A novel way of managing water to protect fish:

a review of California's Environmental Water Account

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Abstract

The Sacramento-San Joaquin Delta, the tidal freshwater reach of the San Francisco Estuary, provides habitat for the threatened delta smelt, endangered winter-run Chinook salmon, and several other salmonid species or races of concern. It is also the location of huge freshwater export facilities that divert ~6 km^3 of water annually from the estuary, while entraining tens of millions of fish per year. We review the first four years of the Environmental Water Account (EWA), a cooperative, adaptive program instituted in 2000 to resolve conflicts between fish protection and water supply reliability. In EWA fishery agencies control a quantity of water to be used for fish protection. The intent is to resolve conflicts between regulatory actions taken to protect fish and exports of freshwater from the south Delta, at no cost to users of exported water. The fundamental assumption behind EWA is that relatively small but carefully timed and targeted reductions in water exports could reduce harmful effects of export pumping. We estimated the effectiveness of EWA during its first four years to be modest for winter-run Chinook salmon and delta smelt, at <1% increase in abundance. Optimally allocating EWA water results in larger gains in survival depending on the amount of water available. An optimally-allocated EWA of equal size to the median of the first 4 years could result in increases in abundance of delta smelt by as much as 5% in spring of dry years. The role of science in the EWA program has been shrinking as the program matures, and its role in a proposed long-term EWA is uncertain. The principal scientific issues for a long-term EWA are to refine estimates of efficacy and, if the program is to be held accountable for quantitative increases in fish populations, to integrate scientific, possibly experimental, approaches into long-term planning and operation.

Keywords: Environmental water, fish, endangered species, California Delta, management, salmon, delta smelt

Introduction

As human populations grow, conflicts sharpen between human consumption and maintenance of natural resources (Costanza and others 1997, Vitousek and others 1997, Sala and others 2000). Meeting human needs for fresh water while maintaining or rehabilitating aquatic resources is one of the greatest challenges now facing water and resource managers around the world (Postel 1996, Postel 2000, Jackson and others 2001). In the United States several strategies have been adopted to meet this challenge. Implementation of the Clean Water Act in 1972 improved water quality in numerous water bodies, restoring many ecosystem services such as recreation and fish habitat. Minimum instream flows have been determined and set to maintain and restore fish populations in regulated rivers and streams. In the southwest in particular, implementation of the Endangered Species Act (ESA) has led to changes in federal, state, and local water project operations and water management to limit adverse effects and to aid in the recovery of fish and other aquatic species. Finally, water resources have been reallocated through legislative mandate or other legal means to provide more water for maintenance or rehabilitation of aquatic resources (e.g., Mono Lake, SWRCB 1994). Key examples of this reallocation in the San Francisco Estuary and watershed are the Central Valley Project Improvement Act of 1992 (CVPIA, see USBR 2006a for details) and a recent agreement to restore river flows for salmon in the San Joaquin River below Friant Dam near Fresno while undertaking one of the West's largest river restoration efforts (see USBR 2006b for details).

Agricultural and urban development of the southwest has depended upon developing the region's water resources (Reisner 1986). In California the economy now relies on an extensive water storage and management system. The federal Central Valley Project (CVP) and California's State Water Project (SWP) store water in foothill reservoirs and divert (export) water from the Sacramento-San Joaquin Delta (Delta) to provide irrigation water for a multibillion-dollar agricultural economy in the Central Valley, and provide at least of part of the drinking water supply for over 20 million Californians in the San Francisco Bay Area, the Central Valley, and southern California. The water diversion facilities in the southern Delta, possibly the world's largest diversions from a tidal estuary, include elaborate "fish facilities" for separating fish from water and returning the fish to the estuary (Brown et al. 1996). The extensive California water management system, along with other land use and water use practices, have been associated with ecological degradation of native ecosystems. For example, in California's Central Valley and San Francisco Estuary several fish have been listed a threatened or endangered under the federal ESA (Table 1). Much of the concern over declining fish abundance has centered, rightly or wrongly, on the effects of water exports in the southern Delta.

Conflicts over water management in the San Francisco Estuary and its Central Valley watershed (Figures 1 and 2) eventually led to the implementation of the CALFED Bay-Delta Program in 2000 (hereinafter, CALFED, CALFED 2000a). The CALFED program includes an ambitious Ecosystem Restoration Program (ERP) intended to restore and improve the condition of the watershed and estuary for all native species, while reducing water management constraints (CALFED 2000a).

The CALFED Record of Decision (ROD) also provided for the establishment of an Environmental Water Account (EWA) with the following objective (CALFED 2000b):

"The EWA has been established to provide water for the protection and recovery of fish beyond water available through existing regulatory actions related to project operations. The EWA is a cooperative management program whose purpose is to provide protection to the fish of the Bay-Delta estuary through environmentally beneficial changes in SWP/CVP operations at no uncompensated water cost to the projects' water users."

Operation of the EWA was to be relatively straightforward. Water would be obtained from willing sellers or other means (e.g., relaxation of regulations or use of unallocated operational capacity) and stored until it was needed for fish protection. Biologists monitoring fish populations in Central Valley streams and rivers and in the Delta (including CVP and SWP water export facilities) could request this water be used for fish protection. Fish protection measures could include temporary reduction of export pumping in the south Delta. With the EWA in place, water project agencies and their contractors would thus not lose any water supply due to the requested fish protection actions.

The primary objective of this paper is to evaluate selected aspects of the EWA during its first four years (2001 through 2004), when it was implemented on a trial basis. Our focus is on the ecological aspects of the program, particularly on the magnitude of the benefits provided to the target fish species, but also on the approach used to evaluate the program and its consequences. We do not judge specific actions taken by the implementing agencies, which were often made under difficult circumstances. We do not evaluate the water acquisition program or its possible unintended consequences, nor do we comment on the EWA's economic costs or benefits. Finally, we do not address other programs using water for environmental purposes, although some are briefly discussed as context for EWA.

