trophic levels, and reported concentration data for the Suisun Bay, the Delta, and several Delta tributaries (Davis et al. 2003, Foe et al. 2003). Primary target species, including largemouth bass, white catfish, striped bass, and Sacramento pikeminnow, were analyzed as individuals. Secondary target species, including channel catfish, black crappie, Sacramento sucker, common carp, bluegill, and redear sunfish, were sampled as multi-individual composites. Significant spatial variation in mercury content of sport fish was found in the watershed. Significantly elevated mercury concentrations (in the range of 1 mg/kg wet weight) were found in fish from the Feather River, northern Delta, lower Cosumnes River, and San Joaquin River regions. Concentrations in the central Delta region were significantly lower than other locations, usually below the screening value of 0.3 mg/kg.

Prior to 2000, a favored working hypothesis among mercury scientists was that the Delta would be a zone of net methylation of mercury. Monitoring data for water and fish (Foe et al. 2003) indicated that the Central Delta is actually lower in methylmercury concentration than the tributary areas such as the Yolo Bypass, Cosumnes River, and San Joaquin River. Preliminary mass balance calculations indicated a net loss of methylmercury in water as it flows through the Delta (Foe et al. 2003). These results constituted a paradigm shift for the local mercury science community because it was anticipated that wetlands in the Central Delta might make it a mercury methylation "hot spot". The main causes of the methylmercury loss are currently thought to be photodemethylation and sedimentation (Stephenson et al. 2007), although these conclusions are based on relatively few data given the extreme complexity of the Bay-Delta ecosystem. Another possible contributing factor to the lower levels of methylmercury in the Central Delta is that high concentrations of reduced sulfur may serve to make reactive forms of mercury less available to the methylation process (Marvin-DiPasquale et al. 2007).

An issue that was not anticipated by ERP at the beginning of Stage I was the use of gold dredge tailings, potentially contaminated with mercury, for restoration projects in rivers and streams of the Central Valley. Several ERP projects have been involved with stream restoration for anadromous salmonids in the Clear Creek watershed (Shasta County). An ERP project was proposed but never funded to remove Saeltzer Dam. Townsend Flat Water Ditch Company ultimately contracted with the Bureau of Reclamation to completely remove but not replace Saeltzer Dam. After the dam removal, several ERP projects dealt with restoration and monitoring in the lower part of the creek: *Lower Clear Creek Floodway Restoration Project* (**ERP-98-F15**), *Genetic Comparison of Stocks Considered for Re-establishing Steelhead in Clear Creek* (**ERP-98-C12**), *Clear Creek Prescription* (**ERP-99-N16**), *Clear Creek Juvenile Salmonid Monitoring Project* (**ERP-01-N47**). Restoration plans were altered when it was

discovered that sediments intended for stream restoration were contaminated with mercury from historical placer gold mining operations (Ashley et al. 2002, Ashley and Rytuba 2004). Restoration plans have been altered to avoid wetland construction in mercury-contaminated areas. More recent projects in the lower Clear Creek watershed have monitored avian populations, geomorphic changes at the project and watershed scale, and riparian habitat. These projects include *Lower Clear Creek Monitoring Program* (**ERP-04-S05**) and *Clear Creek Anadromous Salmonid Monitoring Program* (**ERP-04-S16**).

An unexpected preliminary result of recent ERP-funded research is the finding that not all wetlands in the Bay-Delta are elevated in biotically derived methylmercury (Davis et al. 2007). A preliminary geospatial analysis of available data has indicated that there may not be an overall correlation between wetlands and elevated methylmercury in biota (Melwani et al. 2007).

The ERP-funded mercury projects have resulted in several important advances in the understanding of the behavior of mercury in the Bay-Delta system and its tributaries.

With regard to Endangered and Other At-Risk Species and Native Biotic Communities (Goal 1), concerns for methylmercury exposure primarily center on its potential endocrine disruption capacity and its neurotoxicity; therefore, methylmercury may affect the reproduction and survival of certain fish and bird species. Significant advances in understanding of the possible toxic effects of methylmercury have been achieved, however leading researchers concur that this understanding is far from complete (Mergler et al. 2007, Scheuhammer et al. 2007).

Habitat Restoration in the Delta, Suisun Bay, Suisun Marsh, and San Francisco Bay (Goal 4) may lead to an increase in formation and bioaccumulation of methylmercury. Although ERP Goal 4 is not specifically concerned with contamination issues, research and monitoring associated with several of the ERP-funded mercury studies have provided fundamental information about habitat function (e.g. plant type, density, carbon and nitrogen cycling, redox chemistry of water and sediment) that should be of use to resource managers.

Specific habitats identified as being relatively high in methylmercury exposure to wildlife include high tidal marsh and seasonal wetlands (floodplains), compared with relatively low methylmercury exposure in perennial aquatic habitats and low-tidal areas (Davis et al. 2007, Marvin-DiPasquale et al. 2007, Yee et al. 2007). A working hypothesis that explains these variations recognizes that the higher methylmercury habitats have extended dry periods in which soil and sediment completely dry out. This raises the possibility that oxidation of mercury species during the dry periods leads to higher concentrations of reactive mercury [Hg(II)], which is then more reactive and prone to methylation during subsequent flooding, when sulfate- and/or iron-reducing bacteria facilitate methylation. The oxidation of carbon and sulfur species during dry periods

may also play an important role in increasing mercury methylation rates during subsequent flooding.

Project Summary Table

Table 1. Mercury Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-97-C05	**Effects of Wetland Restoration on Methyl Mercury Levels** Evaluate relationship of physical, chemical, and biological gradients on methyl mercury production and bioaccumulation.	3/3/2003	$546,171	Final report submitted. Titled, "Effects of wetlands restoration on the production of methyl mercury in the San Francisco Bay-Delta System: Preliminary Results".
ERP-98-C12	**Genetic Comparison of Stocks Considered for Re-establishing Steelhead in Clear Creek** This project obtained fine-scale information on the genetic diversity of steelhead/rainbow trout from several locations to determine the preferred sources of a founding stock for re-establishing a self-sustaining steelhead population in Clear Creek following the removal of the McCormick-Saeltzer Dam.	9/30/2004	$45,492	Implemented successfully.
ERP-98-F15	**Lower Clear Creek Floodway Restoration Project (Phase II)** Improved salmon spawning and rearing habitat by implementing the Lower Clear Creek Watershed Management Plan and restoring 2.9 miles of floodplain and riverine aquatic habitat.	6/30/2006	$4,561,939	Implemented successfully.
ERP-99-B06	**Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed** This project will determine the major sources of mercury in the watershed, which forms are most bioavailable, where methylation is most active, fish tissue concentration and mercury effects on avian populations. Two major study areas are Cache Creek and the Delta.	6/30/2003	$4,164,000	Final reports available at http://loer.tamug.tamu.edu/calfed/FinalReports.htm
ERP-99-N16	**Clear Creek Prescription** Created an ecosystem-based watershed management prescription for the Clear Creek watershed to 1) help achieve CBDA's vision of restoring important fishery, wildlife, and plant communities to a healthy condition, and 2) serve as a model for other watersheds in the state.	3/31/2003	$256,260	Implemented successfully.
ERP-00-C01	**Investigation of Abandoned Mine Sites - Yuba River Watershed** Preliminary site assessments of 100 abandoned mine sites in the Yuba River Watershed and development of abandoned mine database.	9/30/2001	$100,000	For final report, see ERP-02-C03-D.

Table 1. Mercury Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-G01	**Measurement of Mercury Release for Delta Wetlands: Amounts, Alterations, and Implications** This amendment of a project on organic carbon loads from wetlands will add mercury measurements. This project will evaluate mercury fluxes from tidal wetlands on Browns Island and interactions between mercury and organic carbon.	12/31/2006	$3,571,121	This project has expired and has not yet submitted the final report.
ERP-01-C07-D	**Cache Creek Settling Basin Feasibility Study (Phase 3)** Feasibility study to evaluate if the Cache Creek Settling Basin flood control project could be modified to trap additional mercury-laden sediment from Cache Creek watershed before it enters the Delta.	12/31/2006	$97,620	This project has expired and has not yet submitted the final report.
ERP-01D-C19	**Phase 2: Research, Outreach and Education on Fish Contamination in the Sacramento-San Joaquin Delta Watershed** Funding for Phase 2 covers pilot fish consumption studies for certain populations, formation of stakeholder and technical advisory groups, and outreach and education activities.	6/30/2006	$421,791	Final report includes list "Groups Receiving Educational Materials" and "Napa County Needs Assessment 2005".
ERP-01-N47	**Clear Creek Juvenile Salmonid Monitoring Project** This project will provide funds for continued monitoring of juvenile salmonid conditions and outmigration in Clear Creek in order to provide information to managers in assessing the effectiveness of restoration activities funded through the CVPIA.	6/30/2007	$1,405,142	To date ERP has not received final report summary. As of December 31, 2006, all projects tasks were complete except final report.
ERP-02-C01-D	**Implement Upper Yuba Studies Program Water Quality and Sediment Studies – USGS** The overall objective is to improve understanding of sediment supply, transport, and storage of sediment in the Yuba River watershed, and to improve understanding of the current level of mercury contamination of Englebright Lake sediments and biota.	6/30/2006	$4,794,966	Final reports available at: http://www2.bc.edu/~snyderno/
ERP-02-C03-D	**Abandoned Mine Lands Inventory & Assessment** Field evaluations of mine sites in several watersheds, including report development. Facilitate several groups related to abandoned mine land issues, including statewide forum and legal workgroup.	9/30/2005	$400,000	Final report submitted. Titled, "Abandoned Mine Lands Assessment of the North Yuba Watershed" and "Summary Report -- Containing Recommendations for CBDA consideration in Developing Future Project Solicitations for Proposition 13 Abandoned Mine Remediation Projects".

Table 1. Mercury Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-C06-a and ERP-02-C06-b	**Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries, An Integrated Mass Balance Assessment Approach** This project will evaluate the transport, cycling and fate of mercury and methylmercury on a temporal and spatial basis using a biogeochemical mass balance framework to assess sources, sinks, and biogeochemical processes.	6/30/2008	$4,181,125	To be completed in 2008.
ERP-02D-C12	**Mercury in San Francisco Bay-Delta Birds: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction** This project will evaluate the risks of mercury exposure to avian reproduction. This project will integrate a field assessment of exposure and effects with a laboratory assessment of the variation on sensitivity of avian embryos to methylmercury.	7/1/2008	$5,337,012	2006 Annual Report: "Mercury in birds of the San Francisco Bay-Delta: trophic pathways, bioaccumulation, and ecotoxicological risk to avian reproduction". Project to be completed June 2008.
ERP-02-P12-D	**Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach (Task 5)** Task 5 evaluates mercury concentrations in dredge tailings and biota in the Merced River.	3/21/2007	$2,497,877	Task 5 was to "Assess the volume and texture of dredger tailings, occurrence of mercury, and refine the restoration concepts for Merced River Ranch" and was awarded $339,914 of the total. Final report submitted. Titled, "Mercury Assessment of the Merced River Ranch".
ERP-02-P40	**Evaluation of Mercury Transformations and Trophic transfer to the San Francisco Bay-Delta: Identifying Critical Processes for ERP** This project will examine processes that affect the biogeochemical transformations and transfers of mercury among physical (sediment and water) and biotic (food web) compartments at Franks Tract and the Cosumnes River.	6/30/2007	$2,684,824	Final report submitted. Titled, "Evaluation of Mercury Transformations and Trophic Transfer in the San Francisco Bay/Delta: Identifying Critical Processes for the Ecosystem Restoration Program".
ERP-02D-P52	**Big Break and Marsh Creek Water Quality and Habitat Restoration Program** This project will educate citizens about ecological processes and further develop a long-term and locally supported watershed stewardship plan. Plans will also be developed for floodplain and tidal marsh restoration along lower Marsh Creek, adjacent to the Dutch Slough restoration project.	10/15/2007	$402,600	Final design report has yet to be submitted.

Table 1. Mercury Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02D-P62	**Mercury and Methylmercury Processes in North San Francisco Bay Tidal Wetland Ecosystems** This study investigates mercury cycling in tidal wetlands of the Petaluma River, with emphasis on quantifying and understanding processes that influence the abundance of methylmercury.	5/14/2008	$1,941,293	To be completed in 2008.
ERP-02D-P67	**A Pilot Program for Monitoring, Stakeholder Involvement, and Risk Communication Relating to Mercury in Fish in the Bay-Delta Watershed** This project is a collaborative pilot project to address mercury contamination in fish in the watershed with a 3-pronged approach: monitoring of mercury in fish, stakeholder involvement, and risk communication.	12/14/2008	$4,323,004	To be completed in 2008.
ERP-03-C01	**Phase 1 - Fish Consumption Study, Outreach and Education for the Sacramento-San Joaquin Delta and its Tributaries** Scoping study to gather information, establish priorities, and design further phases of fish consumption studies, and outreach and education. Cost share with DTMC and CVRWQCB.	9/30/2004	$82,610	See reports for ERP-01D-C9 and ERP-02D-P67.
ERP-03-C02	**Programmatic Quality Assurance and Quality Control for CBDA Mercury Research and Monitoring Projects** Implement and oversee a mercury QA program to ensure comparability and reliability of mercury data from multiple projects. Includes methods evaluation and inter-lab comparison studies.	12/31/2007	$883,254	Contract expired. Current status is unknown.
ERP-03-C03	**Regulatory Activities of Inactive Mercury Mine Sites Affecting Delta Water Quality** The CVRWQCB staff will prepare regulatory permits and enforcement orders to control discharges from inactive mercury mines that are affecting Bay-Delta water quality.	12/31/2005	$100,000	Complete.
ERP-04-S05	**Lower Clear Creek Monitoring Program** This project will include: Avian Monitoring, Geomorphic Monitoring, and Riparian Habitat Monitoring.	1/31/2010	$1,308,449	Ongoing.
ERP-04-S16	**Clear Creek Anadromous Salmonid Monitoring Program** This project is a comprehensive salmonid monitoring program that will provide feedback for the adaptive management and evaluation of restoration actions of the Clear Creek Restoration Program and B2 Water Program.	12/31/2009	$1,974,068	Ongoing.

Other Programs Contributing to ERP Vision

The CALFED Science Program made a major contribution to ERP goals by cooperating with the ERP with regard to the development of the CALFED Mercury Strategy (Wiener et al. 2003b). The Science Program is also contributing to the development of conceptual models for the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) process, including a model for mercury (Alpers et al. in review). By convening a panel of mercury scientists familiar with the Delta, the DRERIP process has contributed to synthesis of available information on the behavior of mercury in the Delta, with important recognition of linkages of mercury to other conceptual models including processes, specific habitats and species.

Within the CALFED project area, mercury TMDL programs are in progress at the RWQCBs in San Francisco Bay (Region 2) and the Central Valley (Region 5, which includes the Delta). Within Region 2, mercury a TMDL for San Francisco Bay (California Regional Water Quality Control Board – San Francisco Bay Region 2006) was adopted by the SWRCB in July 2007 and submitted to the U.S. Environmental Protection Agency (USEPA) for approval. Another mercury TMDL is in progress for the Guadalupe River watershed (Tetra Tech 2005), which drains into south San Francisco Bay. The Guadalupe River watershed is highly contaminated with mining wastes from the New Almaden mining district, one of the two largest past producers of mercury in California (Churchill 2000). In addition, a mercury TMDL for the Walker Creek watershed (Marshall 2007), which contains the Gambonini mercury mine, was approved by Region 2 in January 2007 (Walker Creek is a tributary to Tomales Bay, which is not part of the CALFED study area). To support these TMDLs, Region 2 has funded activities including the monitoring or mercury and methylmercury concentrations in water, sediment, and biological tissues, including small fish (biosentinels) at numerous sites in San Francisco Bay and its tributaries. Since 2005, Region 2 has pursued information from petroleum refineries with regard to mercury mass balance and potential discharges to air and water. These activities have contributed to several of the ERP goals described in the previous section.

