Public Comment
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Analytical Tools Workshop:

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San Luis & Delta-Mendota Water Authority

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1. Introduction

This presentation describes tools available to the State Water Resources Control Board (State Water Board) that should assist it in estimating the potential effects of changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin River Delta, adopted in 2006 (2006 Bay-Delta Plan). The tools fall within three categories: (1) tools to assess the effect of changes on fish; (2) tools to assess the effect of changes on water supply and hydrology; and (3) tools to address uncertainty.

1.1 Tools to Assess the Effect of Changes on Fish

One of the most critical sets of tools available to the State Water Board is lifecycle models. These models integrate the effects of multiple stressors across multiple life stages to evaluate impacts of actions at population scales. They offer the prospect of evaluating the effect of multiple stressors on the ultimate survival or abundance of the species. As a result, lifecycle models are powerful tools for studying complicated ecosystems like the Delta where there are large numbers of interacting habitat variables. This paper identifies and explains the results of existing models for delta smelt and salmon. It also discusses efforts by the Public Water Agencies to complete a longfin smelt model and the National Marine Fisheries Service to complete its own salmon model.

Flows in Old and Middle River ("OMR") have been used by the FWS and NMFS to minimize entrainment in the SWP and CVP Delta facilities. When OMR is used for this purpose, it is not measuring a degradation of water quality. Nevertheless, several parties have raised concerns about OMR and entrainment in the SWP and CVP facilities during these workshops. For this reason, the Public Water Agencies addressed entrainment and OMR in Workshop 2, explaining that current entrainment of smelt and salmonids in the SWP and CVP Delta facilities is very low. The Public Water Agencies further explained that entrainment by the SWP and CVP has never been shown to have a population level effect, nor has there ever been shown to be a statistically significant relationship between entrainment and species abundance. Nonetheless, the Public Water Agencies recognize that adult (and pre-spawning) delta smelt entrainment can often be minimized by managing operations in response to natural turbidity events. Thus, also discussed in this paper are turbidity forecasting tools.

1.2 Tools to Assess the Effect of Changes on Hydrology and Water Supply

There are multiple models available to the State Water Board to assess the effect of changes to the 2006 Bay-Delta Plan on water supply. They include (1) CALSIM-II, (2) CalLite, (3) Delta Simulation Model II (DSM2), and (4) SELFE. The Public Water Agencies understand that the California Department of Water Resources will discuss those tools. Thus, this paper focuses on the use of raw data and an assessment of historical conditions as tools to frame analyses of the impact of ecosystem changes on hydrology.

A hypothesis for the decline of several fishes dependent on the Bay-Delta is changes to through-Delta flows and the location of the low-salinity-zone. This report (1) describes historical outflow, including outflow as measured by the location of X2 over the period of record 1922–

2011 and (2) describes some, but not all, causes of identified changes in outflow over time. The period of record is evaluated annually as well as by decade. The data reflect:

Annual Outflow

- No statistically significant trend in annual Delta outflow from 1922 to 2010,

- Average outflow decreased in the most recent decade (2001–2010) compared to the previous decade (1991–2000), and the difference is primarily explained by changes in precipitation and increased upstream water use.

Fall X2

- Fall X2 location is further downstream in the Delta (the Delta is fresher) in September, and about the same in October, compared to conditions before Shasta Dam was constructed,

- In September, there was a decrease in outflow from the prior decade (1991-2000) to the most recent decade (2001-2010), and the difference is primarily explained by changes in precipitation and increased upstream water use,

- In October, there was a decrease in outflow from the prior decade (1991-2000) to the most recent decade (2001-2010), and the difference is primarily explained by changes in precipitation and increased upstream water use. CVP/SWP Projects reduced exports during this period thereby subsidizing outflows.

Winter X2

- In January-March, the average location of X2 in the most recent decade (2001–2010) is most comparable to the decade 1981–1990, but further upstream than the prior decade (1991–2000).

- In the months January-March, 93% of the difference in outflow (calculated X2) from the prior decade (1991-2000) to the most recent decade (2001-2010) is due to changes in precipitation, with CVP/SWP operations being the primary contributor to the remaining 6% of outflow difference.

Spring X2

- The April data show that the calculated X2 location in 2001–2010 was comparable to the decades 1971–1990, but more easterly than the decade 1991–2000,

- Data from the more recent two decades shows May and June to be fresher than they were in the immediately prior three decades (1971–1990) but comparable to the decade 1961–1970,

- The difference in average April-June outflow from the prior decade (1991–2000) to the most recent decade (2001–2010) is primarily explained by changes in precipitation and increased upstream water use.

This report also estimates average annual Delta outflow for the Sacramento/San Joaquin River watersheds, the Delta, and the San Francisco Bay prior to development. At that time, water did not flow unimpeded through channels into the Pacific Ocean. Rather, it spilled over elevated natural levees into vast natural flood basins. The filling and emptying of these flood basins had the effect of delaying the transmission of flood flows down the major rivers, thereby reducing peak flows and velocities. Some of the water in these flood basins gradually drained back into the main river channels after the floods subsided, through a complex network of sloughs. Some basins drained relatively rapidly while others retained flood waters through the summer or year round. These flood basins also contained vast tracts of tule marsh, riparian forest, and lush perennial grasslands, which retarded the drainage of the basins and evapotranspired residual flood waters. This change in the physical landscape from the predevelopment era to today suggests the that timing of outflows were historically very different, with flows being retained in natural flood basins/floodplains and in groundwater basins for an extended period to slowly drain out over time.

When those conditions and others are taken into account, the preliminary analysis, which is discussed in detail below, shows a long-term average Delta outflow within a range of 15.6 to 23.2 million acre-feet per year. The calculated average outflow is 16 MAF/yr. (based on the 2011 level of development and the 88 year hydrologic record). The result of this preliminary analysis is that current outflow is within the initial estimate of predevelopment annual average outflow. Stated differently, the annual volume of outflow is about the same today as it was in predevelopment conditions.

The other important conclusion to be gleaned from this preliminary analysis is that the estimated annual average outflow is not the same as the unimpaired flow calculation. Unimpaired outflow is 28 MAF, which is above the highest estimate of natural outflow, and therefore unimpaired outflow is not an accurate or meaningful estimate of natural outflow.

1.3 Tools to Address Uncertainty

Inherent in most, if not all, science-based decisions is uncertainty. Defining uncertainty and responding to it is critical to effective decision-making. While most if not all regulatory decisions require exercise of policy judgment, defining uncertainty exposes the limitations of science and marks yet another location where a shift in emphasis must occur, from science to policy. Defining uncertainty thus may allow policy makers to frame their decisions within the context of an adaptive management program – a structured, iterative process of decision making in the face of uncertainty, with an aim to reducing uncertainty over time through monitoring and data collection. It may also allow policy makers to appreciate where additional scientific resources might be focused to better inform future policy decisions.

In this paper, the Public Water Agencies describe adaptive management as one of the tools available to reduce uncertainty. However, at this time, the Public Water Agencies are not addressing whether adaptive management is an appropriate tool for use by State Water Board in reviewing and potentially revising the 2006 Bay Delta Plan, which is a determination that will ultimately involve a mix of science, law and policy.

Adaptive Management is a "formal, systematic, and rigorous program of learning from the outcomes of management actions, accommodating change, and thereby improving management" (NRC, 2011). Structuring and implementing an adaptive management program is a major undertaking in terms of need for institutional buy-in at a sufficient level of support and over a sufficient time scale. Critical elements of any adaptive management program are:

- Establishment of clear and specific objectives,
- Access to models that span a range of time and spatial scales that represent the species, ecological processes, physical conditions, and landscape,
- Management alternatives (options) for each decision point,
- Monitoring and evaluating outcomes tied to the objectives, management actions, models, and hypotheses being tested,
- Mechanisms for incorporating learning into future decisions, and
- Collaboration among decision makers and interested parties.

The Public Water Agencies are involved in a number of collaborative processes designed to reduce uncertainty and to advance scientific understanding. During these proceedings, the need for enhanced coordination and integration of monitoring and modeling activities to support implementation of the updated Bay-Delta Plan was discussed. The need for an open collaborative process was also a major theme during numerous presentations at the recent Bay-Delta Science Conference. The CWQMC, and specifically the work groups formed under its guidance, represents a venue for such efforts.

The California Water Quality Monitoring Council ("CWQMC") is an effort to support the foundation of development of scientific information – monitoring and data collection. The CWQMC is organized using workgroups targeting each beneficial use of water. The California Estuary Monitoring Workgroup (CEMW) is tasked with fishery issues in the Delta. The CEMW utilizes the internet with a password protected site where each member of the group can work and share information. The CEMW is developing a public access internet portal that will ultimately use the same open source software as the Bay Delta Live site. The site will be a virtual depository for the wealth of knowledge and information that already exists and to display it in an easy-to-use interface. The public access site will make it easy to discover, organize and display information about the Delta and its watershed. It will be a site where regulators may go to contribute and gather the necessary information to make decisions. It will serve as a place where stakeholders may track and monitor progress of these decisions.

There are other examples of adaptive management and collaborative processes as well. These include the Bay Delta Conservation Plan ("BDCP"), and the Delta Stewardship Council's Delta Plan. Past and present adaptive management plans, like VAMP and FLaSH, while imperfect, represent examples of past and ongoing efforts whose momentum could be built upon.