Our evaluation begins with summaries of the scope, context, and operation of the EWA during the trial period. We then estimate the population-level effects of EWA on endangered winter-run Chinook salmon (*Oncorhychus tshawytscha*) and threatened delta smelt (*Hypomesus transpacificus*). We selected these two species for analysis because they are of great management interest and recent research has provided much new information on their biology. Finally, we discuss these effects in terms of the EWA objectives, and evaluate the program in terms of its scientific content and effectiveness in meeting biological objectives.

Scope and Context of EWA

The San Francisco Estuary (Estuary), including the Delta, is the largest estuarine system on the west coast of North America, draining approximately 40% of the surface area of California. The Estuary and its watershed have been highly altered by human activities with consequent changes in physical and ecological processes (Conomos 1979; Cloern and Nichols 1985; Hollibaugh 1996) and native fish populations (Bennett and Moyle 1996; Moyle 2002). One consequence of these changes is that several native species of fish have been listed or considered for listing under state and federal endangered species legislation (Table 1).

The principal alterations to the freshwater portions of the system have been the extensive water projects of which the CVP and SWP are by far the largest. The CVP, operated by the U.S. Bureau of Reclamation (USBR), and the SWP, operated by the California Department of Water

Resources (DWR), include large export pumping facilities in the southern Delta (Figure 1). Fish salvage facilities associated with these export plants recover huge numbers of fish of a variety of species (Brown and others 1996). The facilities consist of behavioral barriers – louvers – that divert fish into holding tanks. The fish are then placed in tanker trucks for release in the estuary far from the influence of the pumps. Subsamples of the fish are taken periodically and fish larger than 20 mm are identified to species and counted.

Studies have associated export pumping with changes in hydrodynamics and losses of primary and secondary production (Arthur and others 1996; Brown and others 1996, Jassby and others 2002). However, recent studies have suggested that population-level effects of entrainment may be small for the introduced striped bass (Kimmerer and others 2000, 2001) and the native delta smelt (Bennett 2005). Declines in abundance of fish species probably have multiple causes, so it seems unrealistic to single out the effects of entrainment (Bennett and Moyle 1996). Nevertheless, it is broadly believed that export effects are an important factor in declines of fish populations in the Delta (Armor et al. 2005, 2006).

Although operations of the water projects are complicated, the basic idea is straightforward. When water is plentiful, the pumping plants meet immediate requirements and fill San Luis Reservoir, an off-stream storage reservoir south of the Delta (Figure 2). During dry periods, water is released from reservoirs into the Sacramento and San Joaquin Rivers to flow to the Delta where it is subsequently pumped southward. These exports are supplemented by water released from San Luis Reservoir. Although export pumping historically has been high in most months, restrictions to protect fish in the Delta have limited pumping rates, particularly from April to June.

Current concerns over export effects on fish focus on species listed under state or federal endangered species legislation, specifically winter-run and spring-run Chinook salmon (hereinafter, winter Chinook and spring Chinook), steelhead rainbow trout (*Oncorhynchus mykiss*, hereinafter, steelhead) and delta smelt. In addition, concern over the probable vulnerability of juvenile San Joaquin River fall-run Chinook salmon (hereinafter, fall Chinook) to export effects has led to protective measures in the Delta, some of which are discussed below. Juvenile salmonids, including steelhead, can be present in the Delta at any time but are most abundant in spring (Table 2). Most juvenile winter Chinook migrate to the ocean from January through March (Moyle 2002). Delta smelt are present as adults in late winter and as larvae and juveniles in spring (Table 2).

The conflict between fish protection required by endangered species legislation and the need for reliable water supplies reached a crisis in 1999, when high abundance of delta smelt at the fish facilities resulted in a large and unexpected curtailment of export flow. Concern over these and similar conflicts led to the 1994 Delta Accord and subsequent establishment of the CALFED Bay-Delta Program, including the EWA (CALFED 2000a). Although EWA water can be used upstream, its principal purpose, as implemented, has been to resolve the conflict between fish protection and water diversion at the Delta export pumps. The fundamental assumption behind this use of EWA is that relatively small but carefully targeted reductions in export flow could offset harmful effects of export pumping.

The agencies involved in EWA are divided into two groups, the fish Management Agencies or MAs (USFWS, NMFS, DFG) and the water Project Agencies or PAs (USBR and DWR). The

Operating Principles Agreement (CALFED 2000b), assigned the MAs to "manage the EWA assets and exercise their biological judgment to identify operational changes beneficial to the Bay-Delta ecosystem or the long-term survival of fish species, including those listed under the State and Federal endangered species acts". The PAs were charged to "cooperate with the MAs in administering the EWA… and mak(e) the operational changes proposed by the MAs".

The EWA is intended to provide fish protection beyond that available through existing standards and regulations (as of 2000). Three tiers of protection described in the Record of Decision (CALFED 2000a) are:

- Tier 1: baseline water, provided by existing regulations and operations. The regulatory baseline consists of the biological opinions on winter-run and spring-run Chinook salmon, steelhead and delta smelt, the 1995 Delta Water Quality Control Plan, and 800 thousand acre feet (TAF) of CVP Yield prescribed by the Central Valley Project Improvement Act, Section 3406(b)(2).

- Tier 2: EWA combined with the benefits of the Ecosystem Restoration Program. Tier 1 and Tier 2 comprise, in effect, a water budget for the environment.

Tier 3: the CALFED Agencies may make additional water available if needed for protecting species under the Endangered Species Act (ESA). Tier 3 is seen as an emergency measure. It has not been invoked yet, although preliminary steps were taken in spring 2006 because of concerns over the low abundance of delta smelt.

The practical objectives of the EWA were stated more directly in the EWA Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (EWA Agencies 2004). While acknowledging the original objectives discussed above, the EIS/EIR describes the EWA as having two primary elements: assisting in fish population recovery for at-risk native fish species; and increasing water supply reliability by reducing uncertainty associated with fish recovery actions.