At the RWQCB in Region 5, mercury TMDLs have been completed for Clear Lake (Cooke et al. 2002) and for Cache Creek, Bear Creek and Harley Gulch (Cooke et al. 2004). Mercury TMDLs are pending for the Delta (Wood et al. 2006) and Sulphur Creek (Cooke et al. 2007). To support these TMDLs, Region 5 has done extensive sampling of water, sediment, and biota in the Delta and several of its tributaries. In addition, the SWRCB funded a process-oriented study of mercury transformation and bioaccumulation in the food web in the Bear River watershed, an area highly contaminated by historical gold mining that drains into the Feather River, within the Sacramento River watershed (Alpers et al. 2005). The TMDL-related data and the data analysis regarding potential harm to human health and wildlife health have contributed substantially to ERP goals 2 (Ecological Processes), 4 (Habitats), and 6 (Water and Sediment Quality) as described in Appendix A).

The Surface Water Ambient Monitoring Program (SWAMP, http://www.swrcb.ca.gov/swamp/) administered by the SWRCB, has gathered a large body of data on mercury concentrations in water, sediment, and biota in Regions 2 and 5 (including the CALFED study area) over the past several years. Prior to 2001, data for mercury in fish tissue were collected as part of the Toxic Substances Monitoring Program (TSMP). Since 2001 water and fish tissue data have been stored in the SWAMP database, which has detailed QA-QC information.

There are several regional monitoring programs for water quality in the CALFED project area. In the San Francisco Bay-Delta, the largest such program is the Interagency Ecological Program (IEP) Environmental Monitoring Program (EMP) (http://www.baydelta.water.ca.gov/emp/). Although the EMP does a comprehensive job on important environmental constituents, such as salinity, pH, and abundance of nutrients, phytoplankton, and zooplankton, it does not do any analyses of mercury in water, sediment, or biological tissues.

The Regional Monitoring Program (RMP) (http://www.sfei.org/rmp/), implemented by the San Francisco Estuary Institute (SFEI) has contributed important knowledge about mercury and methylmercury concentrations in water, sediment, and biota in the San Francisco Bay area since its inception in 1993. In cooperation with RWQCB Region 2, the RMP is funded by numerous stakeholders including municipal, industrial, and cooling-water dischargers, communities responsible for stormwater discharges, and dredgers. In addition to monitoring of the Status and Trends of contaminants including mercury, the RMP has carried out several Pilot and Special Studies that relate to mercury issues (Davis 2003).

In the San Francisco Bay Area, the Clean Estuary Partnership (CEP) (http://www.cleanestuary.org/) represents a collaborative effort between the RWQCB (Region 2), the Bay Area Stormwater Management Agencies Association (BASMAA), and the Bay Area Clean Water Agencies (BACWA). BACWA is a consortium of member agencies that own and operate publicly owned treatment works (POTWs) that discharge to the water of San Francisco Bay Estuary. The CEP funded the preparation of several reports related to mercury sources, fate, and transport in San Francisco Bay (http://www.cleanestuary.org/publications/index.cfm#Mercury).

In the Sacramento area, the Sacramento Coordinated Water Quality Monitoring Program (CMP) is a cooperative voluntary program initiated and implemented by the Sacramento Regional County Sanitation District (SRCSD), the City of Sacramento, and the County of Sacramento Water Resources Division that was established in July 1991. Within the CMP, the Ambient Monitoring Program is the primary water-quality monitoring element, for which monthly sampling began in December 1992.

The Sacramento River Watershed Program (SRWP) developed a water-quality monitoring program in close cooperation with the CMP, including mercury and methylmercury sampling at several river sites in the Sacramento and American Rivers. During the period 1999–2005, funding for the SRWP came from the USEPA in a series of grants administered by the SRCSD. During 2006–07, the SRWP monitoring program was continued with funding from a Prop. 50 grant from the SWRCB. The monitoring is scheduled to end in August 2007. Two special studies in the SRWP Proposition 50 grant that address mercury issues are 1) an assessment of mercury bioaccumulation factors in stream sites in the Bear River watershed and 2) determination of mercury methylation potential and methyl and total mercury concentrations in seasonal and permanent wetlands in the Yolo Bypass and the Cache Creek Settling Basin; these studies are being done by the USGS and will be completed in late 2007.

There has been considerable interest during the past several years in quantifying and possibly reducing the discharge of mercury and methylmercury from municipal wastewater treatment plants in the Bay-Delta and its tributaries. Several of the larger plants in the Bay-Delta region have performed studies to evaluate current removal efficiency and the feasibility of improving removal efficiency. A study of the Sacramento Regional Wastewater Treatment Plant (SRWTP) by the SRCSD (Parmer et al. 2005) indicated that approximately 75% of methylmercury and 98% of total mercury were removed by the treatment process (Parmer et al. 2005). A study of the San Jose/ Santa Clara Water Pollution Control Plant began in 2004. Preliminary results indicate that concentrations of total mercury, filtered mercury, total methylmercury, and filtered methylmercury declined by 98, 53, 97, and 73%, respectively during the treatment process (Downing 2007). A summary of methylmercury discharges from municipal waste-water treatment plants in the Central Valley was compiled on behalf of the Central Valley Clean Water Agencies (CVCWA) by Abu-Saba et al. (2005).

The SRCSD has also funded an effort to quantify localized bioaccumulation of mercury associated with its wastewater discharges into the lower Sacramento River. Field work conducted during July–November, 2006 focused on sampling resident and transplanted (suspended) clams, as well as water and sediment at stations both upstream and downstream of the wastewater discharge. Biosentinel fish will also be analyzed, and local anglers have been surveyed regarding fish consumption.

Abandoned mercury and gold mines are known sources of mercury contamination to the Bay-Delta and its tributaries. Several mine remediation projects resulted in reduction of loads of total mercury and methylmercury to tributaries including the Bear River and Cache Creek.

In the Bear River watershed, three sluice tunnels associated with abandoned hydraulic gold mines were remediated by federal agencies: 1) the Polar Star tunnel was remediated by the USEPA in 2000; 2) a tunnel at the Sailor Flat mining district was remediated by the U.S. Forest Service (USFS) in 2003; and 3) a tunnel the Boston Mine

was remediated by the Bureau of Land Management (BLM) in 2006. Other remediation efforts in the northwestern Sierra Nevada (Bear, Yuba, and American River watersheds) are pending with the USFS and BLM.

In the Cache Creek watershed, a remediation effort began in 2007 at the Abbott and Turkey Run mines in the Harley Gulch drainage under an order from the USEPA, with funding by the El Paso Merchant Energy-Petroleum Company (El Paso Natural Gas Corp.), a former owner/operator. Remediation steps completed during summer 2007 include stabilization of slopes to prevent erosion of mercury-contaminated soil, demolition of mercury-contaminated smelter structures, and clean up of mercury contamination in and around buildings. Hydroseeding of regraded slopes will occur during fall 2007 (Morris 2007).

Reconnaissance sampling of abandoned mercury mines has been done by the BLM and the USGS in other watersheds in the Coast Ranges, including upper Putah Creek (upstream of Lake Berryessa). Another mine remediation effort that is pending is the Mt. Diablo mercury mine, in the Marsh Creek watershed (Contra Costa County). Federal legislation that would partially fund this clean-up is pending.

The USGS conducted a project in the South Bay that focused on measurement of benthic fluxes of mercury and other water-quality constituents (Topping et al. 2004). The average flux rates for total mercury, when extrapolated over the greater South Bay, are similar in magnitude to estimates of major riverine sources, including the Guadalupe River, which drains the New Almaden mercury mining area. Therefore, transport of dissolved-mercury species between the estuary bed and the water column may be an important critical process affecting the fate of mercury species in this area.

Another ongoing mercury project in the South Bay is related to the South Bay Salt Pond Restoration Project (SBSPRP) (http://www.southbayrestoration.org/). This project is focused on the potential to inadvertently increase the risk of mercury bioaccumulation in South Bay fish and wildlife through hydrological modification of salt ponds in association with the restoration effort.

At the Hamilton Army Airfield Wetlands Restoration Site (North Bay, near Novato), research by the U.S. Army Corps of Engineers (USACE), with partners from the University of Notre Dame (South Bend, Indiana) has focused on determining the temporal and spatial variability in the concentrations of Hg species in bare and vegetated sediments. The fluxes of mercury species through live and standing dead mass, and litter of two predominant marsh plants were determined, and methylmercury biomagnification was quantified in two postulated food webs, one detritus-based semi-aquatic and near-shore aquatic and the other in the lower-high tidal marsh. In addition a new device (Diffusive Gradient Thinfilm, DGT) was developed to measure mercury species rapidly in water and sediment pore-water and to assist in calculation of net diffusive fluxes of mercury species from sediment to the water column.

Last, at Daguerre Point Dam, on the lower Yuba River, the USGS completed a study of mercury in fluvial sediments trapped behind the dam (Hunerlach et al. 2004), in cooperation with CDFG, DWR, and the BOR. It was found that the finer grained sediments had more elevated mercury concentrations.

Development of the Bay Delta and Tributaries (BDAT) (http://bdat.ca.gov/) database by DWR has been a useful contribution toward the goal of making data from all CALFED and other projects publicly available in a searchable database. However, the entry of data from ERP-funded mercury projects into BDAT has been only partially completed.

The Delta Tributaries Mercury Council (DTMC) (http://www.sacriver.org/issues/mercury/dtmc/) is a stakeholder group that has met regularly (four to six times per year) since 1999 to discuss mercury issues in the Delta and its watershed. For part of that time, the DTMC facilitator was funded through the Sacramento River Watershed Program (SRWP) (http://www.sacriver.org/)

Since 2003, SFEI has hosted an Annual SF Bay Mercury Coordination Meeting at which mercury researchers and stakeholder exchange information regarding ongoing projects and programs. The most recent meeting was in February 2008 (http://www.sfei.org/rmp/mercurymeeting/).

Status of Topic Today

Several of the ERP-funded mercury projects produced reports and presentations that discussed the application of their results with regard to management of ecosystem restoration. These applications are based in part on recommendations by the California Bay-Delta Authority Mercury Project Review Panel (2005, 2007).

From *Mercury in San Francisco Bay-Delta Birds: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction* (**ERP-02D-C12**), the following results are applicable to management concerns:

- Demonstrated complexity and interactions of multiple factors, including foraging habitat, diet and trophic ecology, species and reproductive biology, which strongly influence methylmercury bioaccumulation and exposure for a given species.
- Inter-species variation in sensitivity to methylmercury: toxicological test results are not readily transferable among bird species.
- Species-specific data for mercury toxicology is transferable to other ecosystems but could be confounded by other contaminants.

Two projects involving comparison of methylmercury production and bioaccumulation in different wetland habitats (*Evaluation of Mercury Transformations and Trophic transfer to the San Francisco Bay-Delta: Identifying Critical Processes for ERP* (**ERP-02-P40**) and *Mercury and Methylmercury Processes in North San Francisco Bay Tidal Wetland Ecosystems* (**ERP-02D-P62**) have the following applications:

- Results single out mercury methylation as likely the most important process to understand and to minimize, where possible, in order to reduce MMHg contamination of resident biota.
- Manage floodplain hydrology to minimize MMHg production.
- Monitoring should consider spatial variability of MMHg production, concentration and bioaccumulation within and among tidal marshes.
- Where conditions lead to high MMHg production in marshes, this will likely result in high MMHg in local upper trophic level biota.

The project *Measurement of Mercury Release for Delta Wetlands: Amounts, Alterations, and Implications* (**ERP-00-G01**), concerned with interactions of mercury with dissolved organic matter (DOM), had the following management applications (California Bay-Delta Authority Mercury Review Panel 2007):

- The finding that a tidal wetland might not necessarily be a net source of Hg to surrounding areas is especially encouraging for the future of wetland restoration projects.
- Assessment of tidal transport of DOM and Hg species has important implications for restoration site selection and management (it could be Hg neutral, sink, or source depending on hydrologic regime). Uncertainty in water and sediment mass balances reduces confidence in this conclusion, and additional sites should be monitored using the methodology developed in this study.
- DOM-Hg binding/solubilization studies are directly relevant where wetland creation is planned in areas containing Hg-contaminated sediments. Knowledge of the type of DOM in overlying waters could help in predicting Hg release from the sediments. However, lack of Hg-DOM bioavailability data precludes a direct coupling to the contribution of this release to the methylation process.

Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries, An Integrated Mass Balance Assessment Approach (**ERP-02-C06-a** and **ERP-02-C06-b**) provided the following insights:

- Mass balances for total mercury and methyl mercury are a critical piece of the overall understanding.
- Wetland fluxes are critical to the understanding of effects of ecosystem restoration.

From the Fish Mercury project, *A Pilot Program for Monitoring, Stakeholder Involvement, and Risk Communication Relating to Mercury in Fish in the Bay-Delta Watershed* (**ERP-02-P67**), the following results have applicability to ecosystem restoration management:

- Information from analyses of biosentinel organisms will be useful for assessing the effect of ecosystem restoration activities on methylmercury contamination of aquatic food webs.
- Methylmercury concentrations in aquatic biosentinel organisms can serve as a useful "performance measure" for management and restoration.

Planned Projects for Implementation

Improvement of the sediment trapping efficiency of the Cache Creek Settling Basin (*Cache Creek Settling Basin Feasibility Study (Phase 3)* (**ERP-01-C07-D**) has been identified as one of the most cost-effective ways to reduce loads of mercury and methylmercury in the Yolo Bypass, one of the largest contributors of these contaminants to the Delta (Wood et al. 2006, Stephenson et al. 2007).

Impediments to Implementation

A feasibility study for improvement of the sediment trapping efficiency of the Cache Creek Settling Basin needs to be completed. This project is important for local flood control, but mercury issues have not yet been adequately addressed. There is a need to determine environmentally safe uses for the trapped and subsequently excavated material. It is currently unknown whether the material would be suitable for application on agricultural fields, for use by Yolo County at their landfill for construction and waste disposal operations, or for levee construction. It needs to be determined whether the characteristics of this sediment, in terms of mercury concentration and speciation, organic carbon content and quality, and other properties, make it likely to contain mercury that would be available for methylation and possible release to the environment in these settings.

Planned mine site remediation efforts, which would result in reduced loads of mercury and lower levels of methylmercury exposure, have been delayed or cancelled because of concerns regarding liability under the Clean Water Act and other federal statutes. Although a Good Samaritan law was passed by the State of California, federal statutes have not yet been altered in a similar manner.