2. Tools to Address Uncertainty

2.1 Adaptive management

Adaptive management provides a means for carrying out and assessing alternative management actions in the face of uncertainty. The adaptive management process, when appropriately implemented, should facilitate testing of management alternatives, evaluation of outcomes, iterative modifications of management actions, and learning. However, it cannot compensate for a lack of knowledge, the complexity of ecological systems, or underestimating sources of uncertainty including socio-political uncertainty. In the body of this review, a brief introduction to adaptive management is provided, followed by the necessary elements of an adaptive management plan.

2.1.1 Background Adaptive Management

Adaptive management of environmental resources was formalized in the 1970s as a framework for structuring management actions to incorporate feedback and to manage uncertainty. Holling (1978), whose research was conducted at the International Institute for Systems Analysis, is generally recognized as one of the first to formally describe this approach for natural resources. The National Research Council (NRC 2004) states that adaptive management is not a "one size fits all" or a "cookbook" process. Elements of adaptive management that have been identified in theory and practice are:

- Management objectives that are regularly revisited and accordingly revised,
- A model(s) of the system being managed,
- A range of management options,
- Monitoring and evaluating outcomes of management actions,
- Mechanisms for incorporating learning into future decisions, and
- A collaborative structure for stakeholder participation and learning.

The US Department of Interior (Williams and Brown 2012) echoes these elements:

> The elements in the set-up phase of adaptive management include: stakeholder involvement, objectives, management alternatives, predictive models, and monitoring protocols.

As pointed out by Holling (1978), being aware of and accounting for components of uncertainty is important to adaptive management.

Gregory *et al.* (2006) raises a note of caution with regard to sources of uncertainty in adaptive management programs. The authors state:

> Scientists must be realistic about the ability of AM[1] experiments to reduce uncertainty, rather than simply develop a better understanding of it, and that careful screening of uncertainties is

[1] Adaptive management is sometimes referred to as "AM."

> required to distill which sources of uncertainty are thought to matter the most from the standpoint of stated management objectives and feasible alternatives.

Gregory *et al.* (2006) point out that the following sources of uncertainty must be addressed:

> Structural uncertainty.—Structural uncertainty results when important relationships between ecological variables have not been identified correctly or when their functional form is not known with precision.
>
> Parameter uncertainty.-a common point of contention in the design of AM plans is examination of the statistical uncertainty inherent in a proposed AM application.
>
> Stochastic uncertainty.—Stochasticity, or variation due to pure chance and unrelated to systemic factors
>
> Confidence in assessments.-A final important dimension of ecological uncertainty is the degree of confidence in assessments held by scientists and other participants.

Gregory *et al.* (2006) point out that these and other considerations must be taken into account and that when adaptive management plans are not really structured as adaptive management should be, there are bound to be considerable difficulties. They point out that adaptive management is not an approach to be adopted without forethought and careful analysis, if the adaptive management plan is to be successful.

Lee (1993, Table 3-2) based on his experiences in the Pacific Northwest characterized institutional factors affecting adaptive management, which have particular relevance to the Bay-Delta:

- There is a mandate to take action in the face of uncertainty.
- Decision makers are aware that they are experimenting.
- Decision makers care about improving outcomes over biological timescales
- Preservation of pristine environments is no longer an option, and human intervention cannot produce desired outcomes predictably.
- Resources are sufficient to measure ecosystem-scale behavior.
- Theory, models, and field methods are available to estimate and infer ecosystem-scale behavior.
- Hypotheses can be formulated.
- Organizational culture encourages learning from experience.
- There is sufficient stability to measure long-term outcomes; institutional patience is essential.

A critical aspect of adaptive management is the iterative (feedback) nature of the process (NRC 2004). Adaptive management in its most basic form consists of identifying objectives, selecting management action alternatives to fulfill those objectives, implementing the selected alternative, monitoring the results, evaluating the results, learning from the experience, and revising both the understanding of resource and actions under the program to better meet the objectives. This process is repeated under adaptive management to achieve success. Williams and Brown (2012) emphasize the iterative nature of the process pointing out that decision-making, follow-up monitoring, assessment, learning and feedback, and institutional learning are all part of the iterative (or recursive) process. They view this phase as a follow-on to what they call the set-up phase of initiating the adaptive management plan.

2.1.2 Elements of An Adaptive Management Plan

In this section, the elements necessary for structuring an adaptive management plan are discussed.

2.1.3 Prerequisites

As pointed out by Lee (1993) and NRC (2004), there need to be objectives and a mandate to take action for adaptive management. However, as pointed out by NRC (2011) in a review of BDCP,

> [T]he application of adaptive management to a large-scale problem like the one that exists in California's Bay-Delta will not be easy, quick, or inexpensive.

NRC (2011) further states:

> Walters (2007) concluded that most of more than 100 adaptive management efforts worldwide have failed primarily because of institutional problems that include lack of resources necessary for expanded monitoring; unwillingness of decision makers to admit and embrace uncertainties in making policy choices; and lack of leadership in implementation.

The approaches to adaptive management identified by Lee (1993) identify the pre-requisites of performing large scale adaptive management and the need for institutional buy-in at a sufficient level of support and over a sufficient time scale to carry out the program. The decision-makers also must recognize the experimental nature of adaptive management and the uncertainty of outcomes associated with taking action. This includes recognition of the dedication of sufficient resources for implementation. A basic premise of implementing adaptive management is a commitment to undertake an experimental program over a sufficient time-scale to make the necessary observations, adjustments, and revisions to understanding and subsequent management actions. This may take the equivalent of several generations of the biota of interest and need to include different water year types for a single management alternative. As part of adaptive management, both failures and successes will likely occur during the course of the program. As pointed out by Lee (1993), the implementing agency also needs to recognize that attaining a pristine environment under present circumstances is an unrealistic option.

2.1.4 Objectives

Sources (Lee 1993, NRC 2004, Argent 2009, Williams and Brown 2012, others) agree that clear and specific objectives are needed for a successful adaptive management program. NRC (2004) suggests that goals and objectives should be clearly defined and will need to include a balance between goals and learning (improving knowledge of the resource relationships). They also point out that management objectives should be regularly revisited and revised, as needed. Williams and Brown (2012) state that objectives represent benchmarks against which the effects of different management actions are compared, and serve as measures of effectiveness of those actions. In other words, objectives are how the success of the program is measured. Argent (2009) identifies that clear objectives are not only needed to initiate the adaptive management process, but also to help answer the question of when to end the process. He further points out that clear objectives help to identify exit strategies and to help communicate to stakeholders.

Another aspect of objectives that must be taken into account is institutional requirements. These include both state and federal laws, such as the Clean Water Act, Porter-Cologne Act, federal and state Endangered Species Acts, National Environmental Policy Act, and California Environmental Quality Act, among others. Specific to the Bay and Delta, there are a number of other management and restoration actions taking place, which also must be viewed as requiring some level of coordination and must be accounted for within the adaptive management process, especially in assessing the efficacy of management actions.

2.1.5 Predictive Models

The adaptive management approach to addressing natural resource issues generally relies on models to identify the ecological and physical relationships pertinent to the problem and to predict the outcome of management actions. Models represent simplifications of reality showing cause-and-effect relationships, assumptions related to the structure and function of the ecosystem including physical conditions, and identifying variables that can represent the state of the system. As pointed out by Jakeman *et al.* (in Allan and Stankey 2009), models provide a synthesis of our knowledge of systems and allow us to explore the potential effects of various management alternatives prior to implementing them. Importantly, models identify gaps in our knowledge, assist in learning, assist us with dealing with uncertainty, and help us to identify monitoring needs (see Section 2.3.5 below). As pointed out by Healy *et al.* (2004), not one but many conceptual models that span a range of time and space scales would be needed to represent the species, ecological processes, physical conditions, and landscape to support ecological restoration and adaptive management in the Bay-Delta. In addition, they state that models need to include operations and governance to avoid leaving out key aspects that may be important to restoration.

As stated by Williams and Brown (2012):

> [M]odels that link potential management actions to resource results play an important role in virtually all applications of structured decision making, whether adaptive or otherwise. Smart decision making requires one to compare and contrast management alternatives in terms of their costs and resource consequences.

> Models express benefits and costs in terms of management inputs, outputs, and outcomes. Of critical importance to adaptive management, they allow us to forecast the impacts of management.

The use of models and model predictions along with monitoring allow us to assess whether a model is a successful predictor of outcomes. This allows us to use the adaptive management process to select alternative models that better conform to reality or to modify existing models. This is an important aspect of learning and adaptive management of alternatives. As we improve our predictive capability, we are likely to modify the management actions we select.

As pointed out by Lee (1993), clearly formulated hypotheses need to be derived from models to allow us to test predictions of how one or more important (indicator) species or aspect of the ecosystem will respond to proposed management actions. Clearly, only those actions and resource responses that modeling suggests would be successful would be codified as hypotheses. Through the success or failure of the ecological responses addressed in the hypotheses, we learn whether the management action is successful, whether the model provides an adequate representation of the species and processes we wish to manage, and what alternative potential management action should then be considered.

Authors differ on the level of model complexity needed for adaptive management, with some authors recommending more complex numerical models that model both physical processes and biological populations/communities (Walters 1997). Others suggest that the need for model detail and complexity depends upon how well the model represents the variables of interest.

The representation of uncertainty within and between models also is identified as something that needs to be taken into account when making decisions on the use of models. Lee (1993) and Williams and Brown (2012) both discuss approaches to addressing uncertainty. These include statistical uncertainty associated with models and monitoring, as well as the consequences of not being able to distinguish meaningful results from background uncertainty.