In addition, to be successful EWA must:

1. Protect at-risk species affected by SWP/CVP operations and facilities
2. Contribute to the recovery of these species
3. Allow timely water-management responses to changing environmental conditions and changing needs for fish protection
4. Provide reliable water supplies to water users in SWP/CVP export areas
5. Cause no uncompensated water loss to users.

Several aspects of Tier 1 and 2 deserve special mention. The CVPIA Section 3406(b)(2) identifies 800,000 acre-feet (referred to as "b2" water) for implementing the fish, wildlife, and habitat restoration measures authorized by the CVPIA, assisting state efforts to protect the Estuary, and to help meet the Central Valley Project's state and federal legal obligations. This means that b2 water is typically used in conjunction with EWA actions at the CVP. The CALFED Environmental Water Program is intended to use water for environmental purposes upstream of the Delta, but is still in planning stages. Water released upstream can be pumped and stored for EWA uses when it reaches the Delta. The Vernalis Adaptive Management Plan (VAMP) (SJRGA 2006) has been developed to protect juvenile Chinook salmon emigrating from the San Joaquin River through the Delta, while experimentally determining how survival of juvenile Chinook salmon responds to San Joaquin River flow and export flow.

In the context of EWA, the major action taken by VAMP is an increase in San Joaquin River flow and reduction in export flow extending over one month, generally around 15 April to 15 May. Although VAMP is usually operated with b2 water, EWA may provide some export curtailments for VAMP, and may make additional water available to extend export curtailments before or after the VAMP period.

Implementing the EWA

In principle, EWA operation is straightforward. The PAs obtain water in several ways. The EWA is given a monetary budget for the purchase of water from willing sellers. There are also several operational tools that can be used to make additional water available to EWA (Table 3). For example, environmental standards on project operations may be relaxed during seasons that the MAs deem safe, allowing for increased export flow, with the additional water stored in San Luis Reservoir to support later export curtailments for EWA. The MAs use monitoring data, scientific understanding, and professional judgment to select "fish actions," that they believe will help to protect fish. The PAs then implement those actions using EWA water. Since the water has been purchased from willing sellers or obtained by the use of operational tools, there has been no uncompensated loss to water users. Furthermore, the agreements underlying the CALFED Record of Decision ensure compliance with endangered species regulations, so there is little prospect that water supplies will be disrupted by unanticipated hazards to fish.

Actual implementation was not so simple. Each water year (from October 1 through the end of June the following year) the MAs had a tentative water budget and the flexibility to use EWA water and other tools however they believed best for the resources. In doing so, the MAs accepted some risk, in that needs for environmental water are never clear at the beginning of the year, and can only be evaluated in retrospect. Using water early in the year precludes its use later, but waiting to use the water may result in lost opportunities. Furthermore, although most of the EWA water has been used to reduce export pumping during key periods, upstream uses were also possible (e.g., reservoir releases to protect spawning habitat from dewatering), and these upstream uses competed somewhat with uses in the Delta. Thus, actual implementation of the EWA was an adaptive process that relied on judgment as well as scientific principles. This judgment came increasingly into play as the adverse impacts of relaxation of the environmental standards became apparent, for example for adult delta smelt in winter when most of these relaxation events occurred.

To help with their decisions for using EWA water, the MA biologists developed decision tools based on available data. For winter Chinook, the number of out-migrating juveniles could be estimated from adult return data from the previous spring (numbers, sex ratio, fecundity) and trapping of downstream migrants in the Sacramento River. Therefore a decision process was developed to help ensure that no more than 2% of the young salmon would be lost at the CVP and SWP intakes. The progress of downstream movement was monitored in the river, as was the daily loss of juveniles at the project intakes. Juveniles were identified as potentially winter Chinook based on length-at-date criteria (modified from Fisher 1992), since they cannot be definitively identified without genetic analysis. The decision process also includes actions to protect spring Chinook yearlings based on the use of hatchery late-fall Chinook salmon as surrogates. The combination of data sources and a decision process allowed the agency biologists to target specific periods for using EWA water to protect winter Chinook. For other salmonids (principally spring Chinook and steelhead) this process was made more difficult by their varied life history and protracted migration period.

Delta smelt were not managed in the same way because knowledge of adult abundance, and quantitative links among life stages, is weaker, and movement patterns difficult to predict. In addition, larval delta smelt are not salvaged at all and juvenile delta smelt are not salvaged effectively at the fish facilities, so decisions had to be made on the basis of raw numbers of juvenile delta smelt salvaged, with no mechanism for converting these numbers to total number of fish lost or to estimate population-level impact. Agency biologists established a risk-assessment matrix for delta smelt based on temperature, salvage at the fish facilities, and catch in several Delta sampling programs (USFWS 2006a). Temperature is useful as a predictor of spawning date (Bennett 2005).

The process for making decisions and implementing actions was also fairly complex. The Data Assessment Team (DAT) and the Delta Smelt Working Group (DSWG) met as often as weekly to examine available data and develop recommendations for actions. The five participating agencies met twice weekly, once at staff level through a team called the Environmental Water Account Team (EWAT) and once at management level as a group called the Water Operations Management Team (WOMT), to discuss the program and decide on program actions. Both of these teams comprise members from the five participating agencies. EWA activities are coordinated with the CVPIA b2 Interagency Team, and are an integral part of the annual operating plan for the CVP and SWP. This coordination was necessary to make sure that all the elements of Tier 1 and Tier 2 were working together.

The total water available to EWA was relatively constant for the first 3 years at about 350,000 acre feet, but declined to 106,000 acre feet in year 4 (Table 4). Costs of obtaining water also varied among years. The operational tools never produced as much water as expected (compare Tables 3 and 4) During the first four years of EWA, actions evolved in response to experience and perceived benefits. Several actions were taken specifically for salmon in 2001, the first year of EWA (Table 4); however, subsequent actions were intended to benefit both delta smelt and Chinook salmon (Table 4). In the final 3 years of the test period, most EWA water was expended in association with VAMP, and all expenditures were associated with VAMP in 2004 (Table 4). A significant proportion of water was expended in the 2 weeks after VAMP to improve habitat and afford delta smelt larvae the opportunity to move north and west toward rearing areas in Suisun Bay, Suisun Marsh, and the lower Sacramento River (Poage 2004). The assumption behind the expenditure of EWA water for this post-VAMP "shoulder" is that, should the CVP and SWP resume full export capability immediately following VAMP, planktonic delta smelt larvae in the south Delta would suffer very high entrainment losses in many years (Poage 2004). As this assumption emphasizes, in implementing the EWA the agency biologists focused on reducing the number of delta smelt entrained at the water project intakes, although benefits to Chinook salmon were also expected.