References

Abu-Saba, K. E., J. Leng, W. Tellefson, J. McCall, A. O'Brien, T. Pirondini, M. Paulucci, V. Fry, S. Gittings, C. Hartinger, T. Grovhoug, T. Dunham. 2005. A Regional Assessment of Methylmercury Discharges from Municipal Treatment Plants in California's Central Valley. Paper presented at WEFTEC 2005, Water Environment Federation's 78th annual technical exhibition and conference, Oct. 29 – Nov. 2, 2005. Washington, D.C. http://www.cvcwa.org/letters_actions.htm

Ackerman, J. T., C. A. Eagles-Smith, G. H. Heinz, S. E. Wainwright-De La Cruz, J. Y. Takekawa, T. L. Adelsbach, A. K. Miles, D. J. Hoffman, S. E. Schwarzbach, T. H. Suchanek, and T. C. Maurer. 2007. Mercury in Birds of the San Francisco Bay-Delta: Trophic Pathways, Bioaccumulation, and Ecotoxicological Risk to Avian Reproduction, 2006 Annual Administrative Report. U.S. Geological Survey, Western Ecological Research Center, Davis, CA, and U.S. Fish and Wildlife Service, Environmental Contaminants Division, Sacramento, CA. http://www.delta.dfg.ca.gov/erp/wq_mercury_2007workshop.asp

Alpers, C. N., M. P. Hunerlach, M. C. Marvin-DiPasquale, R. C. Antweiler, B. K. Lasorsa, J. F. De Wild, and N. P. Snyder. 2006. Geochemical Data for Mercury, Methylmercury, and Other Constituents in Sediments from Englebright Lake, California, 2002. U.S. Geological Survey Data Series 151. http://pubs.water.usgs.gov/ds151/

Alpers, C.N., M. P. Hunerlach, J. T. May, and R. L. Hothem. 2005. Mercury Contamination from Historical Gold Mining in California. U.S. Geological Survey Fact Sheet 2005-3014. http://water.usgs.gov/pubs/fs/2005/3014

Alpers, C.N., C. Eagles-Smith, C. Foe, S. Klasing, M. C. Marvin-DiPasquale, D. G. Slotton, and L. Windham-Myers. In review, Mercury Conceptual Model — Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). CALFED Ecosystem Restoration Program. California Department of Fish and Game. Sacramento, CA.

Ashley, R. P. and J. J. Rytuba. 2004. Mercury Associated with Gold Dredge Tailings in the Clear Creek and Trinity River Watersheds, CA. Getting Results: Integrating Science and Management to Achieve System-Level Responses. 3rd Biennial CALFED Bay Delta Program Science Conference Abstracts.*

Ashley, R. P., J. J. Rytuba, R. Rodgers, B. B. Kotlyar, and D. Lawler. 2002. Preliminary Report on Mercury Geochemistry of Placer Gold Dredge Tailings, Sediments, Bedrock, and Waters in the Clear Creek Restoration Area, Shasta County, California. U.S. Geological Survey Open-File Report 02-41.

Bloom, N. 2003. Solid Phase Hg Speciation and Incubation Studies in or Related to Mine-Site Runoff in the Cache Creek Watershed. Final report to CALFED Ecosystem Restoration Program. Task 7C. ERP-99-B06.* http://loer.tamug.tamu.edu/calfed/FinalReports.htm

California Bay-Delta Authority Mercury Project Review Panel. 2005. Summary Project Evaluations. CBDA Project Workshop, Nov. 29 – Dec. 1, 2005. Sacramento, CA.* http://www.delta.dfg.ca.gov/erp/wq_mercury_2005workshop.asp

California Bay-Delta Authority Mercury Project Review Panel. 2007. Summary Project Evaluations. CBDA Project Workshop April 23–25, 2007. Sacramento, CA. June 1, 2007.* http://www.delta.dfg.ca.gov/erp/wq_mercury_2007workshop.asp

CALFED Bay-Delta Program. 2000a. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. July 2000. Sacramento, CA. http://www.delta.dfg.ca.gov/erp/reports_docs.asp

CALFED Bay-Delta Program. 2000b. Ecosystem Restoration Program Plan - Volume II: Ecological Management Zone Visions. Final Programmatic EIS/EIR Technical Appendix. July 2000. Sacramento, CA. http://www.delta.dfg.ca.gov/erp/reports_docs.asp

CALFED Bay-Delta Program. 2001. Ecosystem Restoration Program - Draft Stage I Implementation Plan. Aug. 2001. Sacramento, CA. http://www.delta.dfg.ca.gov/erp/reports_docs.asp

California Office of Environmental Health Hazard Assessment. 2007. Fish Advisories. http://www.oehha.ca.gov/fish.html

California Regional Water Quality Control Board – San Francisco Bay Region. 2006. Mercury in San Francisco Bay Proposed Basin Plan Amendment and Staff Report for Revised Total Maximum Daily Load (TMDL) and Proposed Mercury Water Quality Objectives. Aug. 1, 2006. http://www.swrcb.ca.gov/rwqcb2/TMDL/sfbaymercurytmdl.htm

Churchill, R. K. 2000. Contributions of Mercury to California's Environment from Mercury and Gold Mining Activities: Insights from the Historical Record, *in* Extended abstracts for the U.S. EPA sponsored meeting, Assessing and Managing Mercury from Historic and Current Mining Activities, Nov. 28–30, 2000. San Francisco, CA. Pp. 33–36 and S35–S48.*

Churchill, R. K. and J. P. Clinkenbeard. 2003. Assessment of the Feasibility of Remediation of Mercury Mine Sources in the Cache Creek Watershed. Final report to CALFED. Task 5C1. ERP-99-B06. Sept. 2003.* http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Cooke, J. and staff of the Sacramento River TMDL Unit. 2002. Clear Lake TMDL for Mercury, Final Staff Report. California Regional Water Quality Control Board – Central Valley Region. Feb. 2002.* http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/clearlake.html

Cooke, J., C. Foe., S. Stanish, and P. Morris. 2004. Cache Creek, Bear Creek, and Harley Gulch TMDL for Mercury, Staff Report. California Regional Water Quality Control Board – Central Valley Region. Nov. 2004.* http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/Cache-SulphurCreek/CacheNov04a.pdf

Cooke, J. and S. Stanish. 2007. Sulphur Creek TMDL for Mercury, Final Staff Report. California Regional Water Quality Control Board – Central Valley Region. Jan. 2007.* http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/sulphur-creek/sulphur-creek-tmdl.pdf

Davis, J. A. 2003. Ten Years of Pilot and Special Studies: Keys to the Success of the RMP. San Francisco Estuary Institute, 2003 Pulse of the Estuary. Pp. 32-39.* http://www.sfei.org/rmp/pulse/tenyearsRMP2003.pdf

Davis, J., J. Hunt, L. Grenier, D. Slotton, S. Ayers, R. Brodberg, M. Gassel, M. Stephenson, G. Ichikawa, A. Ujihara, M. L. Tan, J. Kaslow, and E. Silver. 2007. A Pilot Program for Monitoring, Stakeholder Involvement, and Risk Communication Relating to Mercury in Fish in the Bay-Delta Watershed ("Fish Mercury Project"). ERP-02D-P67.*

Domagalski, J. L., D. G. Slotton, C. N. Alpers, T. H. Suchanek, R. Churchill, N. Bloom, S. M. Ayers, and J. Clinkenbeard. 2004. Summary and Synthesis of Mercury Studies in the Cache Creek Watershed, California, 2000–01. U.S. Geological Survey Water-Resources Investigations Report 03-4335. http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Downing, J. 2007. Update on the San Jose/Santa Clara Water Pollution Control Plant Mercury Fate and Transport Study. San Francisco Bay Mercury News. 4(1):5-6.* http://www.sfei.org/rmp/mercury_newsletter/HgNewsletterWinter2007.pdf

Foe, C., J. Davis, S. Schwarzbach, M. Stephenson, and D. G. Slotton. 2003. Conceptual Model and Working Hypotheses of Mercury Bioaccumulation in the Bay-Delta

Ecosystem and its Tributaries. Final report to CALFED Ecosystem Restoration Program. Sept. 23, 2003.*
http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Gassel, M., R. Brodberg, S. Klasing, and S. Roberts. 2007. Draft Safe Eating Guidelines for Fish and Shellfish from the San Joaquin River and South Delta (Contra Costa, San Joaquin, Stanislaus, Merced, Madera, and Fresno Counties). California Office of Environmental Health Hazard Assessment. Sacramento, CA. March 2007. http://www.oehha.ca.gov/fish/so_cal/sjrsd030907.html

Gassel, M., R. Brodberg, S. Klasing, and S. Roberts. 2008. Draft Safe Eating Guidelines for Fish and Shellfish from the Sacramento River and Northern Delta. California Office of Environmental Health Hazard Assessment. Sacramento, CA. April 2008. http://www.oehha.org/fish/so_cal/srnd041108.html

Heinz, G. H. 1979. Methylmercury: Reproductive and Behavioral Effects on Three Generations of Mallard Ducks. Journal of Wildlife Management. 43:394-401.

Heinz, G. H. 2003. The Use of Egg Injections to Rank the Sensitivities of Avian Embryos to Methylmercury. Final progress report to CALFED Bay-Delta Program. ERP-99-B06. Sept. 17, 2003.*
http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Hunerlach, M. P., C. N. Alpers, M. Marvin-DiPasquale, H. E. Taylor, and J. F. De Wild. 2004. Geochemistry of Fluvial Sediment Impounded Behind Daguerre Point Dam, Yuba River, California, August 2001. U.S. Geological Survey Scientific Investigations Report 2004-5165. http://pubs.usgs.gov/sir/2004/5165/

Krabbenhoft, D. P., J. G. Wiener, W. G. Brumbaugh, M. L. Olson, J. F. DeWild, and T. J. Sabinal. 1999. A National Pilot Study of Mercury Contamination of Aquatic Ecosystems Along Multiple Gradients, *in* Morganwalp, D. W., and H. T. Buxton (editors), Proceedings of the U.S. Geological Survey Toxic Substances Hydrology Program Technical Meeting Contamination of Hydrologic Systems and Related Ecosystems, March 8-12, 1999. V. 2 of 3. Charleston, South Carolina. U.S. Geological Survey Water-Resources Investigations Report 99-4018B. p. 147-160. http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionB/2301_Krabbenhoft/

Marshall, J., 2007, Total Maximum Daily Load for Mercury in the Walker Creek Watershed. Staff report of California Regional Water Quality Control Board – San Francisco Bay Region. Oakland, CA.*
http://www.waterboards.ca.gov/rwqcb2/TMDL/walkermercurytmdl.htm

Marvin-DiPasquale, M., A. R. Stewart, N. S. Fisher, P. Pickhardt, R. P. Mason, A. Heyes, and L. Winham-Myers. 2007. Evaluation of Mercury Transformations and

Trophic Transfer in the San Francisco Bay/Delta: Identifying Critical Processes for the Ecosystem Restoration Program. Final report. ERP-02-P40.*

Melwani, A. R., S. N. Bezalel, J. L. Grenier, J. A. Hunt, A. H. Robinson, and J. A. Davis. 2007. The Relationship Between Landscape Features and Sport Fish Mercury in the Sacramento-San Joaquin Delta Watershed. Final draft. San Francisco Estuary Institute. ERP–02D-P67. Task 3.1. Feb. 28, 2007.*

Mergler, D., H. A. Anderson, L. H. M. Chan, K. R. Mahaffey, M. Murray, M. Sakamoto, and A. H. Stern. 2007. Methylmercury Exposure and Health Effects in Humans: A Worldwide Concern. Ambio. 36(1):3-11.

Morris, P. 2007. Regional Water Quality Control Board. Written commun.

Munthe, J., R. A. Bodaly, B. A. Branfireun, C. T. Driscoll, C. C. Gilmour, R. Harris, M. Horvat, M. Lucotte, and O. Malm. 2007. Recovery of Mercury-Contaminated Fisheries. Ambio. 36(1):33-44.

Parmer, A., M. Maidrand, V. Fry, K. Abu-Saba, and L. Whalin. 2005. Methylmercury Fate and Transport Study. Paper presented at WEFTEC 2005, Water Environment Federation's 78th annual technical exhibition and conference, Washington, D.C., Oct. 29–Nov. 2, 2005. Available from the Sacramento Regional County Sanitation District. Sacramento, CA.*

Scheuhammer, A. M., M. W. Meyer, M. B. Sandheinrich, and M. W. Murray. 2007. Effects of Environmental Mercury on the Health of Wild Birds, Mammals, and Fish. Ambio. 36:12-18.

Slotton, D. G., S. M. Ayers, C. N. Alpers, and C. R. Goldman. 2004a. Bioaccumulation Legacy of Gold Rush Mercury in Watersheds of the Sierra Nevada of California. Third Biennial CALFED Bay-Delta Program Science Conference Abstracts. Oct. 4-6, 2004. Sacramento, CA. P. 388.*
http://www.delta.dfg.ca.gov/erp/docs/wq_mercuryissues/Mercury_Poster_Abstracts.pdf

Slotton, D. G., S. M. Ayers, T. H. Suchanek, R. D. Weyand, and A. M. Liston. 2004b. Mercury Bioaccumulation and Trophic Transfer in the Cache Creek Watershed of California, in Relation to Diverse Aqueous Mercury Exposure Conditions. Final report. ERP-99-B06. Task 5B. Jan. 24, 2004.*
http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Stephenson, M., C. Foe, G. A. Gill, and K. H. Coale. 2007. Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries:

An Integrated Mass Balance Assessment Approach. Annual Report to CALFED. ERP-02-C06a and ERP-02-C06b.*

Stillwater Sciences. 2004. Mercury Assessment of the Merced River Ranch. Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach. Prepared for the CALFED Ecosystem Restoration Program. ERP-02-P12-D. Berkeley, CA.* http://www.delta.dfg.ca.gov/AFRp/documents/MRMercAssess2004.pdf

Suchanek, T. H., D. G. Slotton, B. S. Johnson, S. Ayers, and D. C. Nelson. 1999. Effects of Wetlands Restoration on the Production of Methyl Mercury in the San Francisco Bay-Delta System: Preliminary Results. IEP Newsletter. The Interagency Ecological Program for the Sacramento – San Joaquin Estuary. 12(3):19-24.*

Suchanek, T. H., D. G. Slotton, D. C. Nelson, S. M. Ayers, C. Asher, R. Weyand, A. Liston, and C. Eagles-Smith. 2002. Mercury Loading and Source Bioavailability from the Upper Cache Creek Mining Districts. Final report. ERP-99-B06. Task 5A. Jan. 24, 2004.* http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Tetra Tech EM, Inc. 2003. Engineering Evaluation and Cost Analysis for the Sulphur Creek Mining District, Colusa and Lake Counties, California. Final report. ERP-99-B06. Subtask 5C2. Sept. 2003.* http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Tetra Tech RD. 2005. Guadalupe River Watershed Mercury TMDL Project: Final Conceptual Model Report. Report to the California Regional Water Quality Control Board – San Francisco Bay Region. May 20, 2005.* http://www.waterboards.ca.gov/sanfranciscobay/TMDL/guadaluperivermercurytmdl.htm

Topping, B. R., J. S. Kuwabara, M. C. Marvin-DiPasquale, J. L. Agee, L. H. Kieu, J. R. Flanders, F. Parchaso, S. W. Hager, C. B. Lopez, and D. P. Krabbenhoft. 2004. Sediment Remobilization of Mercury in South San Francisco Bay, California. U.S. Geological Survey Scientific Investigations Report 2004-5196.* http://pubs.usgs.gov/sir/2004/5196/

Wiener, J. G., C. C. Gilmour, and D. P. Krabbenhoft, 2003b, Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration, Final Report to the California Bay Delta Authority for Contract 4600001642 between the Association of Bay Area Governments and the University of Wisconsin – La Crosse. http://calwater.ca.gov/Programs/Science/adobe_pdf/MercuryStrategy_FinalReport_1-12-04.pdf

Wiener J. G., D. P. Krabbenhoft, G. H. Heinz, and A. M. Scheuhammer. 2003a. Ecotoxicology of Mercury. Pp 409-463 *in* Hoffman D. J., B. A. Rattner, G. A. Burton Jr., and J. Cairns Jr., eds., Handbook of Ecotoxicology. Second edition. CRC Press LCC. Boca Raton, Florida. P. 409-463.