Williams and Brown (2012) provide a succinct summary regarding models:

> Models play a key role in adaptive management by incorporating different hypotheses about how a resource system works and how it responds to management. Agreements, disagreements, and uncertainties about resource behaviors can be highlighted with models and used to guide investigations through basic research and learning-oriented management interventions.

Thus, even if current models do not completely fulfill the need, it is necessary to have models in place in order to make initial decisions and to configure the adaptive management plan.

Generally, there should be collaboration on the choice of models, with preference going to those models that account for both physical and biological components (Walters 1997). Even if there is disagreement in the selection of a model or model components, the adaptive management framework allows the models to be tested on the basis of performance. The adaptive management approach provides the context for learning if the relationships embodied in the models are correct and allows for revision, as part of the process. However, it is critical that the models considered provide the ability to predict the outcome of contemplated management actions in order for the process to be successful. An alternative that cannot be linked to providing or contributing to a successful outcome is one that likely should not be included.

2.1.6 Management Alternatives and Actions

NRC (2004) states:

> [E]ven when an objective is agreed upon, uncertainties about the ability of possible management actions to achieve that objective are common. That is, existing data rarely point to a single "best" management policy. For each decision, the range of possible management choices is considered at the outset in light of stated objectives and the model(s) of system dynamics.

Williams and Brown (2012) commented:

> [L]ike any iterative decision process, adaptive decision making involves selecting a management action at each decision point, on the basis of the status of the resource at the time. Resource managers and other stakeholders, usually working with scientists, must identify the set of potential actions from which a selection is made.

NRC (2004) further states:

> [T]his evaluation takes into account the likelihood of achieving management objectives and the extent to which each alternative will generate new information or foreclose future choices. When possible, simultaneously implementing two or more carefully monitored actions can allow for rapid discrimination among competing models.

Williams and Brown (2012) state that:

> [S]trategy choices are always limited by the set of available management options. If these options do not span a reasonable range of management actions, or if they fail to produce recognizably different patterns of system responses, adaptive management will be less useful in producing effective and informative strategies.

As discussed by numerous authors, the selection of management alternatives needs to have predicted benefits in line with the objectives. This means that the target or indicator species must benefit, and that benefit would need to occur to portions of the ecosystem that also are part of the objectives (NRC 2011). Similarly, impacts related to the implementation of the management alternatives need to be evaluated. The models, as discussed above, will need to be able to provide information to inform the choices of management alternatives to be selected. The models will need to indicate the relative uncertainty associated with their predictions, including identifying those aspects of the outcomes that are not included in the predictions. In assessing management alternatives, risk assessment for success, failure, and potential impacts will need to be included, in some form.

Since there are a wide range of stakeholders, as well as ecological resources that are likely to be affected by the selection of alternatives, impacts to these stakeholders and their interests will need to be carefully considered. This is especially true of any potential effects that may be irrevocable. Lee (1993) reminds us that there are socio-political and economic costs associated with adaptive management that are beyond the actual adaptive management framework including modeling and monitoring. These risks, costs, and impacts to stakeholders must be clearly annunciated and balanced to some degree for a successful outcome for the process.

Another consideration in the selection of alternatives is the initial alternative to be considered. Since the adaptive management process is iterative in nature, alternatives resulting in lower impacts to other resources and stakeholders should be considered for initial implementation. If objectives are not met by the initial alternative, changes can be made incrementally to achieve the objective. Of course, this may not be satisfactory to some stakeholders, but a critical aspect of the adaptive management process is staying the course for an adequate time to implement the process. On the other hand, if a high impact alternative is selected that accomplishes the objective, it may be politically difficult to modify the alternative to reduce the impact to other resources and uses to determine if objectives can be met at a lower level of impact. The initial management alternative applied needs to be viewed as the first portion of the field experiment and needs to be one that is predicted to be successful, but also one that can be revised as part of the iterative process of examining the efficacy of such actions.

2.1.7 Monitoring

NRC (2004) states that adaptive management requires information for comparing the outcomes management alternatives. Williams and Brown (2012) state that monitoring of outcomes advances scientific understanding and provides the basis to adjust policies or operations as part of the iterative management and learning processes. They state, "Simply put, adaptive management is not possible without effective monitoring."

Williams and Brown (2012) also identify that:

> The learning that is at the heart of adaptive management occurs through a comparison of model-based predictions against estimated responses based on monitoring data. It is by means of these comparisons that monitoring is used to understand resource dynamics, and thus to confirm the most appropriate hypotheses about resource processes and their responses to management.

As indicated above, monitoring needs to focus on significant and detectable indicators of progress toward the attainment of management objectives. Monitoring also should help distinguish between natural perturbations and perturbations caused by management actions (NRC 2011). Monitoring needs to be specifically tied to the objectives, management actions, models, and hypotheses that constitute a major part of the adaptive management process. Monitoring also should assist in the verification of model and the resolution of data gaps pertinent to the adaptive management process. Monitoring must be an integral part of the adaptive management process from its start and not simply added on afterwards (Holling 1978). Conversely, this also means that monitoring should be specific to the adaptive management program's needs. Existing monitoring may or may not fit those needs. Results of such monitoring may have value, but do not take the place of the specific needs of the adaptive management program to address specific hypotheses. Those specific needs are a function of addressing the objectives, the models used to represent the ecosystem, species, and processes, the management alternatives considered, hypotheses posed, and existing knowledge.

As stated by NRC (2004):

> Monitoring programs and results should be designed to improve understanding of environmental and economic systems and models, to evaluate the outcomes of management decisions, and to provide a basis for better decision making (ideally, independent estimates of the value of monitoring information and programs will be periodically conducted).

Adaptive management programs require comprehensive, problem-driven monitoring schemes that deliver data and can link actions to desired outcomes, such as target species abundance and enhancement of identified ecological functions. Adaptive management programs must include monitoring that are purpose oriented, that address explicit objectives, that are capable of detecting salient environmental changes, and that provide quantitative results that can inform reliable management actions.

All monitoring programs should identify response variables drawn from species of conservation concern, resources upon which one or more of those species depend, and valid surrogate measures for both. The programs should also identify and list the fullest possible array of candidate environmental attributes that believed to affect the population dynamics of desired species – the location, timing, and volumes of site-specific flows, water quality variables (including abiotic factors, contaminants, and nutrients), landscape characteristics (morphological and bathymetric factors, physical and biotic resources adjacency and connectivity), and food web structure and composition (including prey and predators). Further, monitoring program should recommend sampling schema across pertinent spatial and temporal gradients using the best available tools and techniques to provide meaningful real time measures of response variable, stressor, and background variable conditions. Programs designed in this manner allow for exploration and development of guidance that can be used by the implementation agencies to maximize the capacity of the program to deliver statistically robust returns. The guidance often includes rule sets to assist in identifying ecologically relevant, parameter-condition thresholds to serve managers working in an adaptive framework.

In the end, monitoring programs must be dynamic; from first deliverables to implementation, it should be expected that there will be continuous adjustment, reformulation, and even monitoring-program redesign in response to new information and inevitable unsuccessful attempts to capture essential information with parsimonious field work. Directed research (or pilot studies) need to inform some (even many) aspects of monitoring design and implementation. Where key uncertainties compromise well-resolved conceptual models, and an incomplete understanding of the ecology and behavior of target species and their habitats, monitoring efforts will include both focused research and modeling.

2.1.8 Decision-Making and Feedback

This element of adaptive management is also known as "learning from doing," which concludes an iteration (or cycle) of adaptive management and begins the next cycle or iteration (Argent 2009). Adaptive management plans are structured with the foreknowledge that they are iterative processes, of necessity, due to the uncertainties that are the drivers for the use of adaptive management. Part of that is the recognition that modifications will need to be made as experiments are completed and knowledge is gained. Williams and Brown (2012) state that in an adaptive management project, the data produced by monitoring are used to evaluate the effectiveness of management actions, resource status, and reduce future uncertainty. An important component of the feedback and learning process is weighing the performance of model predictions with the monitored ecosystem responses. This evaluation can lead to improvement of models and improved understanding of ecosystem relationships. Most importantly, monitoring data can be used to judge the effectiveness of management actions. If monitoring shows that objectives are not being met, management actions need to be modified.

NRC (2004) states:

> [A]daptive management aims to achieve better management decisions through an active learning process. Objectives, models, consideration of alternatives, and formal evaluation of outcomes all facilitate learning. But there should be one or more mechanisms for feeding information gained back into the management process. Without a mechanism to integrate knowledge gained in monitoring into management actions, and without a parallel commitment and the political will to act upon knowledge gained from monitoring—which will not eliminate all uncertainties—monitoring and learning will not result in better management decisions and policies.

2.1.9 Summary

As described above, structuring and implementing an adaptive management plan is a major undertaking in terms of need for institutional buy-in at a sufficient level of support and over a sufficient time scale to carry out the program. Decision-makers must recognize the experimental nature of adaptive management and the uncertainty of outcomes associated with taking action. Adaptive management programs must be implemented over a sufficient duration to make the necessary observations, adjustments, and revisions to understanding to inform subsequent management actions.

2.2 Existing collaborative processes designed to reduce scientific uncertainty

The Public Water Agencies are involved in a number of collaborative processes designed to reduce uncertainty and advance scientific understanding. During these proceedings, the need for enhanced coordination and integration of monitoring and modeling activities to support implementation of the updated Bay-Delta Plan was discussed. The need for an open collaborative process was also a major theme during numerous presentations at the recent Bay-Delta Science Conference. The CWQMC, and specifically the work groups formed under its guidance, represents a venue for such efforts.