Science Within the EWA

The Record of Decision did not prescribe the place of science in the EWA, and defined the role of the CALFED Science Program as convening an annual scientific review of the EWA. No money was earmarked for scientific activities as part of the EWA program. Nevertheless, leadership for EWA science fell to the CALFED Science Program, which established the annual review panels, sponsored the reviews, and held annual workshops

During the first 4 years, the annual review required by the Record of Decision was performed by a standing review panel of outside experts on fishery science, fish ecology, economics, engineering, and social science. Topics of these reviews varied widely, but in later years emphasized the question of demonstrating the benefits of EWA to fish populations (EWA Review Panel 2001, 2002, 2003, 2004). The Review Panel provided observations on both positive and negative aspects of program performance. The Review Panel was especially helpful in identifying scientific weaknesses in EWA (Table 5), stimulating EWA scientists and others to focus on the highest-priority issues to improve the scientific underpinnings and ultimately the performance of the EWA. The CALFED Science Program, MAs, and PAs were straightforward in acknowledging the importance of the issues and made considerable efforts to address the issues identified by the review panel (Luoma 2002, White et al. 2002, 2003).

The role of science was clarified as the 4-year trial EWA proceeded. The CALFED Lead Scientist appointed 2 scientific advisors (WK and RB) with an initial charge to be familiar with the day-to-day workings of the EWA, work closely with the MAs and PAs, and keep the Lead Scientist apprised of developing issues. The advisors were also asked to facilitate communication among CALFED Science Program staff, academic scientists, agency scientists, agency managers, and stakeholders. To accomplish this the advisors worked with CALFED and agency staff to hold and report on annual workshops on biology (Brown and Kimmerer 2001a) and effects of EWA on salmonids (Brown and Kimmerer 2001b, 2002a, 2003) and delta smelt (Brown and Kimmerer 2001c, 2002b, Kimmerer and Brown 2003). These workshops facilitated the exchange of information and helped prepare the community for the annual external review. However, as the program matured during the trial period, the role of science in daily operations of EWA shrank, and the advisors became less involved in daily activities of EWA.

Likely effects of EWA on fish populations

To the extent that the EWA is meant to contribute to recovery of listed species, it would be helpful to quantify these effects. We focus on the uses of EWA water to reduce export losses to winter Chinook and delta smelt in the Delta. The actual reductions in volume exported are rather modest in relation to total monthly export volumes (Figure 3). The intent for operation of EWA was to apply the water in a tightly targeted way to protect fish for a relatively small water cost. Most of the export reductions have been concentrated in April-May, although early in the program EWA water was used in January – April (Figure 3). The shift in timing of EWA use reflects a shift away from protection of winter Chinook toward delta smelt and other salmon races (spring and fall Chinook migrate through the delta in April-June). Also notable in Figure 3 is the large reduction in export pumping under VAMP (SJRGA 2005), and the additional export curtailment before and after VAMP using EWA water.

We examine the effects of EWA for two scenarios of water use: application of EWA water according to the historical pattern, and application of all EWA water for a particular species/life stage. In the latter case we assume that various quantities of EWA water are applied by reducing export flows by a constant amount during a two-month period, from several alternative values of the base export flow up to the historical maximum.

These calculations are based on estimates of the effects of export losses on winter Chinook and adult and larval/juvenile delta smelt (Appendix). Export losses were determined as a function of export flows and, for larval/juvenile delta smelt, also related to freshwater inflow to the Delta. Scenarios of export loss were developed for the historical pattern of EWA water use (Figure 3) by restoring export flow to where it would have been without the EWA reduction, recalculating survival, and comparing this with the values determined with EWA reductions. Hypothetical scenarios were also developed for various alternative magnitudes of EWA up to 1.2 km^3 (1 million acre feet), by first setting up a base case of constant, high export flow (347 $m^3 s^{-1}$ or 12,250 cfs), then reducing it by the amount of flow that would be available if EWA were spread over a 60-day period. The general approach was to compare survival with and without the selected EWA export reduction; for young delta smelt we also had to account for natural mortality (see Appendix). We did not consider the effects changing export flow on either inflow or outflow from the Delta, which is small under most conditions.

All of these calculations refer to direct losses only. If there actually are indirect losses, i.e., losses that occur elsewhere in the Delta attributable to export pumping, these would be in addition to the direct losses. Indirect losses have not been estimated, nor has a method been developed to estimate them.

Winter Chinook Losses to export pumping were estimated for Chinook smolts migrating through the Delta (see Appendix). We used data on recaptures of coded-wire-tagged smolts released at two hatcheries in the upper Sacramento Basin and recovered either at the fish facilities or a trawl survey at Chipps Island (Figure 1). Fractional losses were related to export flow, and this relationship was used to calculate EWA effects assuming the flow reduction occurred around the peak of migration. This seemed reasonable since it should be possible to anticipate that peak using available monitoring data. The reduction in loss due to EWA was calculated as the difference between survival with full export flow and survival with export flow reduced by EWA.

The actual EWA expenditures of water during January- March (Figure 3) resulted in monthly reductions in estimated export losses ranging from 0 to 0.5%, with a median of 0.005% for all data, and 0.25% for all months in which EWA water was used during winter Chinook migration. The gain in survival due to hypothetical magnitudes of EWA used entirely for salmon was modest for EWA magnitudes up to those used in the first 4 years (Table 6). The effectiveness of EWA increases as the base export volume increases because of the nonlinear relationship of export flow to percent losses.