Wood, M. L., C. Foe, and J. Cooke. 2006. Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury: Staff Report. Draft report for scientific peer review. Regional Water Quality Control Board – Central Valley Region. June 2006 (Chapter 7 updated July, 2006).

Yee, D., J. Collins, L. Grenier, J. Takekawa, D. Tsao-Melcer, I. Woo, S. Schwarzbach, M. Marvin-DiPasquale, L. Windham, D. Krabbenhoft, S. Olund, and J. Evens. 2007. Mercury and Methylmercury Processes in North San Francisco Bay Tidal Wetland.

NOTE: * at end of citation indicates that cited report has not been peer reviewed.

5. STRESSORS

5.8. Contaminants

5.8.3. Other Contaminants

Introduction

Contaminants are organic and inorganic chemicals and biological pathogens that can cause adverse physiological response in humans, plants, fish, and wildlife. Contaminants may cause acute toxicity, such as mortality; or chronic toxicity, such as reduced growth, reproductive impairment, or other subtle effects (CALFED 2000a).

Contaminants can affect the sustainability of healthy aquatic foodwebs and interdependent fish and wildlife populations. The effects of water quality toxicity have been documented in shellfish, fish, mammals, and birds from the Bay-Delta and its mainstem rivers and tributaries. This toxicity is most frequently caused by runoff from agriculture, urban areas, and abandoned mines (CALFED 2000a).

Persistent toxicants can accumulate and concentrate in the aquatic foodweb, creating health problems for carnivorous fish and for other predators such as raptors and humans. Most of the organochlorine compounds responsible for these effects, including DDT and PCBs, are now banned, but residues remain in sediments and the tissues of organisms. As their use was discontinued, they were replaced by nonpersistent chemicals, some of which are acutely toxic. When these nonpersistent materials are used for agricultural and residential applications, they can enter watercourses and cause episodic toxicity to resident organisms, including those upon which other organisms must depend for food. This toxicity is subtle, but can have important effects on the aquatic ecosystem.

Some contaminants, such as selenium, occur naturally, but irrigation of agricultural land and water management practices have resulted in toxic levels in some waterbodies. Selenium has caused reproductive failure in fish species and developmental deformities in birds.

Other chemicals present in water, such as dissolved organic carbon (DOC), occur naturally, but are also produced by human activities. While DOC is an important nutrient source for aquatic microbes and algae, certain types of DOC can form toxic compounds when drinking water is treated with disinfection chemicals.

The effects of these contaminants need to be viewed from an ecosystem perspective. In order to characterize those ecosystem effects, individual components such as fate

and transport; distribution and concentrations throughout the watershed; toxicity to individual species; and other parameters need to be defined and understood.

This chapter evaluates ERP projects that address water quality contaminants other than mercury, including pesticides, selenium, and DOC. Mercury contamination is discussed in Chapter 5.8.2.

Applicable ERP Vision

The ERP vision for contaminants is to ensure that all waters of the Bay-Delta and its tributaries are free from deleterious concentrations of toxic substances (CALFED 2000a).

The ERP goal for water quality is to improve water and sediment quality to fully support healthy and diverse aquatic ecosystems. The related strategic objective is to reduce the loadings and concentrations of toxic contaminants in all aquatic environments in the Bay-Delta estuary and watershed to levels that do not adversely affect aquatic organisms, wildlife, and human health (CALFED 2000a).

Stage 1 Expectations

The expectations for Stage 1 were to eliminate, to the extent possible, toxic impacts to aquatic organisms, wildlife, and people. Because toxic effects are pervasive and incompletely understood, developing the needed understanding was identified as a distinct CALFED Program goal.

Changes Attributable to ERP

Water quality changes and trends in the Sacramento-San Joaquin Delta and its tributaries are difficult to identify due to the complexity of the system. Water quality is influenced not only by the amounts (loading) and types of contaminants entering the system, but also by seasonal and yearly fluctuations in flows, weather, tides, and other factors. Therefore, it is seldom possible to definitively link water quality changes in the Sacramento-San Joaquin Delta to specific attempts to improve water quality in that ecosystem.

It is also difficult to determine the exact effect water quality degradation has on the Bay-Delta ecosystem. Chemical monitoring and toxicity testing are two key tools for estimating toxic effects. Chemical monitoring indicates that many chemicals are present in Central Valley rivers and streams, and biological motorizing confirms that many species are in decline, but a critical missing piece is an understanding of the

toxicity and potential ecosystem effects associated with contaminants in the Bay-Delta ecosystem (CVRWQCB, 2001).

Key steps in reducing ecosystem effects from toxic contaminants in aquatic environments are to characterize the distribution, persistence, and causes of toxicity, and to determine the effects of the toxicants on aquatic organisms. Key steps in reducing loading of toxic contaminants are: 1) determine what land management and irrigation practices effectively reduce the runoff of contaminants, 2) disseminate this information and 3) encourage the best management practices to reduce toxic contaminants in water bodies.

Some of the most prevalent contaminants in the Bay-Delta system are pesticides from agriculture and urban uses. Pesticides such as chlorpyrifos, diazinon, and pyrethroids are applied to orchards during the dormant winter season and run off into Central Valley waterways during rain storms. Chlorpyrifos and diazinon have been widely detected in Central Valley surface waters. Pyrethroids are replacing diazinon and chlorpyrifos, but pyrethroids are also toxic to aquatic organisms and are difficult to analyze in water and sediment due to their tendency to adhere strongly to sediment particles.

Because of the importance of characterizing pesticide contamination of Bay-Delta waterways, the ERP funded several projects to support development of water quality criteria for diazinon and chlorpyrifos via *Water Quality Criteria for Chlorpyrifos and Diazinon* (**ERP-98-C06**) and *Water Quality Criteria and Toxicity Identification Profiles for Current-Use Pesticides in the Bay-Delta Watershed* (**ERP-01D-C20**), and development of a method for pyrethroid analysis via *Pyrethroid Insecticides: Analysis, Occurrence, and Fate in the Sacramento-San Joaquin Rivers and Delta* (**ERP-02-P42**). These projects examined the toxicity of organophosphate (OP) pesticides such as diazinon and chlorpyrifos, and pyrethroid pesticides, to help support regulatory actions to reduce these toxic chemicals in Central Valley and Delta waterways.

The length of time toxicity is present is an important aspect of water quality contamination because that effects how long resident organisms are exposed and subsequent chronic effects. Delta sloughs are particularly susceptible because of their longer water residence time. In *Delta Toxicity Monitoring Project, Effects on Anadromous and Estuarine Species* (**ERP-97-N09**), researchers conducted quarterly monitoring of Delta back sloughs that received both urban and agricultural runoff. Results for several of the sloughs, notably French Camp and Paradise Cut, indicated that toxicity persisted for up to 15 days.

Toxicity from diazinon and chlorpyrifos runoff in stormwater from urban areas was characterized in an another ERP-funded study titled *Assessment and Implementation of Urban Use Reduction of Diazinon and Chlorpyrifos* (**ERP-97-N01**), which found that diazinon exceeded the water quality chronic criterion more than 87% of the time, and

the acute criterion more than 73% of the time. The acute and chronic criteria for chlorpyrifos were exceeded more than 78% and 68% of the time, respectively.

Diazinon and chlorpyrifos are often present concurrently in Central Valley waterways, along with other pesticides, so it is important to study mixtures of these chemicals to determine toxicity. The *Assessment of Pesticide Effects on Fish and their Food Resources in the Sacramento-San Joaquin Delta* (**ERP-99-N08**) project found that most combinations of two pesticides exhibit simple additive toxicity, rather than synergy or antagonism. It also found that about 85% of the sediment samples tested contained pyrethroids, and that pyrethroids were present at levels acutely toxic to the test organism (*Hyalella azteca*) in about 20% of the samples tested. The study recommended that more attention be given to sediment-associated pesticides and related toxicity to bottom-dwelling aquatic invertebrates.

As discussed above, water quality monitoring is essential to identifying and reducing the impacts of toxicity to aquatic ecosystems. An essential tool for identifying the source of toxicity is the Toxicity Identification Evaluation (TIE) procedure. ERP funded several projects to develop techniques for TIE. One of the most important projects, titled *Water Quality Criteria and Toxicity Identification Profiles for Current-Use Pesticides in the Bay-Delta Watershed* (**ERP-01D-C20**), developed TIE "fingerprints" for priority chemicals widely used in the watershed and often detected in surface waters, including the insecticides carbaryl, azinphos methyl, and malathion and the herbicides chlorothalonil, oxyfluorfen, and trifluralin. These TIE fingerprints will help identify the cause(s) of toxicity in ambient water quality monitoring programs.

Another potential technique for identifying the effects of pesticides on populations of aquatic organisms is to examine changes in the tissues of organisms (histopathology) exposed to pesticides. This method integrates varying exposures of chemical mixtures over the lifespan of organisms. All life stages of the Sacramento splittail, *Pogonichthys macrolepidotus,* a state-listed species of special concern, are potentially exposed to varying amounts and mixtures of chemical contaminants in the Delta. ERP funded the study *Chronic Toxicity of Environmental Contaminants in Sacramento Splittail: A Biomarker Approach* (**ERP-99-N07**) to determine if this was an effective technique for measuring ecosystem effects. However, the study found that correlations between histopathology and tissue contaminant concentrations were weak and inconsistent, and suggested that other factors such as overall health and nutritional status of many adult splittail may be more responsible for their decline.

Several ERP-funded studies identified trends in water quality contaminants. *Assessment of Pesticide Effects on Fish and their Food Resources in the Sacramento-San Joaquin Delta* (**ERP-99-N08**) noted that ambient concentrations of OPs in mainstem rivers are now far below historical levels, and OP toxicity to *Ceriodaphnia dubia,* observed in the mainstem rivers throughout the 1990s, is now largely confined to small urban or agriculturally-impacted creeks or drains.

This may be due, in part, to a shift in pesticide use patterns. As concerns over OP concentrations in runoff have increased, growers have switched to using pyrethroids, another class of insecticides that adhere more strongly to soils and are therefore less likely to run off agricultural fields. However, pyrethroids are also toxic to fish, and can accumulate in sediments.

Evaluation of Alternative Pesticide Use Reduction Practices and Impacts on Water Quality (**ERP-97-C12**) examined the acute toxicity of orchard runoff from esfenvalerate, a commonly-used pyrethroid insecticide. The study found that concentrations of esfenvalerate in the treated sections were alarmingly high, but were reduced to zero about one month after application, indicating that much of the pyrethroid had either degraded or was firmly bound to soil and organic matter. Esfenvalerate quickly attaches to organic matter and sediments, where it can be relatively stable. The increased used of pyrethroids could result in a long-term water quality problem in the Delta, as another study showed that 50% of the fenvalerate (parent compound of esfenvalerate) was still present in estuarine sediments after six weeks. Persistence increased under conditions of reduced light, low microbial activity, low oxygen and high organic carbon content.

Not all pesticide toxicity is due to organophosphate (OP) and pyrethroid insecticides. Herbicides are widely used for residential and agricultural weed control. The *Algae Toxicity Study* (**ERP-98-C08**) funded by ERP, developed new TIE methods for diuron, a common weed killer. Concentrations of diuron identified through TIEs were high enough to affect resident phytoplankton species. The results of this study also demonstrated that algae can be used as a sensitive indicator of the presence of herbicides at ecologically relevant concentrations. This is significant in the Central Valley where mixtures of herbicides and insecticides are frequently detected, but their ecological impacts are not well understood.

The use of BMPs and Integrated Pest Management (IPM) has increased, at least partly due to efforts to improve water quality. An ERP-funded project titled *Implementing Programs to Reduce the Use of Pesticides and Fertilizers in Sacramento and San Joaquin Watersheds* (**ERP-95-M06**) noted a trend towards the overall reduction of pesticide use, as determined through surveys of California growers.

Pyrethroid Insecticides: Analysis, Occurrence, and Fate in the Sacramento and San Joaquin Rivers (**ERP-02-P42**) found that while OP pesticides continue to cause toxicity to aquatic life, acute effects are now largely limited to agricultural drains and small creeks. This study also recommended further development and implementation of Best Management Practices (BMPs) for pesticide use.

ERP funded several projects designed to encourage a reduction in pesticide and fertilizer use. *Implementing Programs to Reduce the Use of Pesticides and Fertilizers in*

Sacramento and San Joaquin Watersheds (**ERP-97-N20**) conducted extensive outreach and education through existing farm networks such as University of California Cooperative Extension to provide alternatives to pesticides and fertilizers. The project found that application rates dropped in areas where there was more outreach and education, and that growers who participated in the program reduced the average number of pounds per acre of pesticide applied compared to the number applied before they began the program. Reductions remained consistent for at least one year after the study ended. Particularly significant was the reduction in diazinon use, one of the most problematic OP pesticides.

Another project, *Biological Agricultural Systems in Cotton (BASIC) – Reducing Synthetic Pesticides and Fertilizers in the Northern San Joaquin Valley* (**ERP-99-B11**) trained farmers in the use of biological insect control, crop monitoring, and alternative methods of weed control. In a follow-up survey all but two of the trained farmers continued to use biological practices on their farms even after the BASIC program ended.

As discussed above, some naturally occurring chemicals, like selenium, can also have toxic effects. The ERP-funded study called *Selenium Effects on Health and Reproduction of White Sturgeon,* Acipenser transmontanus*, in the Sacramento-San Joaquin Estuary* (**ERP-02-P35**) showed that white sturgeon accumulate potentially hazardous levels of selenium and suggests that sturgeon populations should be monitored for tissue selenium burden to help determine selenium bioaccumulation and effects on reproduction. The study also demonstrated significant increases in mortality rates and defects in larvae containing more than 15 µg/g selenium, which is similar to concentrations associated with developmental toxicity in other fish species

Project Summary Table

Table 1. Contaminants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-C06	**Water Quality Criteria for Chlorpyrifos and Diazinon** Developed water quality criteria for organophosphate (OP) pesticides such as diazinon and chlorpyrifos, and pyrethroid pesticides to help support regulatory actions.	3/31/2001	$67,753	Complete. Final Report in ERP Database.