2.2.1 California Water Quality Monitoring Council

The CWQMC's membership includes key agencies and stakeholders, including representatives from Cal/EPA, Resources Agency, California Department of Public Health, publicly owned treatment works (POTW), storm water interests, agriculture, the general public, citizen monitoring groups, scientific community and water supply interests. The co-chairmen of the CWQMC are from the State Water Board and the Resources Agency.

Under the overarching guidance of the CWQMC, theme-specific workgroups (*e.g.*, CEMW) have been organized to evaluate relevant existing monitoring, assessment, and reporting processes and work to enhance those efforts so as to improve the delivery of water quality and ecosystem health information to the user (*e.g.*, policy makers), in the form of theme-based internet portals. Each of the workgroups formed under the "Are our aquatic ecosystems healthy?" is relevant to the monitoring infrastructure to address questions regarding pelagic and anadromous fish species of relevance to the 2006 Bay-Delta Plan.

Membership in the CWQMC workgroups include scientists from multiple entities and agencies including, but not limited to: Interagency Ecological Program (IEP), Department of Water Resources, Department of Fish and Game, the Water Boards (SWRCB, CVRWQCB, SFBRWQCB), Delta Science Program, Delta Conservancy, San Francisco Estuary Institute, US EPA, US Geological Survey, The Bay Institute and State and Federal Contractors Water Agency. These workgroups include the CEMW, Healthy Streams Partnership (streams and rivers), and California Wetland Monitoring Workgroup. These workgroups serve as venues for the types of enhanced coordination, integration, assessment and reporting of on-going and potential future monitoring efforts discussed during Workshop 1 (September 5 and 6, 2012).

The CWQMC was formed as a result of a Memorandum of Understanding (MOU) signed by the Secretaries of the Resources Agency and the California Environmental Protection Agency in November 2007, as mandated by the Senate Bill 1070. The MOU and Senate Bill 1070 (Water Code sections 13167 and 13181) require that the CWQMC develop specific recommendations to improve the coordination and cost-effectiveness of water quality and ecosystem monitoring and assessment, enhance integration of monitoring data across departments and agencies, and increase public accessibility to monitoring data and assessment information. A key recommendation of the CWQMC (2008) is to provide a platform for intuitive, streamlined access to water quality and ecosystem information that directly addresses users' questions and decision-making needs. Previously, monitoring data collected by agencies as part of regulatory compliance was not easily accessible by the entire scientific community. This effort is creating a web-site that will make all of monitoring data easily accessible in a single location. The California Estuary Monitoring Workgroup (CEMW) has a web site that presents the data contained in the annual water quality condition reports submitted by DWR in compliance with the monitoring requirements in D-1641. A GIS interface and data query tool help users visualize the data in additional ways than in the posted annual report. This effort will also provide greater coordination of monitoring activities.

2.2.2 Other Adaptive Management and Collaborative Processes

There have been a number of adaptive management processes that have been undertaken in recent years. The Vernalis Adaptive Management Plan undertaken through Water Rights Decision D-1641 (State Water Resources Control Board 2000) is such a program. The recent FLaSH (Fall Low Salinity Habitat Investigation) was described as an adaptive management program (Brown et al. 2012). While these processes could be (or could have been) improved, they represent examples of past and ongoing efforts whose momentum could be built upon.

There are also adaptive management plans that are under development, including the Delta Stewardship Council's Delta Plan and adaptive management program, which is required by Water Code section 85308(f). The Bay Delta Conservation Plan ("BDCP") is also developing a comprehensive science and monitoring program, and adaptive management plan. The Department of Water Resources presentation in Workshop 2 described some of the components of the plan targeted at reducing scientific uncertainty, including goals and objectives, monitoring, decision tree process and adaptive management.

3. Tools to Assess the Effect of Changes on Water Supply and Hydrodynamics

3.1 Modeling of trends in outflow and salinity

A hypothesis for the decline of several Bay-Delta fishes is changes to through-Delta flows and the location of the low-salinity-zone. Enright and Culberson (2010) did an extensive review of trends in Delta outflow and salinity. They examined precipitation, outflow, and salinity trends before and after 1968 to discern outflow and salinity response to Central Valley Project (CVP)/State Water Project (SWP) operations (they also include analysis of pre- and post-Suisun Marsh salinity control gate operations, which began in 1988). They conclude that the data do not verify variability reduction; rather, annual and by-month salinity variability is generally greater in the post-project period; and that coefficients of variability for precipitation, outflow, and salinity increased after the projects were initiated. These increases in variability suggests that more powerful mechanisms are at play including land-use changes and climate, which overpower the homogenizing influence of appropriations of water, including those by the CVP/SWP, when considering long-term trends.

This section of the report (1) describes historical outflow, including outflow as measured by the location of X2 over the period of record 1922–2011 and (2) describes some, but not all, causes of identified changes in outflow over time. The period of record is evaluated annually as well as by decade.

The analysis of outflow over time is limited to the seasons that the state and federal fisheries agencies have identified as being potentially important to various aquatic species: fall (September through November) and winter-spring (January through June). The 2008 USFWS Biological Opinion (BiOp) for coordinated operation of the SWP/CVP (OCAP) included a fall outflow experiment (Fall X2 experiment) covering the months September through November (USFWS 2008, pp. 282-283). While acknowledging the uncertainty of benefit, the 2010 Flow Criteria Report also proposed a fall outflow requirement for the months September through November (State Water Board 2010, p. 98). For these reasons, fall outflow (September-November) is analyzed in this report.

The 2010 Flow Criteria Report further proposed a percent of unimpaired flows approach for the winter-spring months, covering January through June (State Water Board 2010, p. 98). They are the same months Jassby *et al.* (1995) used in their statistical analysis of the relationship between winter-spring outflows and longfin smelt abundance. For these reasons, Winter-Spring outflow (January through June) is also analyzed here.

3.1.1 Outflow and Calculated X2 Location (1922-2010)

The 2010 Flow Criteria Report suggests that the magnitude and timing of outflow and the location of the low-salinity zone have changed significantly over time, as evidenced by the difference between calculated unimpaired outflows and actual outflows (State Water Board 2010, pp. 28-33). The analysis contained in the 2010 Flow Criteria Report concludes the difference between unimpaired outflow and actual outflow is a result of increased appropriation of water from the Bay-Delta estuary and the Sacramento/San Joaquin River watershed. (State Water Board 2010, p. 28). That analysis is not appropriate and the conclusion is not accurate.

Unimpaired flow calculations are informative illustrations of precipitation, and they are used in this report for that purpose. However, as explained in detail below, unimpaired flow calculations are not appropriate estimations of natural outflow. The 2010 Flow Criteria Report fails to account for that fact or the fact that unimpaired flow is a calculation of a hypothetical environment. Unimpaired flow has never existed in our system and cannot be used as a surrogate measure for natural outflows. (DWR 1987, p. 10; *see also*, DWR presentation to State Water Board available on the State Water Board website and incorporated herein by this reference.) To do so would be counter to accepted scientific principles.

Further, it was and would continue to be an error to assume appropriation of water is the sole driver of outflow. As concluded by Enright and Culberson (2010), "seasonal outflow and salinity variability is primarily climate driven." Enright and Culberson demonstrated that consecutive month outflow differences are consistent with watershed precipitation, suggesting that climate is a more powerful mechanism controlling seasonal variability than water project operations on seasonal and decadal scales.

A further concern with the data cited to support the 2010 Flow Criteria Report is that the grouping of years averaged and used for comparative purposes does not avoid the potential for upstream hydrology to bias the results (State Water Board 2010, pp. 28-32). The analysis presented below evaluates the historical period of record (Water Years 1922 to 2010) and compares this period to the predevelopment era, providing a factual and scientifically sound basis for discussion.

3.1.1.1 Data and Methods

Table 1 summarizes the data used for this trends analysis. The analysis uses monthly flow time series in units of cubic feet per second (cfs.) for the available period of record from October 1921 through September 2010 (Water Years 1922 to 2010). All references to years in this study are to water years (October 1 through September 30 of the calendar year in which it ends) unless otherwise noted. These time series were used to compute annual time series in units of thousand acre-feet (TAF) per year or million acre-feet (MAF) per year. These time series were also used to create 12 monthly data series (*e.g.*, a January series, a February series, etc.) where successive values are 1 year apart.