Adult delta smelt Losses to export pumping were calculated for 2002 – 2005 as described in the Appendix. Briefly, losses were calculated from salvage data and population size was estimated using data from the Kodiak trawl survey. These two data sets were intercalibrated using limited data from the Kodiak trawl in the south Delta. Losses were related to net flow in lower Old and Middle Rivers (Figure 1) which flow southward (negative) when export flow is high and flow in the San Joaquin River is low. Net flow in Old and Middle Rivers has been determined daily (with some gaps filled by regression) since 1987 by the U.S. Geological Survey (Ruhl et al. 2005). For adult and young delta smelt we ignored dispersive transport.

The estimated effects of EWA actions were calculated by assuming that the number of fish per unit volume did not change as Old and Middle River flow changed, and that on any given date a reduction in export flow produced a corresponding increase in the (northward) flow in Old and Middle Rivers. The percentage increase in survival was calculated from survival for each scenario determined as in the Appendix:

$$S_{mo} = \prod_{mo} \left(1 - \frac{F_d \dfrac{Q_{SDi}}{Q_{SDb}}}{A_{mo}} \right) \quad (1)$$

where S_{mo} is the survival for a month, F_d is the daily fish flux to the export facilities, A_{mo} the monthly estimate of population size, Q_{SDi} is the south Delta flow in Old and Middle Rivers adjusted by the selected reduction in export flow, and Q_{SDb} is the base flow. For the historic analysis Q_{SDi} is the actual flow and Q_{SDb} is the actual flow with the EWA flow added.

The effect of EWA on survival of adult delta smelt for the four years of available data was small (Table 7), mainly because EWA was not used much during winter in these years. Using all EWA water with a nominal allocation of 300 TAF (0.4 km^3) during a 2-month period centered on mid-January gave increases in survival between 0.6 and 2.1% (Table 7). The maximum EWA allocation resulted in a 2-7% improvement in survival (Table 7). These values would be ~40% higher (e.g., 2.8 to 10% improvement in survival for 10^6 AF) with the single free parameter at its upper 95% confidence limit.

Juvenile delta smelt The basic calculation used abundance from the 20mm survey of young fish, which took an adequate sample in the southern Delta that could be used to estimate losses without the need to correct for different gear efficiencies. Calculation of losses of young delta smelt was complicated by the extended hatch period (~60 days), the low efficiency of the net for newly-hatched fish, and the need to take natural mortality into account (Appendix). Losses due to export entrainment were placed together with natural mortality in a survival equation similar to equation (1) above, and the contribution of export entrainment was determined from the ratio of survival with and without entrainment losses. Similar scenarios to those done for adult smelt were run using these data.

The effect of EWA on young delta smelt was larger than that for adult smelt, for two reasons (Table 8, Figure 4). First, a greater proportion of juvenile smelt is lost to export pumping (see Appendix). Second, the base export flow during March – May when young smelt are in the southern Delta is reduced because of VAMP, so additional reductions due to EWA are proportionately larger and more effective. Similar hypothetical EWA magnitudes gave correspondingly larger improvements in survival than for the adults (Table 8).

Discussion

The four-year trial EWA was an innovative program from several perspectives. It involved the purchase of water on the open market by a government agency. It allowed for the use of that water for environmental purposes. It provided flexibility in application of environmental regulations (i.e., flow requirements). It was responsive to new information regarding the best use of water for fish protection. It also included a substantial degree of review and scrutiny. As an experiment in management and organization, EWA demonstrated that a rather complex consortium of agencies can work together to effect change.

Has EWA achieved its objectives, and could it be modified to achieve them more effectively? We consider the five characteristics of the EWA from the EIS/EIR in a somewhat different order reflecting mainly the difficulty of achieving them. First, it appears that elements 4 (reliable water supplies) and 5 (no water loss to users) were achieved during the trial period. (CBDA 2004). The water was purchased on the open market or obtained through operational flexibility and relaxation of regulations and applied in most cases to protect fish. No uncompensated export curtailments were mandated by the MAs, indicating that at least from a reliability perspective the EWA has reduced uncertainty as intended.

Element 3 (timely responses) was also achieved. The organization established to decide on EWA actions has been remarkably effective. Decisions were made rapidly through a consensus process, involving many agencies with different missions.

Element 1 (protect at-risk species) arguably has also been achieved. Since EWA water has been used mostly to reduce entrainment in the south Delta, and reducing export flow almost certainly reduces entrainment, the result has been fewer fish killed at the export facilities. Some have argued that fish not entrained because of reduced export flow may enter the export facilities when pumping is resumed. However, this would require that the concentration of fish per unit volume somehow increase during the period of curtailed exports, which does not seem possible.

The central question about the effectiveness of EWA, though, hinges on element 2: EWA is supposed to contribute to recovery of at-risk species. Presumably this means that EWA should contribute materially and substantially; if so, our calculations show that EWA has a mixed record of achieving this objective. We showed EWA actions to protect winter Chinook probably had very small effects. To put these effects in perspective, the cohort replacement rate of winter Chinook for the last 10 years has been about 148% (Kimmerer and Brown in prep.). EWA could achieve an additional increment to the cohort replacement rate of <1%. We suggest that this is not a substantial contribution to recovery. Timing of spring Chinook migration is much more spread out and identification much less certain than for winter Chinook because of the size overlap with the much larger fall Chinook (Williams in press). Therefore, although using EWA water during the spring Chinook migration would reduce mortality as calculated above for winter Chinook, we expect the improvement at the population level would be even less than for winter Chinook. The contribution of EWA to VAMP, intended to improve survival of emigrating San

Joaquin fall Chinook smolts, could have a substantial impact, with ancillary benefits to delta smelt.

EWA actions to protect delta smelt have occurred in every month from January to June (Poage 2005). We showed above that the effect of export pumping on adult smelt is probably small, and that on young fish is maximum in mid-March to late April. This suggests that the post-VAMP period of curtailment of exports likely did not make a large contribution toward recovering the population. The relatively small amount of EWA water used from mid-March to late April was likely effective for delta smelt, but the effect on the population was modest, based on our analysis.