Table 1. Contaminants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-01D-C20	**Water Quality Criteria and Toxicity Identification Profiles for Current-Use Pesticides in the Bay-Delta Watershed** Developed key components for evaluating ecological effects from pesticides, including TIE "fingerprints" for priority chemicals widely used in the watershed and often detected in surface waters to help identify the cause(s) of toxicity in ambient water quality monitoring programs.	6/30/2006	$149,982	Complete. Final Report in ERP Database.
ERP-02-P42	**Pyrethroid Insecticides: Analysis, Occurrence, and Fate in the Sacramento and San Joaquin Rivers and Delta** Developed multi-residue methods for analysis of pyrethroid insecticides in water, sediments and biota.	1/4/2008	$800,000	Complete. Final Report in ERP Database.
ERP-97-N09	**Delta Toxicity Monitoring Project, Effects on Anadromous and Estuarine Species** Developed comprehensive monitoring program, including quarterly monitoring of Delta back sloughs, to better understand the distribution, residency, and sources of toxic pollution.	11/10/1999	$100,000	Complete. Final Report in ERP Database.
ERP-97-N01	**Assessment and Implementation of Urban Use Reduction of Diazinon and Chlorpyrifos** Characterized baseline temporal and spatial trends of diazinon and chlorpyrifos toxicity in urban runoff in the Sacramento region.	11/1/2001	$663,500	Complete. Final Report in ERP Database.
ERP-99-N08	**Assessment of Pesticide Effects on Fish and their Food Resources in the Sacramento-San Joaquin Delta** Developed data to apply toxicity values to resident species in the Sacramento-San Joaquin Delta and identified trends in water quality contaminants.	12/29/2003	$1,586,894	Complete. Final Report in ERP Database.
ERP-99-N07	**Chronic Toxicity of Environmental Contaminants in Sacramento Splittail: A Biomarker Approach** Assessed Sacramento-San Joaquin splittail population to better understand potential impacts of contaminant exposure and to determine if biomarkers are effective for measuring ecosystem effects.	1/30/2006	$673,684	Complete. Final Report in ERP Database.
ERP-97-C12	**Evaluation of Alternative Pesticide Use Reduction Practices and Impacts on Water Quality** Addressed pesticide impacts from agricultural and urban sources and examined the acute toxicity of orchard runoff from esfenvalerate, a commonly-used pyrethroid insecticide.	7/31/2002	$1,221,145	Complete. Final Report in ERP Database.
ERP-98-C08	**Algae Toxicity Study** Evaluated the toxicity and water quality in the Delta and its effect on ecological processes and developed new TIE methods for diuron, a common herbicide.	11/30/2002	$500,000	Complete. Final Report in ERP Database.

Table 1. Contaminants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-95-M06	**Implementing Programs to Reduce the Use of Pesticides and Fertilizers in Sacramento and San Joaquin Watersheds (BIOS)** Promoted reduced pesticide use, monitored progress in reducing pesticide use, and identified a trend toward overall reduction of pesticide use by California growers.	12/30/1998	$660,000	Complete. Final Report in ERP Database.
ERP-97-N20	**Implementing Programs to Reduce the Use of Pesticides and Fertilizers in Sacramento and San Joaquin Watersheds** Increased awareness of farmers to impacts of and mitigation for synthetic chemicals and conducted extensive outreach and education through existing farm networks such as University of California Cooperative Extension to provide alternatives	1/31/1999	$1,680,631	Complete. Final Report in ERP Database.
ERP-99-B14	**Biological Agricultural Systems in Cotton-BASIC-Reducing Synthetic Pesticides & Fertilizers in the Northern San Joaquin Valley** Provided funds for significant expansion of the BASIC program in the Northern San Joaquin Valley to reduce the dependence of farmers on chemical pesticide and fertilizer inputs	3/31/2003	$460,000	Complete. Final Report in ERP Database.
ERP-98-B09	**Integrated Pest Management Partnership to Improve Water Quality in Suisun Bay and Local Creeks** Increased awareness of detrimental impacts of the use and disposal of pesticides and provided education and outreach of integrated pest management to improve water quality in the Suisun Bay and local creeks.	10/31/2001	$266,000	Complete. Monitoring reports in ERP Database.
ERP-97-C06	**Role of Contaminants in the Decline of Delta Smelt in the Sacramento-San Joaquin Estuary** Evaluated the potential impact of contaminants on Delta smelt and their potential role in its decline.	6/30/2001	$437,326	Complete.
ERP-01-N22	**Rainbow Trout Toxicity Monitoring: An Evaluation of the Role of Contaminants on Anadromous Salmonids** Determined the toxicity of waterbodies to rainbow trout embryos as an indicator of contaminant effects.	6/30/2007	$530,000	Complete. Final Report in ERP Database
ERP-98-C07	**Fathead Minnow Toxicity Study in the Sacramento River** Evaluated toxicity in the Bay-Delta system.	11/30/2002	$400,000	Complete. Final Report in ERP Database.
ERP-02-P35	**Selenium Effects on Health and Reproduction of White Sturgeon, *Acipenser transmontanus*, in the Sacramento-San Joaquin Estuary** Researched key areas of scientific uncertainty on toxic effects of selenium accumulation in white sturgeon.	11/30/2004	$150,047	Complete. Final Report in ERP Database.

Table 1. Contaminants Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-B07	**Evaluation of Selenium Sources, Levels, and Consequences in the Delta** Evaluated sources of selenium and impact of selenium on critical prey/indicator species, and measured levels and kinetics in species of concern.	12/31/2001	$1,589,000	Complete. Journal articles in ERP Database
ERP-98-B14	**Irrigation Drainage Water Treatment for Selenium Removal: Panoche Drainage District Demonstration Facility** Demonstrated the effectiveness of microalgae as a substrate for nitrate and selenium reduction in agricultural discharge water.	9/30/2002	$1,149,000	Complete. Final Report in ERP Database.

Other Programs Contributing to ERP Vision

As the regulatory agency responsible for water quality, the CVRWQCB is a key partner in ERP's water quality improvement efforts. In keeping with the requirements of Section 303(d) of the federal Clean Water Act, the CVRWQCB has listed the Delta, the Sacramento River, and the San Joaquin River as "impaired" for a number of contaminants, including chlorpyrifos, diazinon, and selenium. Total Maximum Daily Loads (TMDLs) have been prepared to help reduce these toxicants, and ERP has provided funding for projects that support specific aspects of these regulatory efforts, such as developing water quality criteria and evaluation procedures. The ERP has also provided funding for development of BMPs to reduce agricultural runoff that carries pesticides into Delta tributaries.

The California Department of Pesticide Regulation also contributes to meeting ERP water quality goals with its Surface Water Monitoring Program for pesticides, and its regulatory reevaluation of organophosphate and pyrethroid pesticides. This reevaluation is leading to changes in use patterns that are intended to reduce pesticide runoff into surface waters.

Other agencies and programs that contribute to meeting ERP goals are the State Water Resources Control Board, the U.S. Geological Survey National Water Quality Assessment Program (NWQA), and the California Nonpoint Source Program.

Status of Topic Today

Efforts to reduce toxicity from organophosphates, pyrethroids, and selenium in Central Valley and Delta waterways are continuing as regulatory actions and their associated

implementation programs address the sources of these chemicals and the mechanisms that allow them to enter waterways.

There is no clear indication that Delta water quality has improved since the inception of the ERP. The water quality problems addressed by the ERP are persistent and large scale, usually resulting from current and historical land uses, such as agriculture. In addition, assessing Delta water quality is complicated by hydrology and water operations, and requires a long record to consistently identify and measure changes.

However, if the trend toward reduced pesticide use, documented in the ERP projects cited above, continues and BMPs developed in ERP projects become more widely used, then water quality impairments from pesticides are likely to decrease in both distribution and severity.

Early ERP projects to reduce water contamination by pesticides focused on the widely-used OP pesticides such as diazinon and chlorpyrifos. This was a reasonable approach, both because of their wide use, their detection in Delta waterways and their subsequent listing on the 303(d) list. However, as OP toxicity received increasing attention from the Central Valley Regional Water Quality Control Board (CVRWQCB) and other regulatory agencies, the use of pyrethroids increased. Later ERP projects supported the development of detection methods for pyrethroids to help address this shift in use patterns. While these detection methods are essential for assessing the effects of pyrethroids in Delta waterways, they don't by themselves provide a solution to pesticide toxicity.

An unintended consequence of the efforts to reduce the contamination of Delta waterways by OP pesticides has been to help encourage a shift to other pesticides that are more difficult to detect and that may expose aquatic organisms to more chronic effects. This shift was only partly the result of regulatory efforts, as the use of pyrethroids was already increasing due to their lower costs.

In the last several years, the abundance indices for delta smelt, young striped bass, longfin smelt, and threadfin shad have been at or near record lows. The problem has been termed the "Pelagic Organism Decline" (POD), and appears to be limited to fish dependent on the upper portion of the San Francisco Bay-Delta estuary. The low abundance levels are especially remarkable because winter-spring river flows into the San Francisco Estuary were moderate during this period of low abundance, which would be expected to support at least modest production (IEP 2005a,b). Studies on the potential causes of POD note the changes in pesticide use patterns, but caution that these changes don't necessarily pose serious risks for aquatic species (IEP 2005a,b).

The Irrigated Lands Conditional Waiver, issued by the CVRWQCB in 2005, mandated a monitoring and reporting program involving extensive toxicity testing of Central Valley waterways where irrigation runoff has resulted in violations of water quality standards.

Results from the monitoring conducted from May 2004 through October 2006 provide baseline data on water quality conditions. Predominant pesticides detected throughout Central Valley waterways were diazinon, chlorpyrifos, the herbicides simazine and diuron, and DDT breakdown products. The studies also found that sediment toxicity occurred throughout the Central Valley (CVRWQCB, 2007).

Planned Projects for Implementation

Continued support for the efforts of the CVRWQCB and other water boards is the most effective way to address water quality contaminants because of the water boards' regulatory authority and staff resources. However, ERP can continue to support the water boards by providing appropriate funding, when available, and through coordination and oversight.

Impediments to Implementation

Close communication between ERP and the water boards is essential to improving environmental water quality. ERP staff should be involved with the water boards' efforts to improve water quality by reviewing and providing comments on draft reports, attending public workshops, and participating in work groups related to environmental water quality issues. However, with the transfer of the ERP to California Department of Fish and Game, most staff previously involved with environmental water quality issues were lost and have not been replaced. Therefore it is difficult for the ERP to participate in the TMDL process and other water quality actions in a meaningful way.

References

CALFED Bay-Delta Program. 2000a. Final Programmatic EIS/EIR Technical Appendix. Ecosystem Restoration Program Plan - Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Sacramento, CA.

CALFED Bay-Delta Program. 2000b. Final Programmatic EIS/EIR Technical Appendix. Ecosystem Restoration Program Plan - Volume II: Ecological Management Zone Visions. Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVRWQCB). 2007. Review of Monitoring Data. Revised draft, July 13, 2007. Irrigated Lands Conditional Waiver Program.

CVRWQCB. 2001. Rainbow Trout Toxicity Monitoring: An Evaluation of the Role of Contaminants on Anadromous Salmonids. Project contract. ERP-01-N22.

Interagency Ecological Program for the San Francisco Estuary (IEP). 2005a. Interagency Ecological Program 2005 Workplan to Evaluate the Decline of Pelagic Species in the Upper San Francisco Estuary.

IEP. 2005b. Interagency Ecological Program Synthesis of 2005 Work to Evaluate the Pelagic Organism Decline (POD) in the Upper San Francisco Estuary. http://science.calwater.ca.gov/pdf/workshops/IEP_POD_2005WorkSynthesis-draft_111405.pdf

5. STRESSORS

5.9. Fish and Wildlife Harvest and Artificial Propagation

Introduction

Many Central Valley fish and wildlife species whose populations are declining are not harvested commercially or recreationally (e.g. delta smelt). This suggests that underlying problems with ecosystem processes and functions and habitat conditions throughout the Bay-Delta watershed are primary causes of the decline. For many species populations, harvest restrictions, without an integrated ecosystem management program, will have very little benefit to the long-term sustainability of these species.

Current harvest levels are not a population-limiting stressor on waterfowl and upland game in the Bay-Delta. Proposed restoration of wetland and upland habitats is expected to increase resident and wintering waterfowl and upland game populations. Wildlife managers anticipate that harvest levels would increase in response to increased species abundance. Some proposed actions may also increase public hunting access and opportunities. For example, wetland and upland habitat restoration would involve acquiring lands through conservation easements or purchase from willing sellers and, depending on the conditions of such agreements, hunting access may be allowed.

Harvest management tools include regulations that control daily and seasonal bag limits, size limits, limits based on sex, gear restrictions, and open and closed harvest seasons based on time or location.

Artificial propagation supports important sport and commercial fisheries and mitigates loss of Chinook salmon and steelhead from the construction of large dams and reservoirs. Hatchery fish also supplement the numbers of naturally spawning Chinook salmon and steelhead in the rivers. Restoration of Central Valley Chinook salmon and steelhead populations emphasizes the need to recover naturally-spawning populations by improving habitat conditions for them and by augmenting flows in spawning streams.

The role of hatcheries for each run of salmon and steelhead needs to be carefully evaluated to determine if and how hatchery practices should be changed. The effects of catchable trout programs on wild stocks of trout, steelhead, and other organisms such as endangered native frogs also needs to be closely evaluated to make sure the programs are compatible with the CALFED goals.

Applicable ERP Vision

The vision for fish and wildlife harvest is to support strategies that maintain a sustainable commercial and recreational Chinook salmon fishery in a manner consistent with the recovery of individual stocks; steelhead trout harvest strategies that fully protect naturally spawning stocks while redirecting harvest to hatchery-produced stocks; the continued legal harvest of striped bass and reduction of illegal harvest; and the present white sturgeon harvest strategy, which protects the species from overexploitation while providing a sustainable trophy fishery (CALFED 2000a).

The vision for artificial propagation is to operate hatcheries in a manner that is fully integrated into ecosystem management and restoration of naturally spawning anadromous fish (CALFED 2000a).

Stage 1 Expectations

Stage 1 expectations for fish and wildlife harvest were to, "Maintain and/or enhance populations of selected species for sustainable commercial and recreational harvest, consistent with the other ERP strategic goals" (CALFED 2000b).

Changes Attributable to ERP

Numerous projects were funded to monitor fish and wildlife population trends, conduct marking studies to estimate abundance, investigate genetic structure of wild and cultured populations, and explore various culture methods (Table 1). These projects provided valuable data for the fish and wildlife agencies to better manage harvest and artificial propagation programs for salmon and steelhead for population restoration and recovery. The ERP has invested in several projects that would help to better understand the population dynamics of Chinook salmon and steelhead. These projects are region-wide and not confined to specific locations. No projects specifically directed at restricting or controlling fish and wildlife harvest have been considered for funding. Harvest is under the specific authority of several state and federal agencies.

Since 1998, the ERP has funded the development of a comprehensive marking/coded-wire tagging program for production releases of fall-run Chinook salmon from Central Valley hatcheries (*Constant Fractional Marking/Tagging Program for Central Valley Hatchery Chinook Salmon* (**ERP-05D-S20**), *Evaluation of Increasing Tagging Levels for Chinook Salmon and Steelhead and a Demonstration Project on Mass Marking* (**ERP-98-B15**), *Development of a Comprehensive Implementation Plan for a Statistically-Designed Marking/Tagging and Recovery Program for CV Hatchery-Produced Chinook Salmon & Steelhead* (**ERP-99-N13**), and *Development of a Staged Implementation*

Plan for Coordinated Marking of Chinook Salmon at Sacramento River System Hatcheries (**ERP-99-N13b**)). In the spring of 2007, the tagging program was fully implemented. To complete the Constant Fractional Marking Program, coded-wire tags will need to be recovered from adult fish in the ocean commercial and recreational fisheries, and tags processed in an expanded coded-wire tag processing laboratory. Funding for this recovery phase will also be provided by the ERP program; the program is included in the ERP Plan Year 8 and Year 8 Annotated Budget (2008-09). When recovery information becomes available, the program will provide critical data in the evaluation of: 1) contribution rates of hatchery fish to Central Valley Chinook salmon populations; 2) success of restoration actions designed to increase natural production of Central Valley Chinook salmon; 3) the propagation programs' genetic and ecological effects on natural Chinook populations; and 4) exploitation rates of hatchery and natural Central Valley Chinook salmon in ocean and inland fisheries.