Table 1Data Utilized in Trends Analysis

Data Record	Period of Record	Source
Net Delta Outflow	October 1921 – September 1929 October 1929 – September 2010	DWR BDO DAYFLOW
Sacramento River at Freeport	October 1990 – September 2010	DAYFLOW
Yolo Bypass	October 1990 – September 2010	DAYFLOW
San Joaquin River at Vernalis	October 1990 – September 2010	DAYFLOW
Mokelumne River below Woodbridge	October 1990 – September 2010	DAYFLOW
Cosumnes River at Michigan Bar	October 1990 – September 2010	DAYFLOW
Miscellaneous Stream Flow	October 1990 – September 2010	DAYFLOW
Delta Net Consumptive Use	October 1990 – September 2010	DAYFLOW
Delta Exports	October 1990 – September 2010	DAYFLOW
Unimpaired Flows	October 1990 – September 2010	DWR BDO
Sacramento River @ Shasta	October 1990 – September 2010	CDEC
American River @ Nimbus	October 1990 – September 2010	CDEC
Feather River @ Thermalito	October 1990 – September 2010	CDEC
Yuba River @ Marysville	October 1990 – September 2010	CDEC
Sacramento Accretions	October 1990 – September 2010	Calculated
Unimpaired Sacramento Accretions	October 1990 – September 2010	Calculated
X2 Location	October 1921 – September 2010	Calculated

BDO- Bay-Delta Office

CDEC – California Data Exchange Center (DWR 2011)

Calculated unimpaired flows include: Sacramento Valley, Sacramento River @ Red Bluff, Feather River, Yuba River, American River, San Joaquin Valley, East Side Streams, and In-Delta Consumptive Use

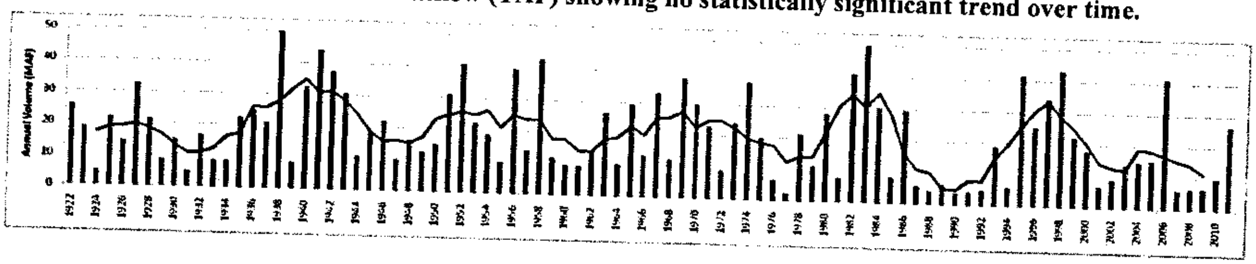
The primary source of historical Delta inflow and outflow data is the DAYFLOW database (DWR 2012). Monthly averages are computed from daily values provided in the database. Historical flows prior to October 1929 are based on a joint DWR-Bureau of Reclamation (1958) hydrology study and provided as monthly averages by the staff of DWR's Bay-Delta Office. Historical Eastside inflow is computed as the sum of historical river flows from the Mokelumne, Cosumnes, and miscellaneous streams. Historical Delta outflow, as reported in the DAYFLOW database, is a computed value based on water balance. In reality, Delta outflow is tidally influenced and fluctuates over daily diurnal flood-ebb cycles and over bimonthly spring-neap cycles. For example, outflow during summer tidal cycle can vary in direction and amount from 330,000 cfs. upstream to 340,000 cfs. downstream (Delta Atlas, 1993).

3.1.2 Annual Delta Outflow (1922–2010)

Annual Delta outflow shows no clear long-term time trend. Fox *et al.* (1990) found no statistically significant trend in annual Delta outflow between 1922 and 1986. The investigators concluded that precipitation had increased faster than water use within the watersheds. They noted that other factors, including imports, the redistribution of groundwater, and changes in runoff patterns, may have balanced the increase in water use within the watersheds.

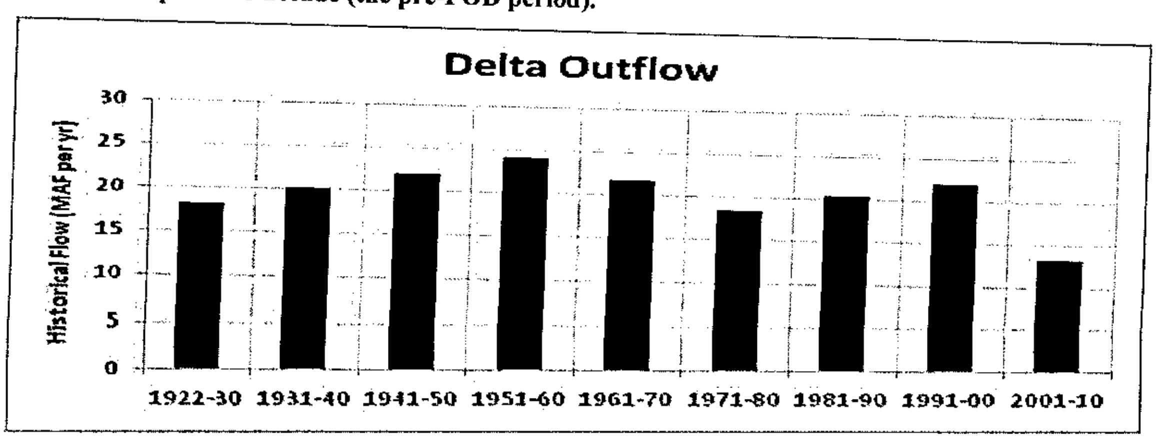
As shown on Figure 1, visual inspection suggests no statistically significant long-term trend in Delta outflow (shown as the blue bars) from 1922 and 2010. The black line shows a 5-year center-weighted average outflow. A Sen's nonparametric estimate of the long-term trend was conducted. A Mann-Kendall test, a two-sided test performed at the 95 percent confidence level, confirms that no statistically significant time trend exists.

Figure 1 Annual Variation in Outflow (TAF) showing no statistically significant trend over time.



To further characterize the outflow time series, Delta outflow is shown as decadal averages on Figure 2. The figure shows that decadal average outflows have varied, following no particular trend. However, outflow decreased in the most recent decade (2001–2010), the decade often described as the Pelagic Organism Decline (POD) period, compared to the previous decade (1991–2000), the pre-POD period and the second wettest period of record.[2]

Figure 2 Delta outflow by decade (1922–2010) showing no particular long term trend and a decrease in outflow in the most recent decade (the POD period) compared to the previous decade (the pre-POD period).

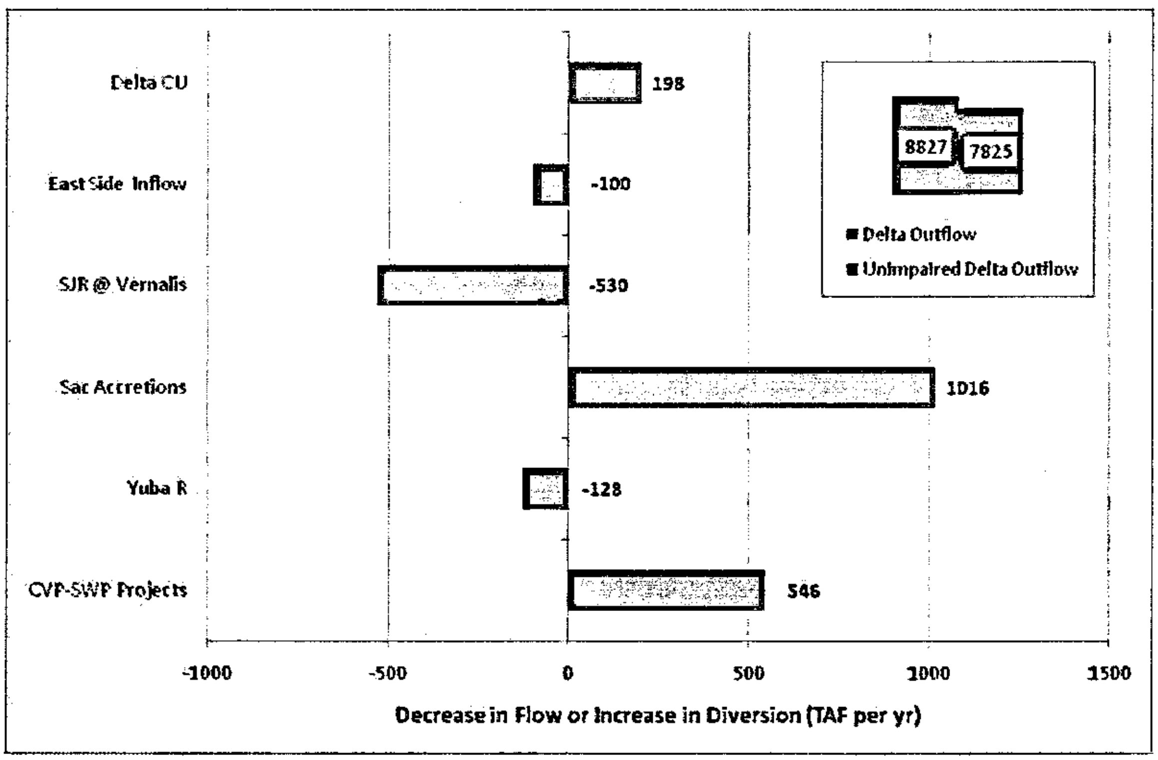


In an effort to understand the reasons for the decrease in outflow from the prior decade (1991–2000) to the recent decade (2001–2010), this analysis evaluates changes in inflows to the Delta and increases in water diversions, by source, both upstream and in-Delta.

[2] The 1991-2000 is the second wettest period of record based on the 8-River index.

Figure 3 demonstrates that annual outflow reduction is primarily the result of dryer hydrologic conditions between the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is explained in large part by the difference in unimpaired outflow (i.e. the unimpaired outflow reduction [red bar at 7,825 TAF/year] accounts for a majority of the outflow reduction [blue bar at 8,827 TAF/year]). In other words, the outflow reduction between decades is primarily the result of dryer hydrologic conditions; however, water management also contributed to the outflow reduction. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. The blue bars in the main body of the figure represent the changes in outflow other than hydrology, which is the largest driver of changes in outflow. These horizontal blue bars sum to the difference between the vertical bars. The figure shows that, after the reduction in unimpaired outflow, the reduction in Sacramento Valley accretions (1,016 TAF/year) is the most significant hydrologic factor explaining the decrease in outflow between the 2 decades. In-Delta appropriations by the CVP and SWP have a much smaller contribution to the outflow reduction (546 TAF/year); this contribution aggregates effects of in-Delta appropriations by the CVP and SWP and inflows from the Sacramento River (below Shasta), the Feather River, and the American River.