EWA actions in the Delta may have other effects than those due to reduced entrainment. Export pumping may alter hydrodynamic conditions in ways that could have what are termed "indirect" effects on fish. These would include effects such as increased exposure to predators or contaminants if fish are diverted from the fastest migration routes, or effects acting through the foodweb. However, the actual magnitude of the flow changes due to EWA are rather modest and their temporal extent is limited (Figure 3). Furthermore, these indirect effects are likely difficult to measure, and are not supported by data. For example, substantial losses of phytoplankton to export pumping determined by mass balance had no measurable effect on temporal variability in phytoplankton biomass, which is largely governed by other factors (Jassby et al. 2002). Until some theory or evidence is developed to provide support for indirect effects, we believe they should not be included among the ancillary benefits claimed for EWA.

If EWA were to be applied under the most optimal conditions, it could have substantial population-level effects on delta smelt in the spring, moderate effects on adult delta smelt in late winter, and mostly small effects on winter Chinook (Tables 6 - 8). The effects on young delta smelt would accrue only during dry springs. Furthermore, these effects last only until summer, after which highly variable survival (> 10-fold among years) between summer and fall obscures the signal due to spring survival. The prospect of density-dependent survival during this period (Bennett 2005) has probably vanished because of low population size, implying that fall abundance is affected by both summer abundance (and therefore spring survival) and summer-fall survival which is unrelated to abundance. Whether realized gains in abundance of any of the species or life stages are a sufficient contribution to recovery to justify the expenditure is beyond our scope.

Singling out EWA for intense scrutiny may seem unbalanced, in that other programs within CALFED and other organizations do not undergo annual reviews or any external scientific oversight. Even large programs such as VAMP and the Anadromous Fish Restoration Program (US Fish and Wildlife Service) have not been reviewed and critiqued to the same extent as EWA. The Ecosystem Restoration Program no longer has an external scientific review board, although CALFED as a whole does. We assert that the lack of scientific scrutiny applied to other programs is not a reason to withhold this scrutiny from EWA. Rather, an intense examination of the underpinnings and the degree of success of EWA should set an example for how large-scale restoration and management programs should be operated.

From the beginning the EWA program has been identified as a science-based program; however, there is a clear lack of funding to improve the scientific basis for EWA mentioned in the Record of Decision and other documents. Nevertheless, the CALFED Science Program has gone to great lengths to apply some elements of a scientific approach to the first four years of the program. The most important element has been peer review, achieved principally through the annual review panels. These panels and the work they engendered in the agencies, both during preparation for the reviews and in response to review comments, have led to significant improvements in how the EWA has been operated. However, the comments of the review panel showed frustration at the slow progress in addressing needs for new research to provide scientific information the panel viewed as critical to EWA science. The agencies whose biologists worked on EWA issues did not provide sufficient resources to address all the science-related EWA issues. The review panel suggested hiring outside experts, post-doctoral associates, and students as a way to circumvent some of these problems, and expressed puzzlement regarding the failure to apply such mechanisms (EWA Review Panel 2003).

It is important to realize that the EWA has no requirement to follow the suggestions of the review panel or of the CALFED Science Program. The Science Program has operated outside of the EWA program, depending on the considerable cooperation of the agency staff and inputs from stakeholders to facilitate the reviews and improve how EWA was operated. The science advisors (WK and RB) played a role in this interaction between EWA, the EWA review Panel, and the Science program. However, disagreements arose between the advisors and some agency personnel about the role of science in EWA. Furthermore, as the program matured it became more routine and the opportunities and need for scientific input diminished; therefore, the Science Program has become less involved in EWA. In a way, this article reflects the fact that scientific scrutiny has shifted from operations to the overall goals and efficacy of EWA in helping to support biological populations.

In spite of the scientific activities within the EWA program, we do not consider the EWA to be fundamentally based on science. Rather, it is based on mostly poorly-defined conceptual models of how export flow affects fish. Although the models have evolved over time, there has been no attempt to test or verify them. There has been little effort to compute the magnitude of the benefits of EWA either alone or in the context of other restoration efforts (e.g., VAMP, CVPIA). Furthermore, there has been almost no interest in placing the EWA in a larger context such as biological populations, or in considering upstream actions that could provide a greater population-level benefit than the actions that have been taken. Thus, in spite of its emphasis on flexibility and response to events, the EWA has evolved into a management system with the fairly static goal of limiting entrainment at the export pumps.

The first four years of EWA have generally been viewed as a success in that the program has functioned successfully as a multi-agency collaboration, conflicts among stakeholders have been reduced, and fish have been saved through reductions in entrainment. The quantity and quality of work accomplished by all involved in the EWA, from agency staff to the Review Panel, is impressive. However, without some fundamental changes in staffing and funding it seems unlikely that an extended EWA will have any improved success at establishing a rigorous scientific basis for documentation of population-level or ecosystem benefits. Scientific advances supporting EWA have principally been made through funding and studies not specifically targeted at EWA. A recent proposal solicitation by the CALFED Science Program included a request for work related to EWA, but EWA was only one of four priority topic areas. There is no guarantee that EWA research will be selected for funding or address the priority questions within EWA as part of this or future solicitations. It seems unlikely that research efforts will focus on topics relevant to EWA without dedicated funding.

A call for Adaptive Management has become a common response to managing with uncertainty. We suggest that the current operation of the EWA is an example of managing adaptively, meaning that management is flexible in the face of variability. Adaptive Management, as defined by Holling (1978) and Walters (1986) and discussed in an extensive literature, is a very different approach in which all actions are seen as scientific experiments. Operating the EWA as an Adaptive Management program would be difficult: the export manipulations are modest compared with other flows, and the immediate responses have low signal-to-noise ratios. The greatest impediment, though, may be the lack of willingness to experiment with the system. This resistance arises because of the emphasis of the ESA on take rather than population recovery, but it also implies that the actions currently being taken are known to be effective in protecting and enhancing the populations, which is clearly not true.