Development of a Comprehensive Central Valley Adult Chinook Salmon Escapement Monitoring Plan (**ERP-05D-S04**) and *Development of a Central Valley Steelhead Comprehensive Monitoring Plan* (**ERP-05D-S05**) are providing funding for development of Central Valley-wide Chinook salmon and steelhead monitoring plans. Existing adult Chinook salmon escapement monitoring programs in the Central Valley may not be adequate to estimate population status and evaluate population trends in a statistically valid manner for management purposes including: providing a sound basis for assessing recovery of listed stocks, monitoring the success of restoration programs, evaluating the contribution of hatchery fish to Central Valley populations, and sustainably managing ocean and inland harvest. In addition, very few monitoring programs collect data on Central Valley steelhead populations.

In 2007, funding was directed at the development of long-term monitoring plans to estimate population status and trends in abundance of adult Central Valley Chinook salmon and steelhead in a statistically valid manner. Development of the plans will include the review of existing Chinook escapement programs for adequacy of statistical power and bias. Sampling designs will be reviewed and recommendations made for improvement of existing programs. Comprehensive databases and reporting will be developed to link escapement, hatchery production, and coded-wire tag data. For steelhead, a statistically-valid monitoring strategy will be developed, along with comprehensive databases and reporting systems.

The *Upper Sacramento River Basin Chinook Salmon Escapement Monitoring Program (PSMFC)* (**ERP-04D-S08a**), *(CDFG)* (**ERP-04D-s08b**), and *(USFWS)* (**ERP-04D-s08c**) has provided funding for adult Chinook salmon escapement monitoring programs in the USRB since 2006. Data on adult Chinook salmon populations is used to evaluate the success of habitat restoration projects, assess recovery of listed stocks (winter-run, spring-run Chinook), manage water project operations, evaluate the contribution of hatchery fish to assist in species recovery, and manage ocean and inland harvest at sustainable levels.

Determination of Age Structure and Cohort Reconstruction of Central Valley Chinook Salmon Populations (**ERP-05D-S11**) addresses the need to improve data on Chinook salmon population age structure by brood year. Lack of aging data has precluded accurate reconstruction of the size of each Chinook salmon brood year at various points in the life cycle, and thus precluded accurate life cycle modeling needed to evaluate restoration programs. This information provides the foundation data used to determine the success of restoring naturally-spawning populations of Chinook salmon and monitoring the success of meeting recovery goals. When age data are available, cohort reconstructions of each brood can provide population parameters such as total ocean abundance, ocean harvest rates, maturation rates, stray rates and the relationship between younger ages in-river to predict older ages remaining in the ocean. The program has completed identification of the age composition of the 2006 escapement year. As more data become available, cohort reconstructions of each brood will be developed.

Declining Chinook populations in the Central Valley have prompted an intense restoration effort of this valuable resource, which is a key element of the state's aquatic diversity. *Health Monitoring of Hatchery and Natural Fall-run Chinook in SJ River* project (**ERP-99-B19**) characterized the health and physiological condition of both natural and hatchery juvenile Chinook in the San Joaquin River and Delta. The findings showed no signs of disease, virus, or obligate bacterial pathogens in any of the juvenile fall-run Chinook salmon that were examined. Light infections of an agent causing a type of kidney disease were detected in a few hatchery and natural fish. The Merced River hatchery release dates seemed to correspond with increased smoltification and resulted in rapid out-migration.

Sacramento River Chinook Salmon Carcass Survey (**ERP-01-N46**) estimated the abundance of adult endangered winter-run salmon with greater accuracy than current estimates, collected life history attributes, evaluated effectiveness of the propagation program, and collected tissue for genetic analysis. A series of annual reports summarizing the data were developed from 1996 through 2006.

Genetic Comparison of Stocks Considered for Re-establishing Steelhead in Clear Creek (**ERP-98-C12**) obtained fine-scale information on the genetic diversity of steelhead/rainbow trout from the Coleman National Fish Hatchery; the mainstem of the Upper Sacramento River; and Mill, Deer, and Clear Creeks. Information gathered can be used to determine the preferred sources of a founding stock for re-establishing a self-sustaining steelhead population in Clear Creek following the removal of McCormick-Saeltzer Dam.

Several projects relating to delta smelt culture were funded by ERP. One such project was the *Culture of Delta Smelt, Hypomesus transpacificus, at Delta Site, in Support of Environmental Studies and Restoration* (**ERP-98-C02**). The objective of this project

was to develop methods to culture the threatened delta smelt. The ready supply of delta smelt will accelerate research efforts aimed at determining the environmental factors impacting the smelt population. Researchers are looking for a supply of smelt for basic and applied research, such as toxicology testing and improved fish screen design work. Emphasis for this project was on improving the physical facilities at the project site, optimizing spawn performance, and larval culture procedures. In addition, the researchers investigated methods for the capture of post-larvae from the field for culture. The first year of this three year project was funded as **ERP-98-C02**. The final two years of this project were funded under **ERP-00-B03**.

Culture of Delta Smelt Phase II & III (**ERP-00-B03**) enabled the evaluation of the important parameters of temperature and rearing-tank size on smelt performance, and provided a summary evaluation of system performance, culture protocols and methodologies. Some of the main objectives of this project were to develop a reliable and technically feasible culture system for all life stages of delta smelt; initiate the supply of live animals for testing in laboratory and field research; and provide data and observations on the development and behaviors of delta smelt.

Delta Smelt Culture and Research Program (**ERP-02-P31**) continued the on-going Delta Smelt Culture Project to develop methods for the successful culture of delta smelt so that a reliable supply of all life stages is available to the research community, while improving culture protocols through investigative work. This supply also represented a refuge population needed for conservation. This program learned more about the basic biology of delta smelt, in order to develop successful culture techniques. Research efforts were directed in two areas that currently restrict production: larval nutrition and spawning.

Project Summary Table

Table 1. Fish and Wildlife Harvest and Artificial Propagation Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-B03	**Culture of Delta Smelt Phase II & III** Developed a functional culture system for delta smelt. Continuance of phase I of ERP-98-C02.	10/31/2003	$811,380	Complete.
ERP-01-N46	**Sacramento River Chinook Salmon Carcass Survey** Estimated the abundance of adult endangered winter-run Chinook with greater accuracy than current estimates, collected life history attributes, evaluated effectiveness of the propagation program, and collected tissue for genetic analysis.	12/31/2006	$622,400	Complete.
ERP-02-P31	**Delta Smelt Culture and Research Program** Created a reliable supply of live delta smelt at all stages to meet the needs of the research community.	10/31/2005	$400,000	Complete.

Table 1. Fish and Wildlife Harvest and Artificial Propagation Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-02-P34	**Restoration of Sacramento Perch to San Francisco Estuary** The project goal is to develop strategies to restore Sacramento Perch to self-sustaining wild populations in the San Francisco Estuary and to assure the Sacramento Perch long-term future in Central California.	1/30/2007	$507,432	Ongoing
ERP-04D-S08a	**Upper Sacramento River Basin Chinook Salmon Escapement Monitoring Program (PFMC)** Will monitor the annual abundance, migration timing, spawning distribution, and several life history characteristics of hatchery and natural winter, spring, late fall and fall-run Chinook salmon during the 2006, 2007, and 2008 spawning seasons.	12/31/2008	$777,700	Ongoing
ERP-04D-S08b	**Upper Sacramento River Basin Chinook Salmon Escapement Monitoring Program (CDFG)** Will monitor the annual abundance, migration timing, spawning distribution, and several life history characteristics of hatchery and natural winter, spring, late fall and fall- run Chinook salmon during the 2006, 2007, and 2008 spawning seasons. The DFG contracted directly for the major equipment purchases to be made.	12/31/2008	$68,500	Ongoing
ERP-04D-S08c	**Upper Sacramento River Basin Chinook Salmon Escapement Monitoring Program (USFWS)** The purpose of this project is to estimate the abundance of winter-run Chinook spawners and to evaluate the winter-run Chinook propagation program at the Livingston Stone National Fish Hatchery.	3/31/2010	$496,210	Ongoing
ERP-05D-S04	**Development of a Comprehensive Central Valley Adult Chinook Salmon Escapement Monitoring Plan** Develop a long-term comprehensive plan designed to estimate population status and trends in abundance of adult Central Valley salmon in a statistically valid manner.	9/30/2009	$373,349	Ongoing
ERP-05D-S05	**Development of a Central Valley Steelhead Comprehensive Monitoring Plan** Will be a comprehensive plan for steelhead population monitoring that will provide the data necessary to assess whether or not restoration and recovery goals are being achieved, and to improve management of the species.	6/30/2009	$367,888	Ongoing
ERP-05D-S11	**Determination of Age Structure and Cohort Reconstruction of Central Valley Chinook Salmon Populations.** This project will accurately determine the age of all returning Chinook salmon populations to the Central Valley, using the aging data, in combination with the Coded-wire Tag (CWT) recovery data.	1/31/2009	$637,412	Ongoing

Table 1. Fish and Wildlife Harvest and Artificial Propagation Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-05D-S20	**Implementation of a Constant Fractional Marking/Tagging Program for Central Valley Hatchery Chinook Salmon** Marking/tagging program that will provide CALFED the specific information needed to evaluate Ecosystem Restoration Program Plan (ERPP) actions and goals related to improving conditions for Central Valley Chinook salmon.	9/30/2008	$6,775,998	Ongoing
ERP-95-M08	**Molecular Genetic Identification of Chinook Salmon Runs focused on Spring Run Integrity** The primary objective was to contribute to the development of molecular and statistical tools for stock discrimination among Central Valley Chinook salmon.	10/31/2000	$598,086	Complete.
ERP-96-M11	**Molecular Genetic Identification of Chinook Salmon Runs Focused on Spring-run Integrity** Bodega Marine Laboratory performed a study on molecular genetic identification of Chinook salmon runs focusing on spring-run integrity, relationships between different spring-run populations and comparisons to other Chinook runs of the Central Valley,	6/30/2000	$750,000	Complete.
ERP-97-C09	**San Joaquin River Drainage Fall-Run Chinook Salmon Genetic Baseline and Discrimination Evaluation** Characterized the genetic makeup of San Joaquin River fall-run Chinook salmon.	6/30/2002	$387,003	Complete.
ERP-98-B15	**Evaluation of Increasing Tagging Levels for Chinook Salmon and Steelhead and a Demonstration Project on Mass Marking** Evaluated the feasibility of mass marking and/or tagging to increase the knowledge about juvenile salmon and steelhead distribution in inland and marine waters.	6/30/2002	$616,191	Complete.
ERP-98-B36	**Development and Implementation of an Environmental Education Program to Include Slide Cards, Journalism Tours, and Secondary and Community College Educator's Workshops** Increased public awareness of environmental issues in the Bay-Delta and environmental restoration process.	12/31/2001	$40,000	Complete.
ERP-98-C02	**Culture of Delta Smelt, Hypomesus transpacificus, at Delta Site, in Support of Environmental Studies and Restoration** Developed culture methods to supply all life-stages of delta smelt for research studies.	10/1/1999	$194,870	Complete.
ERP-98-C12	**Genetic Comparison of Stocks Considered for Re-establishing Steelhead in Clear Creek** Obtained fine-scale information on the genetic diversity of steelhead/rainbow trout from several locations to determine the preferred sources of a founding stock for re-establishing a self-sustaining steelhead population in Clear Creek.	9/30/2004	$45,492	Complete.

Table 1. Fish and Wildlife Harvest and Artificial Propagation Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-C14	**Monitoring Adult and Juvenile Spring and Winter Chinook Salmon and Steelhead in Battle Creek, California** Monitored salmon and steelhead in Battle Creek for life history information to be used to assess the current health of the habitat and provide an evaluation tool for restoration activities.	8/31/2002	$150,000	Complete.
ERP-98-N03	**Life History and Stock Composition of Steelhead Trout** Will characterize the life history patterns and stock composition of steelhead in the Yuba River to support ecosystem restoration and species recovery programs.	8/31/2006	$120,000	Ongoing
ERP-99-B19	**Health Monitoring of Hatchery and Natural Fall-run Chinook in SJ River** Characterized the health and physiological condition of both natural and hatchery juvenile Chinook salmon in the San Joaquin River and Delta.	Unknown	$37,860	Complete.
ERP-99-N12	**Central Valley Steelhead Genetic Evaluation** Recent microchemical analysis of otoliths from three rainbow trout from the Calaveras River provides evidence that this population is polymorphic. This project will evaluate and describe the genetic variation and the genetic and population structure of Central Valley steelhead populations.	12/31/2003	$70,636	Complete.
ERP-99-N13	**Development of a Comprehensive Implementation Plan for a Statistically-Designed Marking/Tagging and Recovery Program for CV Hatchery-Produced Chinook Salmon & Steelhead** Developed a plan to implement a Constant Fractional Marking (CFM) program that integrates traditional coded-wire tagging/fin marking (CWT) and otolith thermal marking (OTM) to address Central Valley Chinook salmon and steelhead management question	11/30/2004	$92,657	Complete.
ERP-99-N13b	**Development of a Staged Implementation Plan for Coordinated Marking of Chinook Salmon at Sacramento River System Hatcheries** 99-N13B is the proposal that was submitted as a subcontract with DFG to complete a portion of the original 99-N13 contract. This project focused primarily on Phase IV of the DFG contract (99-N13) to create a staged implementation plan segment for CFM.	1/31/2004	$74,249	Complete.

Other Programs Contributing to ERP Vision

Through a variety of other programs, several CALFED member agencies have made significant contributions during Stage 1 to support the ERP vision of maintaining and/or enhancing populations of selected species for sustainable commercial and recreational harvest. The federal Central Valley Project Improvement Act programs have contributed considerable funding during Stage 1 to work toward the Act's goal of

doubling natural production of anadromous salmonids in the Central Valley, including several harvested species. On-going hatchery mitigation programs through federal, state, and local water agencies have continued to support commercial and recreational harvest of Chinook salmon. State and federal management agencies have used best available information during Stage 1 to manage harvest for long-term sustainability.

Status of Topic Today

By using information from the monitoring programs funded by ERP, resource agency managers now have better tools to manage fish and wildlife resources for sustainable commercial and recreational harvest.

Planned Projects for Implementation

To complete the Constant Fractional Marking Program, coded-wire tags will need to be recovered from adult fish in the ocean commercial and recreational fisheries, and tags processed in an expanded coded-wire tag processing laboratory. Funding for this recovery phase will also be provided by the ERP program; the program is included in the ERP Plan Year 8 and Year 8 Annotated Budget (2008-09).

When the Central Valley Chinook salmon escapement and steelhead monitoring plans are complete, recommendations will be made for revised and new monitoring programs for these species. Additional funding will be needed to implement the new programs.

Impediments to Implementation

In the past, there has been limited funding for programs to monitor adult salmon and steelhead escapement and abundance. Programs have evolved over the years, with varying methods used, intensity of sampling effort, and reliability of estimates. These monitoring programs are now funded by many different agencies, with little Central Valley-wide coordination in methodology. In order to ensure that adequate data are available for sustainable harvest management, coordinated Central Valley monitoring programs with stable, long-term funding, are needed.

References

CALFED Bay-Delta Program. 2000a. Ecosystem Restoration Program Plan Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. CALFED, Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2000b. Ecosystem Restoration Program Plan Volume II: Ecological Management Zone Visions. CALFED, Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

CALFED Bay-Delta Program. 2000c. Ecosystem Restoration Program Plan Strategic Plan for Ecosystem Restoration. CALFED, Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

5. STRESSORS

5.10 Stranding

Introduction

Although stranding was historically a natural event, today it is generally considered a stressor that contributes to the loss of important aquatic resources including adults and juveniles of important fishes.