Figure 3 **Contributions to decrease in annual outflow. Horizontal bars indicate sources of the change in outflow between decades. The majority of the difference in outflow between these two decades is due to differences in natural hydrology as measures by unimpaired outflow. Reductions in Sacramento accretions are the next largest contributor, followed by increases in CVP/SWP appropriations.**



3.1.3 Calculated X2 Location (1922–2010)

The 2010 Flow Criteria Report focuses on fall (September through November) and winter-spring (January through June). As a result, this analysis of X2 location focuses on the data from these two seasons over the historical period (1922-2010).

The location of X2[3] is determined by a variety of factors. Freshwater from the upstream watersheds mixes with salty ocean water in the Delta. This freshwater flow (*i.e.,* Delta outflow) pushes the freshwater- seawater interface downstream; therefore, changes in Delta outflow (annual volumes as well as seasonal timing) affect the location of X2. Long-term changes in tidal energy, including sea level rise, influences how effectively freshwater flow pushes seawater downstream. Geometry of the land-water interface plays a key role in determining the tidal prism, amplitude, and excursion. Therefore, historical changes, including, but not limited to, changes in floodplains, channel configuration, bathymetry, and depth, affect long-term trends in the position of X2. Operation of water facilities such as the Suisun Marsh salinity gates and the Delta Cross Channel influence the flow paths within the Bay-Delta, therefore, also affect X2 positions.

The analysis presented in this paper is limited in its ability to evaluate the multiple factors that affect long-term X2 trends. As described in the following section, the X2 locations described in this study were estimated from flow data and therefore capture the influence of Delta outflow only. Therefore, the trend analysis does not reflect possible changes associated with sea-level rise, Delta island flooding, etc. It is anticipated that further analysis will be undertaken that will utilize measured salinity data to evaluate long-term X2 trends and, therefore, will reflect changes associated with other factors.

3.1.3.1 Data and Methods

The metric used in this study to evaluate long-term X2 trends is the calculated monthly average X2 location. The Delta outflow data described in Table 1 were used to estimate time series of the monthly average X2 location. These time series were also used to create 12 monthly data series (*e.g.,* a January series, a February series, etc.) where successive values are 1 year apart. A time series of the historical monthly average X2 location was developed for this trend analysis using the Kimmerer-Monismith (K-M) equation (Jassby *et al.* 1995). The K-M equation predicts average X2 location as a function of current month Delta outflow and previous month X2 location. The early historical Delta outflow time series includes several months when the value was negative. Since the K-M equation is a function of the common log of Delta outflow,

[3] The authors of this paper are not aware of any studies that conclude that the two part per thousand isohaline location (X2) is preferred by native fish over, for example, the one part per thousand or three parts per thousand isohaline positions. The resident native fish are largely adapted to a wide range of salinities (euryhaline). Instead, management of the X2 location was believed to create hydrodynamic conditions that maintain the "entrapment zone" in a location that is conducive to successful fish rearing (Jassby *et al.* 1995). References in this paper to shifts in the X2 location, therefore, should be understood to refer to shifts in hydrodynamic conditions and are not intended to suggest that any absolute salinity level has been found to be a central driver to fishery success.

the equation is not defined when outflow is less than 1 cfs. Therefore, an alternate approach was developed and utilized to estimate the X2 location when the K-M equation is not valid (Hutton 2011). As the X2 location used in the comparison and trend analysis reported below is a calculated location, differences may occur between the calculated X2 locations and the actual location, particularly in low outflow years after 1990.

3.1.4 Fall X2

The 2010 Flow Criteria Report cited Feyrer *et al.* (2007, 2011), (the latter of which was still in review at the time), for the conclusion that the average X2 location during fall has moved upstream, resulting in a corresponding reduction in the amount and location of suitable delta smelt abiotic habitat, as estimated by the X2 location (State Water Board 2010, p. 108). The Public Water Agencies reviewed these analyses and concluded that:

- Fall outflows were higher than unimpaired flows during the period 1956 to 1987 because the reservoirs were operating and making releases to reach mandatory reduced storage levels before the next rainy season. During this period, water demand throughout the watershed and in the Delta was developing so reservoir releases to create flood control space kept the Delta artificially fresh.

- The relevance of the time periods used in the 2010 Flow Criteria Report and in Feyrer *et al.* (2007, 2011) is not clearly articulated nor justified. The hydrological conditions that existed in the 1950s thru 1980s were highly altered, as further evidenced by the artificially fresh Delta in the fall, which to a certain extent flattened the hydrograph rather than supported variability.

- The actual trends in the location of X2 in fall are different than those presented in the 2010 Flow Criteria Report. The X2 location is, in fact, further downstream in the Delta (the Delta is fresher) in September, and about the same in October, compared to conditions before Shasta Dam was constructed.

The historical data indicate that the calculated X2 location early in the fall has been moving west (Delta becoming fresher) over time, with a flattening of that trend in more recent decades. The X2 data for the months August and September show the location of X2 trending closer to the San Francisco Bay, a downward trend (Figures 4 through 7). The month of August is added to this analysis because X2 in August affects X2 in September. A Sen's nonparametric estimate of the long-term trend was conducted, showing downward trends in August and September of 1.2 and 0.7 kilometers per decade, respectively. A Mann-Kendall test confirms the statistical significance of these trends.

Figure 4 Calculated X2 location in August 1922–2010, showing a statistically significant downward trend of 1.2 kilometers per decade over the time period.

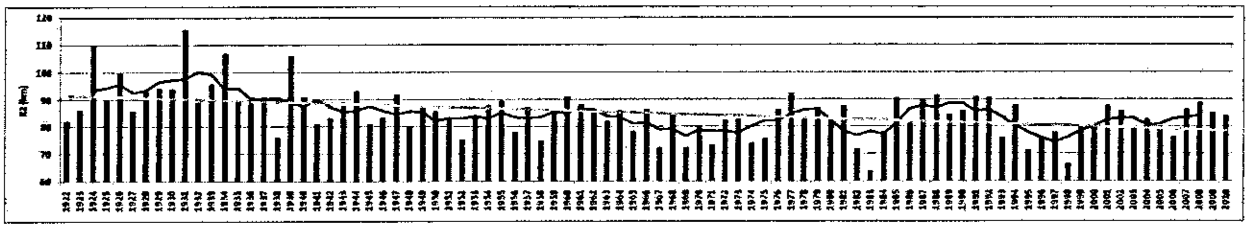


Figure 5 Calculated X2 location in August by decade (1922–2010).

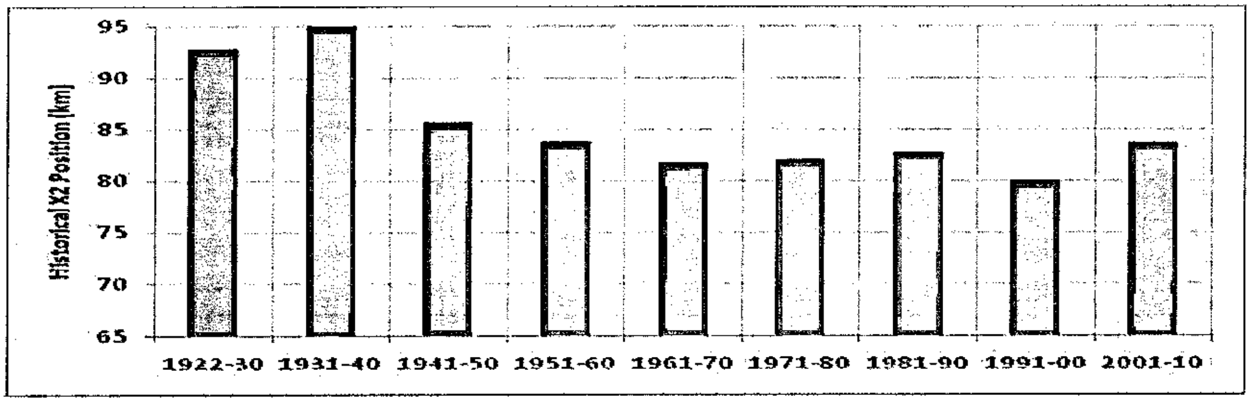


Figure 6 Calculated X2 location in September 1922–2010, showing a statistically significant downward trend or 0.7 kilometers per decade over the time period.