EWA will not become a science-based program, nor will it be in a position to apply Adaptive Management, unless science is incorporated in the guiding documents and becomes an integral, funded part of the program. Are there advantages to EWA to incorporating science more fully? That depends on the development of the long-term version of EWA. If it is clearly designed only to reduce entrainment at the export facilities, then the current, low level of scientific activity is commensurate with the scientific content of the program. However, if EWA is actually meant to be held accountable for quantitative improvements in fish populations, then there seems to be no other choice than to incorporate science fully and thoroughly in the program. This would require that the weaknesses and uncertainties in the current conceptual models, including those presented here, be made explicit and available for testing.

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Table 1. Species of concern in the Sacramento-San Joaquin Delta listed or proposed for listing under State and Federal endangered species acts (from USFWS 2006, NOAA 2006, Moyle 2002).

Common name	Scientific name	Federal status [1]	State status [2]
Chinook salmon	*Oncorhynchus tshawytscha*		
Winter run		E	E
Spring run		T	T
Fall and late fall run		C	--
Steelhead rainbow trout	*Oncorhynchus mykiss* [3]	T	T
Delta smelt	*Hypomesus transpacificus*	T [4]	T
Sacramento splittail	*Pogonichthys macrolepidotus*	DL	SSC
Green sturgeon	*Acipenser medirostris*	T	--
Longfin smelt	*Spirinchus thaleichthys*	NW	SSC
Pacific lamprey	*Lampetra tridentata*	NW	--
River lamprey	*Lampetra ayersii*	NW	--

[1] E, endangered; T, threatened; PT, proposed for threatened status, C, candidate; NW, species was proposed for listing but listing was found to be not warranted; DL, delisted; ND, petition has been submitted but no decision.

[2] E, endangered; T, threatened; C, candidate; SSC, species of special concern; --, no special status.

[3] Central Valley ESU

[4] Delta smelt is currently being considered for status as endangered.

Table 2. Months when vulnerable lifestages [1] of species of concern may be present in the Sacramento-San Joaquin Delta (from Brown and Kimmerer 2001a, Moyle 2002).

	Month											
Common name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinook salmon												
Winter run	S	S	S									
Spring run [2]	S, F	S, F	S, F									
Fall and late fall run	F	F	F	S	S	S						
Late fall run												
Steelhead rainbow trout	S	S	S	S	S							S
Delta smelt	A	A	A, J	A, J	A, J	J	J					A
Sacramento splittail				J	J	J	J	J				

[1] F, fry; S, smolt; J, juvenile; A, adult

[2] These time periods are approximate for all fishes, but the life cycle of spring-run Chinook salmon is particularly complex. Smolts represent yearling fish emigrating as smolts. Fry represent young-of-year fish emigration the same year of adult spawning.

Table 3. EWA operational assets expected according to the Record of Decision (modified from CBDA 2004).

Operational Asset	CALFED ROD (average in TAF)
Half of (b)(2)/ERP releases pumped by SWP in the Delta	40
Variation of E/I ratio [1]	30
500 cfs dedicated capacity at SWP Banks pumping plant	(50) [2] (Capacity only)
Joint Point of diversion (the use of excess capacity at SWP Banks pumping plant	75 [3] (pumping excess water in Delta)
ROD Total	195

[1] E/I represents the ratio of exports to inflows. The MAs may request relaxation of regulatory limits on the E/I ratio to pump additional water for storage as EWA assets.

[2] Capacity: represents a quantity expected to be moved using dedicated 500 cfs at SWP Banks pumping plant from the summer-time capability above the 6,680 cfs that is provided in the U.S Army Corps of Engineers permit, which is valid through the 2004 transfer season. This tool is used to transfer water purchased upstream of the Delta and, unlike the other tools, does not constitute an additional source of water for the EWA except possibly under the very wettest Delta conditions with high Delta flows in the summer.

[3] Capacity: represents one-half of the available excess capacity at the SWP Banks pumping plant. Under balanced conditions, this tool provides only pumping capacity and the EWA must supply water it has either purchased or stored upstream to take advantage of this EWA tool. In normal and wet years, if SWP Article 21 demand is satisfied, this tool can result in the EWA being able to obtain Delta water during excess conditions provided that EWA has either an existing debt in San Luis Reservoir to repay or a location other than San Luis Reservoir, where it can be stored.

Table 4. EWA accounting and water cost in water years 2001-2004 (adapted from DWR 2005).

	2001	2002	2003	2004
EWA water acquired (TAF)				
Water Purchases				
Sources upstream of Delta	105	142	70	119
Sources in export area	231	98	145	35
Total purchases	336	240	215	154
Operational water	48	83	91	0
Losses [a]	-17	-51	-16	-48 [b]
Total net water acquired	367	272	290	106
Water carried over from prior year	0	77	58	0
Total water available	367	240	215	154
EWA asset costs (in millions)				
State	$54.4	$17.8	$30.1	$19.6
Federal	$10.0 [c]	$11.5	$0	$0
Total cost	$64.4	$29.3	$30.1	$19.6
EWA asset use				
SWP/CVP pumping reductions for fish actions				
Chinook salmon and steelhead	86	0	0	0
Salmonids and delta smelt	137	67	121	0
Vernalis Adaptive Management Program (VAMP)	43	45	32	19
Post-VAMP period: delta smelt and Chinook salmon	24	137	195	104
Total SWP/CVP pumping reductions for fish actions	290	249	348	123

Pumping reductions converting EWA water to project water in San Luis Reservoir [d]	0	38	0	0
Total EWA asset use	290	291	348	124

[a] Includes carriage water losses associated with EWA transfers through the Delta, conveyance loss to Delta from San Joaquin River tributary sources, and water lost when spilled from a storage facility due to relatively low priority for EWA water.

[b] Based on assumed carriage losses and operational losses in2004. Of these losses, 19 TAF represents late season releases to the American River to provide habitat enhancement for Chinook salmon (benefit to be shown in 2005). The releases could not be pumped in the Delta.