Anthropogenic changes to the valley and its tributaries have led to unnatural topography such as borrow ponds and water diversion canals which can trap large numbers of fish. Nonnative game fish species often thrive in isolated ponds and prey on trapped native fish.

Multiple stressors have led to declines in native fish populations, resulting in lower production to offset stranding losses. Stranding appears to be of primary concern for migratory species such as Chinook salmon, steelhead trout, sturgeon and splittail. Important mechanisms for stranding include:

- Stranding of adults and juveniles on bypass floodplains.
- Stranding of natal and non-natal juveniles within floodplains confined by setback levees.
- Stranding of salmonid redds as a result of flow fluctuation in river channels.
- Stranding of migratory and resident species from Delta levee breaches.

The original description of stranding did not include the adverse consequences of water diversions and inadequate flow for fish passage (CALFED 2000). These issues are discussed in other sections including dams and other structures, Central Valley streamflow, and water diversions. Numerous other projects related to fish passage are included in this discussion since upstream migrating adult fish and downstream emigrating juvenile fish are subject to stranding when stream flows are diverted in quantities that prevent further migration. Thus the fish become stranded within specific stream reaches.

Applicable ERP Vision

The vision for stranding is to reduce the number of aquatic organisms lost when rivers recede or overflow into flood bypasses; to reconnect areas that become isolated from flowing water; and to reduce the frequency by which low-lying areas are inundated.

The strategic objective for stranding is to reestablish frequent inundation of floodplains by removing, breaching, or setting back levees and, in regulated rivers, by providing flow releases capable of inundating floodplains where feasible.

Stage 1 Expectations

During Stage 1 it was expected that initial assessments of the potential for stranding of juvenile and adult fish in the floodplains and bypasses in the Central Valley would be completed. In addition, small-scale adaptive experimentation projects were to be implemented to reduce the potential losses due to stranding and to increase the value of bypasses as rearing habitat for splittail and juvenile Chinook salmon.

Changes Attributable to ERP

The projects listed in Table 1 exhibit a wide variation in the project types that contribute to reduced stranding of adult and juvenile fish. The most significant advances resulted from efforts to improve fish passage and eliminate stranding on tributary streams to the mainstem rivers. The fish passage efforts on Butte Creek, *Butte Sink Water Control Structure Modifications - Phase III Construction* (**ERP-02-P07**) and *Gorrill Dam Fish Screen and Fish Ladder Project* (**ERP-96-M22 and ERP-97-M03**), contributed to a much larger program to restore spring-run Chinook salmon. Three projects, *Fish Passage Improvement Project under Bay Delta Project - Category III* (**ERP-98-B03**), *Fish Passage and Fish Screening Improvement Project, Phase II* (**ERP-98-B24**), *ACID Fish Passage Improvement Project, Phase III* (**ERP-99-N01**), for the Anderson-Cottonwood Irrigation District seasonal diversion dam on the upper Sacramento River effectively reduced the potential for stranding adult and juvenile salmonids and spawning areas by replacing the antiquated diversion dam. *Narrows 2 Powerplant Flow Bypass System Project* (**ERP-02-P47**) solved an infrequent but recurring stranding problem on the Yuba River below Englebright Dam that would happen when the power plant unexpectedly went offline.

The Yolo Bypass Fish Habitat Project (**ERP-96-M13**) provided an opportunity to examine the relationship between the Yolo Bypass and the estuary. The 1997 study provided seining data on the length of salmon gathered at ponds formed by receding floodwaters. Mean salmon size increased faster in the Bypass than in the Sacramento River, suggesting better growth rates. An estimate of salmon stranding was developed and estimated at a few hundred thousand fish. The Bypass appears to be a valuable link in the downstream estuarine food web (California Department of Water Resources 1998). Sampling in 1998 suggested that the bypass produced large pulses of phytoplankton downstream in the estuary following successive filling and draining cycles of the floodplain (California Department of Water Resources 1999).

Project Summary Table

Table 1. Stranding Projects Summary Table

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-E04	**Sonoma Creek Watershed Conservancy** Implemented riparian and aquatic habitat restoration activities and continued watershed stewardship and education programs in the Sonoma Creek watershed.	3/1/2004	$438,923	Complete. Funded 800 ft. of riparian restoration by revegetating stream banks at 3 different sites on Carriger Creek.
ERP-00-F06	**Liberty Island Acquisition** Proposes to acquire fee title interest in the remaining two privately-owned properties on Liberty Island, estimated at 449 acres; and to conduct restoration of tidal shallow water habitat, tidal emergent wetlands, and seasonal wetlands for aquatic and terrestrial species.	09/30/2007	$2,625,153	Ongoing.
ERP-01-N55	**RD 2035 Fish Screen and Environmental Design Review** Provided engineering design services for a 400-cfs landslide pump station and screened intake facility.	12/31/2003	$1,384,000	Complete.
ERP-02-P07	**Butte Sink Water Control Structure Modifications - Phase III Construction** Provided passage for adult salmonids by installing fish ladders and overflow gates at the Morton and End weirs and a control weir at the North Weir site to keep adult salmon and steelhead in the main migration path of Butte Creek.	07/31/2008	$5,748,112	Complete.
ERP-02-P16	**Patterson Irrigation District Fish Screen Design and Environmental Review** Covered the tasks necessary to complete the preliminary and final engineering design for a new diversion and pumping enclosure facility adjacent to the existing diversion. The existing diversion will be abandoned in place per regulatory requirements. The primary objective is to provide a positive means of preventing entrainment of migrating at-risk native fish species by the intake facility.	02/12/2007	$639,700	Complete.
ERP-02-P47	**Narrows 2 Powerplant Flow Bypass System Project** Provided a structural remedy to eliminate flow and temperature fluctuations from emergency and maintenance shutdowns at the Narrows 2 Hydropower Plant on the Yuba River by constructing a 3,000 cfs synchronous bypass system to maintain stable flow releases.	06/30/2008	$8,535,567	Complete.
ERP-04-S16	**Clear Creek Anadromous Salmonid Monitoring Program** A comprehensive salmonid monitoring program that will provide feedback for the adaptive management and evaluation of restoration actions of the Clear Creek Restoration Program and B2 Water Program.	12/31/2009	1,974,068	Ongoing.

Table 1. Stranding Projects Summary Table

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-06D-S15	**Sacramento River Conservation Area Forum (SRCAF)** Funds efforts of the Sacramento River Conservation Area Forum to act as a coordinating body between local, state, and federal agencies regarding restoration activities in the Sacramento River watershed.	3/31/2010	$656,277	Ongoing.
ERP-95-M07	**Suisun Marsh Fish Screen Project** Phase 1 (diversion evaluation and selection) of a larger program to construct fish screens on 5 diversions in the Suisun Marsh to reduce downstream migrant salmonid mortality and mortality of delta smelt and splittail.	12/31/1996	$450,000	Complete.
ERP-96-M13	**Yolo Bypass Fish Habitat** Examined the relationship between the Yolo Bypass and the rest of the Estuary and to develop recommendations for restoration actions that would improve Bypass habitat for fisheries and other aquatic organisms.	11/30/2000	$226,000	Complete.
ERP-96-M17	**Browns Valley Irrigation District Fish Screen Project** Reduced entrainment of important anadromous fish species by providing funds for the construction of a fish screen at the Browns Valley Irrigation District's diversion facility on the Yuba River.	12/31/1999	$114,750	Complete.
ERP-96-M19	**Feasibility Study for Intake Screen at Wilkins Slough Diversion** Phase II (feasibility study) of a five-phase project to design and construct a state-of-the-art fish screen at Reclamation District 108's Wilkins Sough diversion facility on the Yuba River to reduce entrainment of anadromous fish.	6/30/1997	$100,000	Complete.
ERP-96-M22	**Gorrill Dam Fish Screen and Fish Ladder Project** Studied feasibility of a fish ladder and screen on Gorrill Dam on Butte Creek to reduce entrainment and improve passage for anadromous fish.	12/31/1998	$67,990	Complete.
ERP-97-B03	**Liberty Island Acquisition** Protected and restored tidally influenced wetlands, riparian corridors, and upland habitats on Liberty Island in the Yolo Bypass.	09/30/2003	$8,926,000	Complete.
ERP-97-C01	**Positive Barrier Fish Screen Project, Wilkins Slough Pumping Plant** Constructed a positive fish barrier intake screen at Reclamation District 108's diversion structure at Wilkins Slough for the protection of Chinook, splittail, and other fish species.	12/31/1999	$2,500,000	Complete
ERP-97-M03	**Gorrill Dam Fish Screen and Fish Ladder Project** Provided funds to construct a fish ladder and fish screen at the Gorrill Dam on Butte Creek to reduce entrainment and improvement passage for anadromous fish.	12/31/1999	$369,641	Complete.

Table 1. Stranding Projects Summary Table

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-98-A02	**Habitat Restoration/Flood Control Bypasses System** Evaluated restoration needs and opportunities to improve habitat, reduce stranding and improve connectivity with the Sacramento River and the north Delta.	12/31/2002	$947,226	Complete.
ERP-98-B03	**Fish Passage Improvement Project under Bay Delta Project - Category III** Planning phase for construction of fish passage improvement structures at the Anderson-Cottonwood Irrigation District main diversion dam for the benefit of anadromous fish.	03/31/1999	$325,000	Complete.
ERP-98-B24	**Fish Passage and Fish Screening Improvement Project, Phase II** Provided funds for completing the final design, environmental documentation, and permitting for improved fish passage structures on the Anderson-Cottonwood Irrigation District diversion dam on the Sacramento River.	08/31/1999	$840,759	Complete.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** Implementation of monitoring and applied research that provides data and information necessary to evaluate the performance of completed CALFED program actions and ongoing programs.	12/31/1999	$800,000	Complete.
ERP-98-E01	**Napa River Watershed Stewardship** Built upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/31/2000	$250,000	Complete.
ERP-98-E07	**Local Watershed Stewardship: Steelhead Trout Plan, Corte Madera Creek Watershed, Marin County, California** Developed a steelhead restoration plan for the Corte Madera Creek as part of a larger watershed management plan for the Corte Madera Creek watershed.	12/31/2000	$47,500	Complete. Develop a steelhead trout plan and identify the limiting factors of steelhead trout populations in the watershed.
ERP-98-E11	**Watershed Restoration Strategy for the Yolo Bypass** Facilitated broad based local stakeholder group in development of watershed plan.	03/31/2002	$287,353	Complete.
ERP-98-F15	**Lower Clear Creek Floodway Restoration Project (Phase II)** Improved salmon spawning and rearing habitat by implementing the Lower Clear Creek Watershed Management Plan and restoring 2.9 miles of floodplain and riverine aquatic habitat.	06/30/2006	$4,561,940	Complete.

Table 1. Stranding Projects Summary Table

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-99-B04	**Preliminary Design and Engineering of Lower Western Stone Site, Merced River Salmon Habitat Enhancement Project (Phase IV)** Reduced entrainment of out-migrating fish. Improve river and floodplain dynamics and enhance the riparian corridor.	04/30/2003	$125,000	Complete.
ERP-99-N01	**ACID Fish Passage Improvement Project, Phase III** Provided funds for construction of improved fish passage structures on the Anderson-Cottonwood Irrigation District diversion dam on the Sacramento River.	09/01/2002	$5,100,000	Complete.
ERP-99-N02	**Fish Treadmill Developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes** Provided the data necessary to develop the "proven technology" for protective positive barrier fish screens for priority native fishes in the Sacramento-San Joaquin watershed.	3/31/2002	$1,069,750	Complete.

Other Programs Contributing to ERP Vision

Efforts to reduce stranding have involved the cooperation and support of established programs already underway to restore habitat and fish populations throughout Central Valley streams and rivers:

- The Central Valley Project Improvement Act (CVPIA) calls for doubling of the anadromous fish populations (including striped bass, salmon, steelhead, sturgeon and American shad) by 2002 through changes in flow, project facilities and operations. The program involves actions that may reduce stranding rates through habitat or flow improvements.
- The California Department of Fish and Game is required under State Legislation (The Salmon, Steelhead, Trout and Anadromous Fisheries Program Act of 1988) to restore numbers of anadromous fish in the Central Valley.
- The Four Pumps and Tracy Fish Mitigation Agreements. These two agreements involve mitigation in the Sacramento and San Joaquin basins to offset fish losses at the SWP and CVP pumping plants. Restoration projects in these programs frequently deal directly or indirectly with fish stranding issues.

Status of Topic Today

The potential for fish stranding is a complex mix of stream channel dynamics; the degree or ease of connectivity between flood plains and rivers; stream flows and water

diversion; and provisions for up and downstream fish passage. Many of the upstream-downstream fish passage problems have been addressed and reduced in various areas.

Overall, *The Yolo Bypass Fish Habitat Project* (**ERP-96-M13**) found that the bypass supported at least 40 species of fish including delta smelt, steelhead trout, sturgeon, and winter-run Chinook salmon. Suggested habitat improvements for the system included modifications to increase the frequency and duration of flooding; a recommendation for a no-net-loss policy for seasonal floodplains; modification of weirs to reduce fish passage and stranding problems; and improved connectivity between floodplain ponds and the Toe Drain to reduce stranding.

Planned Projects for Implementation

The Habitat Restoration/Flood Control Bypasses System Project (**ERP-98-A02**) evaluated restoration opportunities and needs in the Yolo Bypass, with a resulting cooperative study that assessed the feasibility of managing a portion of the Yolo Bypass floodplain to support aquatic species (Natural Heritage Institute et al. 2002). Putah Creek was identified as the most promising location for construction of a pilot scale demonstration project. Potential actions included various combinations for channel realignment, check dam operation, and floodplain excavation. One Putah Creek scenario would inundate a substantial area of floodplain habitat (up to 1,100 acres); create an opportunity to improve fish passage to allow Chinook salmon better access to Putah Creek; and mesh with the existing topography to simulate historical alignment and floodplain features of Putah Creek.

Impediments to Implementation

For many projects, inadequate funding remains a significant impediment to implementation.

References

CALFED Bay Delta Program. 2000. Ecosystem Restoration Program Plan - Volume 1: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix. July 2000.

California Department of Water Resources. 1998. Results of the 1997 Yolo Bypass Studies. 96-M13-R_Yolo_Bypass_Study_Results.pdf.

California Department of Water Resources. 1999. Results and Recommendations from 1997-1998 Yolo Bypass Studies. 96-M13-R Results and Recs from Bypass Studies.pdf

Natural Heritage Institute, California Department of Water Resources, California Department of Fish and Game, Yolo Basin Foundation, Northwest Hydraulic Consultants, G. Yates, P. Kiel and Jones & Stokes. 2002. Habitat Improvement for Native Fish in the Yolo Bypass. Dec. 2002. 98-A02-R_12-02_Habitat_Improvement_for_Native_Fish_in_the_Yolo_Bypass.pdf

5. STRESSORS

5.11 Disturbance

Introduction

Disturbance resulting from human activities can adversely affect habitat for a substantial number of fish, wildlife, and plant communities, including many special-status species and plant communities. Types of disturbance include recreational boating, angling and picnicking, airplane and vehicle traffic, and the secondary effects of residential development adjacent to wildlife habitat

Recreational boating is a popular activity in the ERP area, particularly in the Sacramento-San Joaquin Delta and Suisun Marsh/North San Francisco Bay Ecological Management Zones. Boating activities include the use of small, human-powered craft, such as canoes and kayaks, and jet skis, sail boats, boats ranging from small fishing skiffs to ski boats, and larger pleasure craft. Wind surfing is also expanding in popularity. Excessive, unrestricted boating activities can result in increased erosion of adjacent channel banks that also increases turbidity. Carefully designing recreational access points can reduce the level of disturbance on wildlife, while also meeting other goals (e.g. locating access points to avoid impacts to levees and to keep trespassing and vandalism of private lands to a minimum).