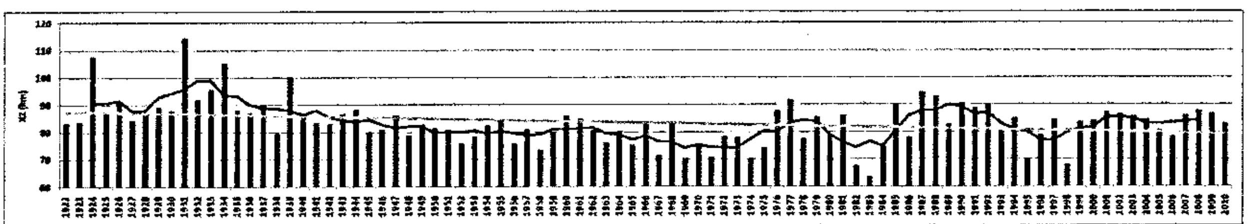
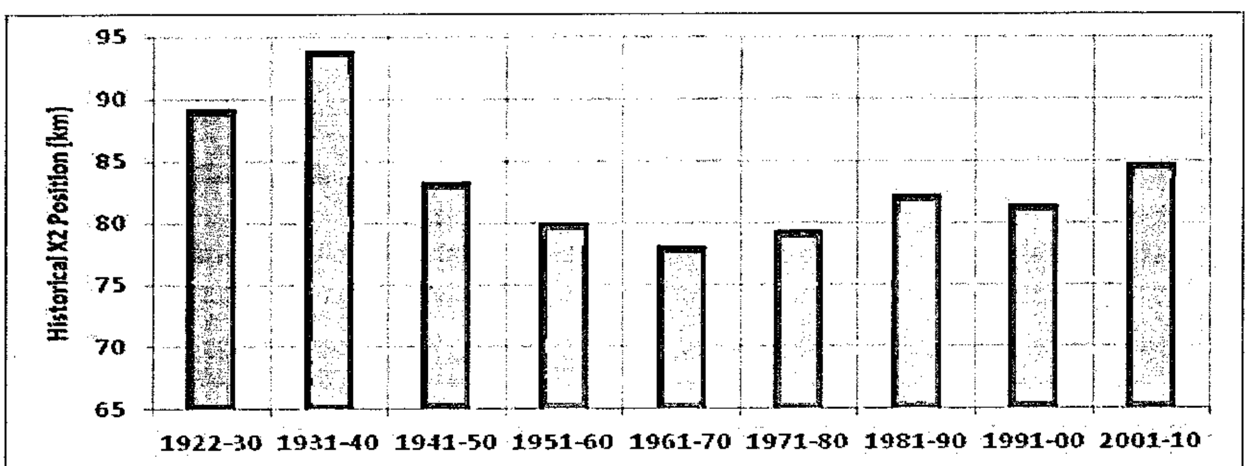


Figure 7 Calculated X2 location in September by decade (1922–2010).



Figures 8 and 9, upon visual inspection, indicate no long-term trend in the position of X2 in Octobers. A Mann-Kendall test confirms that no significant long-term trend exists. Figures 10 and 11 for the month of November show a different trend, with increasing X2 over time. A Sen's nonparametric estimate of the long-term trend was conducted, resulting in an increasing trend of 0.5 kilometer per decade. A Mann-Kendall test confirms the statistical significance of this trend.

Figure 8 Calculated X2 location in October 1922–2010, showing no significantly significant trend in salinity over the time period.

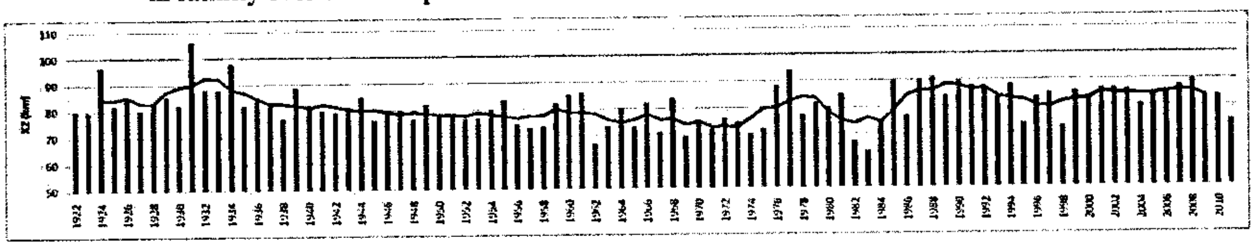


Figure 9 Calculated X2 location in October by decade (1922–2010).

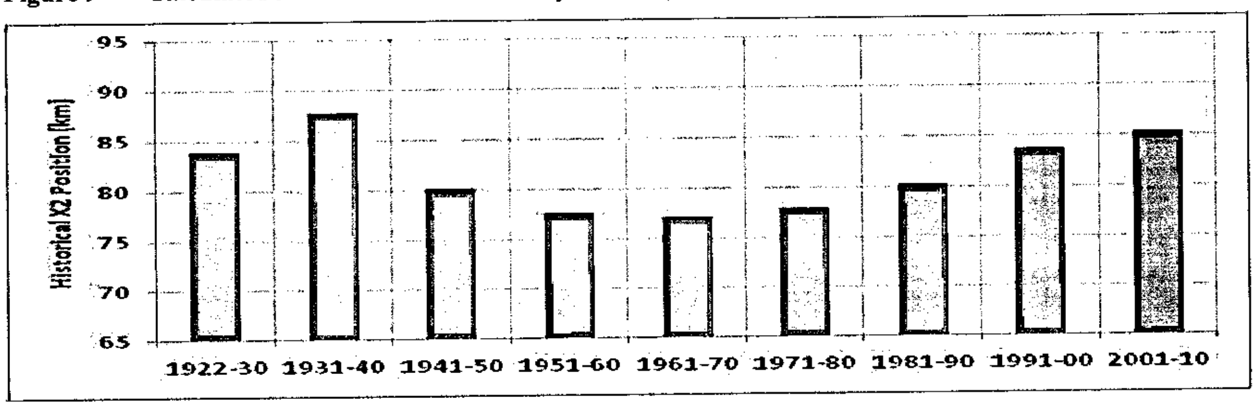


Figure 10 Calculated X2 location in November 1922–2010, showing a statistically significant increasing trend of 0.5 kilometers per decade over the time period.

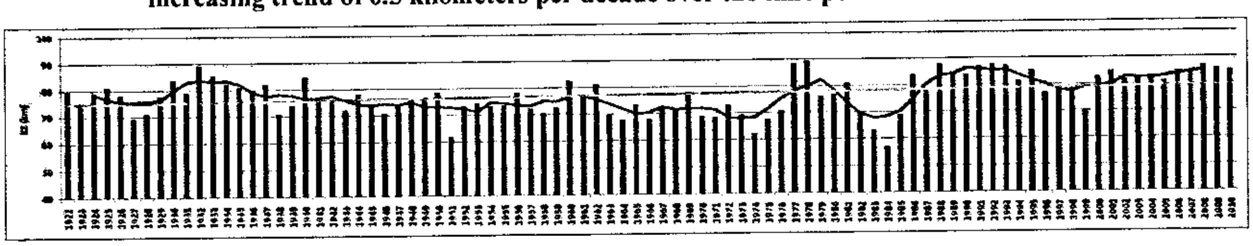


Figure 11 Calculated X2 location in November by decade (1922–2010).

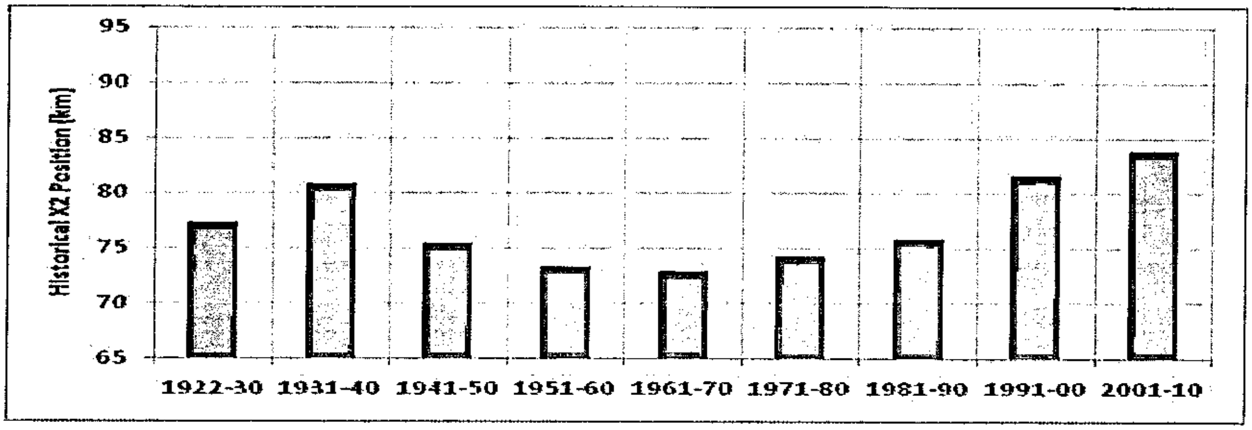
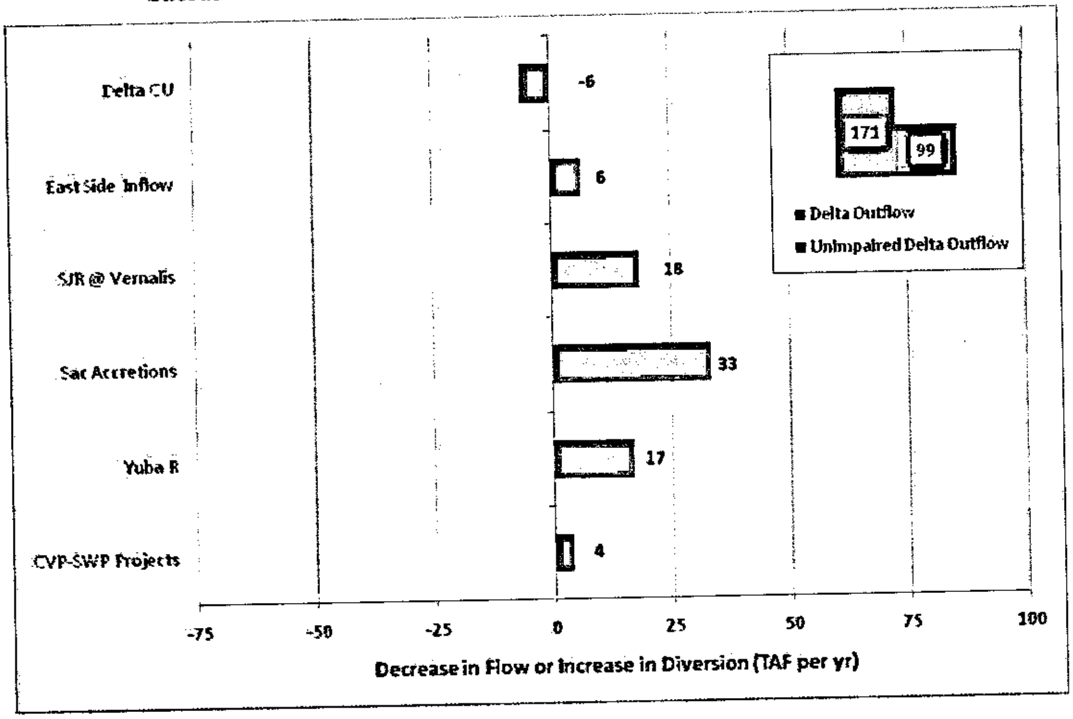