[c] Amount paid for water by the U.S. Bureau of Reclamation for CVP purposes and subsequently provided to EWA.

[d] This is an operational tool by which EWA water stored in San Luis Reservoir is transferred to the water projects in exchange for pumping reductions.

Table 5. A brief summary of major scientific issues identified by the EWA review panel during the 4-year trial period of EWA (EWA review panel 2001, 2002, 2003, 2004).

2001 EWA review panel

- Additional personnel and research dollars dedicated to EWA research tasks
- General science recommendations
  - assemble a salmonid data base
  - fill in gaps in knowledge of delta smelt biology
  - evaluate existing monitoring data
  - analyze risk and re-allocation of Tier 3 water
  - set aside water for experiments
  - develop models of Delta processes
  - quantify losses of delta smelt
  - improve understanding of entrainment events
  - improve the decision making process (decision trees)

2002 EWA review panel

- Science challenges for EWA
  - determining the combinations of physical conditions that give rise to entrainment events
  - determining the growth and mortality rates, habitat use, and movement patterns of juvenile Chinook salmon in the Delta
  - developing a quantitative synthesis of the life cycle of delta smelt and Chinook salmon
  - determining the magnitude of predation in Clifton Court For4ebay
  - optimizing Delta Cross Channel operations
  - identifying reservoir management strategies that improve the availability of cold water for instream habitat enhancement

2003 EWA review panel

- Most comments from 2002 still relevant
- Lack of progress in addressing critical science needs
- Need to manage long-term opportunities and risks
- Continue annual science reviews
- More effective incorporation of science into the policy and regulatory measures that form the context for EWA implementation
- Increased mobilization of resources to address critical science needs.

2004 EWA review panel

- Consider the biological consequences of water purchases
- Need for credible evidence of success in protecting and restoring threatened and endangered fish species
- Include more biological information and treat uncertainty explicitly in gaming exercises
- Develop population models to help in understanding the impacts of entrainment
- Link a delta smelt population model to a water management model (e.g., CALSIM) to better predict changes to management and environmental changes
- Develop a mechanistic foundation that characterizes the diversion and movement of juvenile salmon into the inner Delta, where they experience increased mortality relative to migration through the mainstem of the river, to improve models describing the effects of EWA actions on salmon survival
- Modeling must include stochasticity in forcing variables and responses
- All models should be clearly described and peer reviewed
- Panel frustrated with lack of progress toward new research to provide needed scientific information
- Continue the review process with some improvements

Table 6. Calculated percentage increase in winter Chinook emigration from the Delta under various scenarios of base export volume and size of EWA. The entire year's EWA allocation is assumed to be used over 2 months centered on the anticipated migration time of winter Chinook.

	Base Monthly Export Volume, TAF					
EWA, TAF	**300**	**400**	**500**	**600**	**700**	**800**
100	0.1	0.2	0.2	0.3	0.5	0.7
200	0.3	0.3	0.4	0.6	0.9	1.3
300	0.4	0.5	0.7	0.9	1.4	2.0
400	0.5	0.7	0.9	1.3	1.8	2.7
500	0.7	0.8	1.1	1.6	2.3	3.4
600	0.8	1.0	1.3	1.9	2.7	4.0
800		1.3	1.8	2.5	3.6	5.4
1000			2.2	3.1	4.5	6.7

Table 7. Increase in percent survival for historical EWA and various projected values of EWA. All values are for the base value of Φ (Appendix); using the upper 95% confidence limit of Φ increases these values by ~40%. Projected values of EWA assume a start date of 15 December which gave the highest improvement over the base case.

		Magnitude of EWA, TAF						
Year	Historic	100	200	300	400	600	800	1000
2002	0.2	0.3	0.7	1.0	1.3	2.0	2.7	3.4
2003	0.6	0.7	1.4	2.1	2.8	4.3	5.8	7.3
2004	<0.01	0.2	0.4	0.6	0.8	1.2	0.6	2.0
2005	0.03	0.2	0.4	0.6	0.8	1.3	1.7	2.1

Table 8. Young delta smelt in the 20mm survey. Increase in percent survival for historical EWA and various projected values of EWA. Values assume a fixed natural mortality of 0.023 d^{-1}, the mean of the calculated values. Base losses are for a constant export flow of 30 $m^3 s^{-1}$ (12250 cfs) which is the base case in the EWA projection. Values of X_2 during March-May are given to show

Year	X_2	Historic	Base Losses	Magnitude of EWA, TAF						
				100	200	300	400	600	800	1000
1995	49	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	53	-	6.3	0.6	1.2	1.8	2.4	3.7	4.8	5.6
1997	62	-	48.4	1.4	3.0	4.8	6.8	11.5	17.5	25.3
1998	48	-	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999	56	-	29.3	0.8	1.7	2.6	3.6	5.8	8.3	10.8
2000	57	-	41.5	1.4	2.9	4.5	6.3	10.1	14.5	19.6
2001	71	3.4	55.6	1.5	3.2	5.0	7.1	11.9	17.8	25.3
2002	73	5.9	51.5	0.9	1.8	2.9	4.1	7.0	10.9	16.3
2003	70	5.8	48.8	0.7	1.5	2.3	3.3	5.7	8.7	12.7
2004	61	0.8	23.5	0.6	1.1	1.7	2.4	3.6	5.0	6.5
2005	64	0.1	8.6	0.9	1.9	3.0	4.1	6.0	7.2	8.1

Figure Captions

1. Map of the upper San Francisco Estuary showing locations mentioned in the text.

2. Map of the watershed showing major water projects.

3. Monthly export volumes during the EWA period (line) and reduction in export volumes attributable to EWA (green bars).

4. Gains in percent survival of young delta smelt for various magnitudes of EWA, under alternative assumptions about mortality (0 or 2% d^{-1}) and the base export volume (15 or 30 H 10^6 m^3 d^{-1}). Lines represent means of all years (1995 – 2005) or four dry years (1999, 2001-2003).