Vehicle traffic close to wildlife habitat reduces the value of that habitat to wildlife, particularly to species such as the greater sandhill crane. Disturbance associated with the pets of people who live near wildlife habitat can result in harassment of wildlife, particularly ground-nesting birds.

Applicable ERP Vision

The vision for disturbance is to reduce the adverse effects of boating and other recreational activities, temporary habitat disturbances, and other human activities on wildlife and their habitats in the Bay-Delta system.

The general approach to achieving the vision for this stressor is to ensure that the location of restored habitat takes into account adjacent land uses; that adequate buffer areas to protect against disturbance are used; and that recreational activities are managed to avoid or minimize conflicts with fish and wildlife habitat. This will contribute to the recovery of at-risk native species in the Bay-Delta estuary and its watershed.

Stage 1 Expectations

Stage 1 expectations were to identify critical areas and times necessary to completely protect species that are vulnerable to human-induced disturbance. This information was to be used to refine and implement restoration actions and to identify sites that can be developed for recreational and public uses.

Changes Attributable to ERP

Many other projects (such as watershed planning, and restoration) discussed in other sections of this report indirectly addressed disturbance issues. For example, in the Sacramento-San Joaquin Delta EMZ, the *Staten Island Acquisition* (**ERP-01-N23**) acquired approximately 11,703 acres; the majority is or will be managed as wildlife-friendly agriculture that will protect Sandhill Cranes from human disturbance. Two projects directly related to reducing the adverse effects of disturbance on fish and wildlife populations or habitats have been selected for funding.

Brush boxes were a biotechnical bank protection measure utilized to reduce disturbance in the Sacramento-San Joaquin Delta (*Tyler Island Levee Protection and Habitat Restoration Pilot Project* (**ERP-97-N13**)). Brush boxes were found to decrease erosional processes and favor depositional processes. They also maintained planted species and recruited others. According to Hart and Hunter (2004), the most promising use of these biotechnical structures is in those situations where a calming period is required to establish plants, after which they would be self-sustaining.

The Demonstration Project for the Protection and Enhancement of Delta In-Channel Islands (**ERP-01-N13** and **ERP-97-N11**) installed various biotechnical methods to control erosion and attenuate wave energy adjacent to three eroding in-channel islands (ICI) in the Delta. The Delta In-channel Island Workgroup (2006) made various observations following the completion of the *Phase II: Demonstration Project for the Protection and Enhancement of Delta In-Channel Islands (Construction & Monitoring)* (**ERP-01-N13**). The Workgroup found that shorelines of the Delta and in-channel islands are dynamic and exposed to extremely different physical forces dependent on location, exposure, elevation, and substrate. The placement of the designed structures in this demonstration project were functional in reducing erosion and providing habitat, and are environmentally friendly, but are relatively expensive to install and require maintenance. Structure placement provided an increase in native emergent vegetation (planted and volunteer), conservation and protection of productive terrestrial and aquatic habitats that support important fish, wildlife, and plant communities, and protection of islands that provide important buffers to levees from erosive forces. Without this project, there would be further loss of habitat and impacts to the resources of the Delta from erosive wave, current, and tidal forces. The project is a model for future projects that deal with preserving and constructing new land/water interfaces

specifically in the Delta, and for other aquatic systems. The structures tested serve as good models for future Delta In-channel Island management, levee protection, and tidal wetland protection.

Project Summary Table

Table 1. Delta Sloughs Project Summary

ERP Project Number	Project Name and Description	End Date	Total Funding	Project Status
ERP-00-E04	**Sonoma Creek Watershed Conservancy** Implemented riparian and aquatic habitat restoration activities and continued watershed stewardship and education programs in the Sonoma Creek watershed.	3/1/2004	$438,923	Complete. Funded 800 ft. of riparian restoration by revegetating streambanks at 3 different sites on Carriger Creek.
ERP-01-N13	**Phase II: Demonstration Project for the Protection and Enhancement of Delta In-Channel Islands (Construction & Monitoring)** Demonstrated that biotechnical methods can be used in lieu of riprap or other hard surfaces to protect valuable tidal wetlands associated with in-channel islands in the Delta.	9/30/2006	$1,145,400	Complete. 0.4 miles of shoreline were treated, protecting a total of 6.24 acres of ICI habitat.
ERP-01-N30	**Digital Soil Survey Mapping and Digital Orthophotoquad Imagery Development** Made soils information more accessible to individuals and groups engaged in ecosystem restoration projects in the Bay-Delta Region, and in doing so, improve the responsiveness of these projects to establishing habitat and supporting sustainable populations of valuable species.	8/15/ 2004	$430,390	Complete.
ERP-01-N31	**Willow Slough Watershed Rangeland Stewardship Program** Built on restoration efforts in the Willow Slough watershed to enhance and restore riparian and grassland habitats, improve forage quality, improve water quality, and reduce erosion. www.plantbiology.msu.edu/malmstrom/Audubon/index.htm	12/31/2005	$1,800,668	Complete. Enhanced/ restored 843 acres of grassland, 98 acres/ 5.95 miles of riparian.
ERP-01-N34	**Estuary Action Challenge Environmental Education Project** EAC worked with elementary school teachers and students to explore, clean up, and restore creek and bay habitats, reduce urban runoff pollution and address issues of water quality and safe bay food consumption. Programs took place in various locations around the Bay Area.	11/30/2001	$50,000	Complete.
ERP-01-N61-04	**San Joaquin River Dissolved Oxygen Depletion Control Project: Sediment Deposition Rates and Associated Oxygen Demand** Studied water and suspended sediments in the San Joaquin River and Stockton Deep Water Ship Channel to elucidate settling and resuspension mechanisms that influence DO concentrations. The information derived from these studies is necessary in determining the impact on DO from algae and other particulate matter and assessing its significance relative to the impacts from all oxygen demand sources.	8/31/2002	$112,000	Complete.
ERP-01-N61-05	**San Joaquin River Dissolved Oxygen Depletion Control Project: Aeration Technology** Provided an engineering evaluation of the potential to use aeration to eliminate the Dissolved Oxygen deficit that occurs in the Deep Water Shipping Channel below water quality objectives.	12/31/2002	$165,000	Complete.

ERP-02D-P52	**Big Break and Marsh Creek Water Quality and Habitat Restoration Program** Developed a public outreach and education program in the Marsh Creek watershed.	10/15/2007	$402,600	Complete.
ERP-02-P10	**Estuary Action Challenge Environmental Education Program** Hands on environmental education project focused on local water resources and environmental justice issues in underserved urban communities. Worked with elementary school teachers and students to explore, clean up, and restore creek and bay habitats, to reduce urban runoff pollution, address issues of water quality, and safe bay food consumption.	7/10/2004	$120,000	Complete.
ERP-02-P26	**Mill and Deer Creeks Protection and Stewardship** This project proposes to help address water quality and quantity, salmon habitat, and existing wildlife-friendly agriculture on Mill Creek and Deer Creek through conservation easements and active land stewardship.	12/31/2007	$4,700,000	Ongoing. Conservation easement on 23,459 acres protected (fenced) 1.6 miles, 387 acres of riparian.
ERP-96-M24	**Butte Creek Watershed Management Strategy** Created Butte Creek Watershed Management Strategy that provides specific implementation actions aimed at maintaining a sustainable river ecosystem while addressing the concerns of local stakeholders.	12/31/1998	$83,100	Complete. Mapping and environmental investigation for a Watershed Management Strategy.
ERP-97-N06	**Butte Creek Riparian Protection and Restoration Project** This project provides a portion of the funds for the acquisition of the McAmis Property, development of a management plan for the Ecological Preserve, and incorporation of the site into the Butte Creek Education Project.	12/31/2001	$187,128	Complete. Acquired 93.40 acres of riparian land to incorporate into the Butte Creek Education Project. Developed management plan for the Ecological Preserve.
ERP-97-N11	**Demonstration Project for the Protection and Enhancement of Delta In-Channel Islands** This project demonstrated effective biotechnical methods to reduce erosion of in-channel islands and adjacent delta island banks.	5/29/2000	$270,270	Complete. Provided organizational, administrative, pre-evaluation of sites, and permitting.
ERP-97-N13	**Tyler Island Levee Protection and Habitat Restoration Pilot Project** Evaluated alternative vegetative and biotechnical techniques for stabilizing bank erosion restoring levees, as well as riparian and shallow water habitat.	5/31/2002	$885,202	Complete. Georgiana Slough 0.85 miles and North Fork Mokelumne River 0.57 miles of biotechnical bank protection/creation of vegetation on top of riprap.
ERP-98-B10	**Cat Creek Watershed Project, Review of the Forest Road System for Repair, Relocation or Obliteration** Developed a watershed restoration plan to reduce erosion in the Cat Creek Watershed.	6/30/2000	$38,000	Complete. Developed and field-tested a method to prioritize forest roads for repair, re-location, closure or de-commissioning.
ERP-98-C09a	**Delta Dredging Reuse Strategy** Developed a Delta Dredging Reuse Strategy that includes an analysis of regulatory and technical issues related to contaminants in dredging projects and dredge material reuse.	6/30/2002	$24,000	Complete.

ERP-98-C09b	**Delta Dredging Reuse Strategy** Developed a Delta Dredge Reuse Strategy that includes analysis of regulatory and technical issues related to contaminants in dredging and dredge material reuse.	6/30/2002	$276,000	Complete.
ERP-98-C09c	**Delta Dredging Reuse Strategy** Developed a Delta Dredge Reuse Strategy that analyzes the regulatory and technical considerations of contaminants in dredging and dredge material reuse.	6/30/2002	$200,000	Complete.
ERP-98-C10	**Comprehensive Monitoring Assessment and Research Program - CMARP** Implementation of monitoring and applied research that provides data and information necessary to evaluate the performance of completed CALFED program actions and ongoing programs. An adaptive management strategy as a process for implementing proposed changes and ongoing activities to many aspects of the Bay-Delta environment and water management system. Provides information and scientific interpretations necessary for program implementation and to judge the Program's success. Provides information on all of the CALFED program elements and contributes to the mitigation design.	12/31/1999	$800,000	Complete.
ERP-98-E01	**Napa River Watershed Stewardship** This project builds upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/31/2000	$250,000	Complete. Watershed management stewardship to encourage long-term effective habitat management and developed a computer modeling and monitoring program.
ERP-98-E07	**Local Watershed Stewardship: Steelhead Trout Plan, Corte Madera Creek Watershed, Marin County, California** Developed a steelhead restoration plan for the Corte Madera Creek as part of a larger watershed management plan for the Corte Madera Creek watershed.	12/31/2000	$47,500	Complete. Developed a steelhead trout plan and identified the limiting factors of steelhead trout populations in the watershed.
ERP-98-E10	**South Yuba River Coordinated Watershed Management Plan** Facilitated broadbased local stakeholder group in development of watershed plan. The South Yuba River Coordinated Watershed Management Plan was developed for the 40 miles of South Yuba River between Spaulding and Englebright reservoirs.	5/30/2003	$264,000	Complete.
ERP-98-E12	**Lower Mokelumne River Watershed Stewardship Program (Phase I)** Facilitated broadbased local stakeholder group in development of watershed plan, develop Environmental Farm plan and expand Neotropical bird monitoring for the Mokelumne River Watershed.	9/1/2000	$159,000	Complete.
ERP-98-E14	**American River (North and Middle Forks) Integrated Watershed Plan and Stewardship Strategy** Developed a Watershed Management Plan and Stewardship Strategy to address a wide range of environmental, institutional, social, and economic issues for the watershed encompassing the North and Middle Forks of the American River.	12/31/2002	$220,750	Complete.

ERP-98-E16	**Lower Putah Creek Watershed Stewardship Program** Developed a community-based watershed stewardship program from the lower Putah Creek through a collaborative process involving stakeholders, landowners, state and federal resources agencies, and local groups.	3/31/2002	$100,500	Complete.
ERP-99-B21	**Estuary Action Challenge Environmental Education Project** Helped fund educational outreach activities for the Estuary Action Challenge (EAC) program, enabling the EAC to promote environmental awareness of habitat restoration, pollution prevention, and safe bay food consumption through implementation and continued support of several outreach programs in collaboration with area teachers and students.	9/30/2000	$50,000	Complete.
ERP-99-F04	**Part A: The McCormack-Williamson Tract Acquisition** Acquire the McCormack-Williamson Tract.	12/31/2004	$5,356,000	Complete. 1,512 acres acquired, multiple habitats (Delta EMZ)
ERP-99-N04	**Lake Red Bluff Riparian Area Restoration and Education Support Project** Restored 2 acres of riparian habitat in the Lake Red Bluff Riparian Area on the mainstem of the Sacramento River by removing invasive exotic plant species, reintroducing native species, and reducing erosion.	3/27/2003	$29,114	Complete.
ERP-99-N15	**Lower Mokelumne River Watershed Stewardship Plan Program (Phase II/III)** Completed preparation of the Lower Mokelumne River Watershed Stewardship Plan/Watershed Owner's Manual, Action Plan, and Monitoring and Evaluation Program and implemented the Initial Watershed Stewardship Actions.	6/30/2002	$227,000	Complete.
ERP-99-N20	**Napa River Watershed Stewardship Year 2** Built upon work in the Napa River watershed by continuing to address a broad range of ecological and biological issues relating to habitat restoration for anadromous fish and other priority species by promoting collaborative watershed stewardship.	12/30/2001	$191,100	Complete. Hydrologic modeling. Multiple habitats enhanced. Eroding bank stabilization, Himalayan blackberry eradication, riparian enhancement and revegetation, spawning habitat improvement (0.05 stream miles, 0.25 acres).

Other Programs Contributing to ERP Vision

Agencies charged with regulating human activities within their respective jurisdictions include the U.S. Coast Guard, California Department of Boating and Waterways, California Department of Parks and Recreation, local park districts such as the East Bay Municipal Parks District, local sheriffs in the affected counties, California Department of Fish and Game, California Department of Water Resources, and U.S. Fish and Wildlife Service.

Status of Topic Today

The Stage 1 expectations to identify critical areas and times necessary to protect completely species that are vulnerable to human-induced disturbance were not accomplished. ERP has not identified sites that can be developed for recreational and public uses. However, ERP projects have demonstrated that protection from boat wakes is important to the establishment and maintenance of shoreline vegetation as well as protection against further erosion of islands and marshes. Furthermore, projects such as the *Staten Island Acquisition* (**ERP-01-N23**) have protected critical areas from human-induced disturbance. Human-caused disturbance continues to adversely affect habitats and species. Shoreline erosion from boat wakes continues to impair ERP efforts to protect and restore shoreline vegetation and shallow water emergent vegetation, particularly in the Delta and along the mainstem Sacramento and San Joaquin Rivers.

Planned Projects for Implementation

No projects have been planned for implementation.

Impediments to Implementation

None.

References

CALFED (CALFED Bay-Delta Program). 2000a. Ecosystem Restoration Program Plan Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. CALFED, Final Programmatic EIS/EIR Technical Appendix. Sacramento, CA.

Hart, J., and J. Hunter. 2004. Restoring Slough and River Banks with Biotechnical Methods in the Sacramento-San Joaquin Delta. Ecological Restoration. 22(4): 262-268.