Figure 12 demonstrates that the September outflow reduction is primarily the result of dryer hydrologic conditions that have occurred between decades, from the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is explained in large part by the difference in unimpaired outflow (i.e., the reduction in unimpaired outflow [red bar at 99 TAF/year] accounts for a majority of the reduction in outflow [blue bar at 171 TAF/year]). However, water management also contributed to the outflow reduction. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. These horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, the reduction in Sacramento Valley accretions (33 TAF/year) is the next most significant hydrologic factor explaining the decrease in September outflow between the 2 decades. The CVP/SWP Projects appear to have had minimal (4 TAF/year) contribution to reductions in outflow. Increased exports are nearly balanced by increased upstream project reservoir releases.

Figure 12 Contributions to decrease in September Delta outflow (1991-2000 compared to 2001-2010). The majority of the difference in outflow between these two decades is due to differences in natural hydrology as measured by unimpaired outflow. Reductions in Sacramento accretions are the next largest contributor.



Similar to Figure 12, Figures 13 and 14 identify the hydrologic factors that drive the decrease in October and November outflow from the prior decade (1991–2000) to the most recent decade (2001—2010), respectively. The vertical bars on Figure 13 show that unimpaired flow was higher in 2001–2010 than in 1991–2000 (red bar at -14 TAF/year). The figure shows that the reduction in Sacramento Valley accretions (93 TAF/yr) and San Joaquin River inflow at Vernalis (40 TAF/year) were the most significant factors in explaining the decrease in October outflow between the 2 decades. The CVP/SWP Projects actually contributed to higher outflow in 2001–2010 (-57 TAF/year), i.e., increased exports were more than fully balanced by increased upstream project reservoir releases. The vertical bar chart inset in the top right-hand corner of Figure 14 demonstrates that the difference in November outflow is explained in large part by the difference in unimpaired outflow; that is, the reduction in unimpaired outflow [red bar at 107 TAF/year] accounts for a majority of the reduction in outflow [blue bar at 136 TAF/year]. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. These horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, no single hydrologic factor stands out in explaining the decrease in November outflow between the 2 decades. In other words, while water management also contributed to the outflow reduction between decades that reduction is primarily the result of dryer hydrologic conditions.

Figure 13 Contributions to decrease in October Delta outflow (1991-2000 compared to 2001-2010). Unimpaired flow was higher in the most recent decade. Reduction in Sacramento Valley accretions and San Joaquin River inflow at Vernalis were the most significant factors in explaining the decrease in October outflow between the two decades. CVP/SWP Projects contributed to higher outflow in 2001-2010.

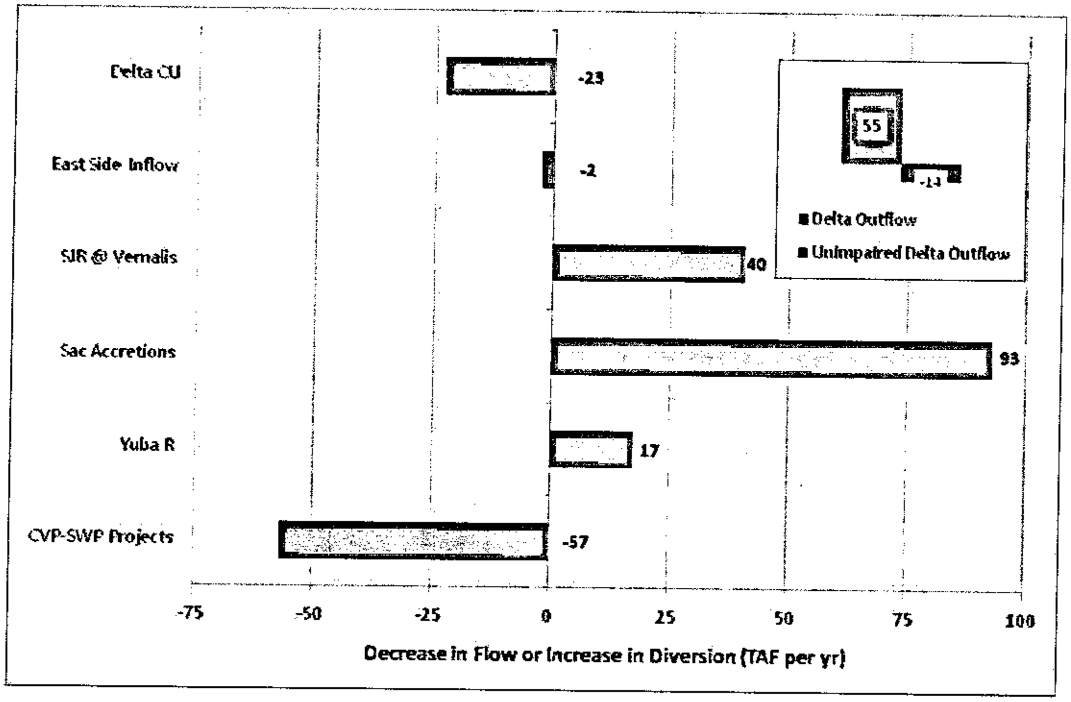
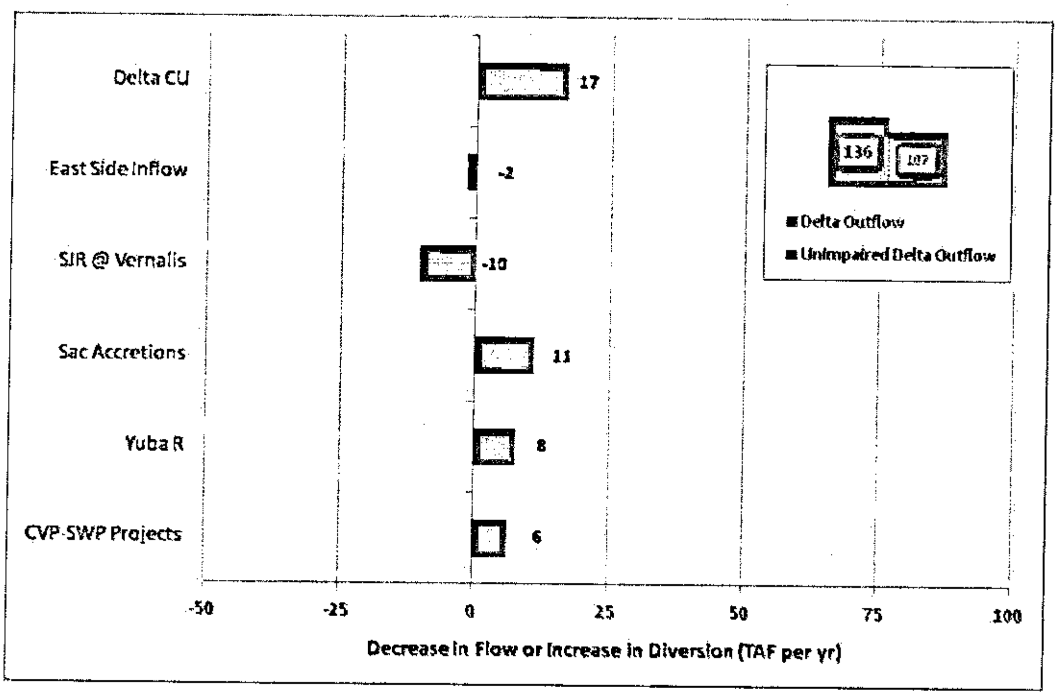


Figure 14 Contributions to decrease in November Delta outflow (1991-2000 compared to 2001-2010). The difference in November outflow is explained in large part by the reduction in unimpaired outflow. After reduction in unimpaired outflow, no single hydrologic factor stands out in explaining the decrease in November outflow between the two decades.



3.1.5 Winter-Spring X2

The 2010 Flow Criteria Report proposed a percent of unimpaired flow approach to managing outflow from January through June (State Water Board 2010, p. 98). The primary justification for this recommendation was the statistical correlation between winter-spring (January-June) outflow (X2) and longfin smelt abundance (State Water Board 2010, pp. 100-108). A secondary rationale was the existence of various other statistical correlations between abundance of several non-Endangered Species Act listed species and outflow (X2) during various months within the January-June (winter-spring) timeframe (State Water Board 2010, pp.100-108). A third rationale was a citation to Bunn and Arthington (2002) and their four principles that generally describe how flow affects aquatic biodiversity, although the 2010 Flow Criteria Report did not explain the potential applicability of those principles to the Bay-Delta estuary (State Water Board 2010, p. 100). To support the conclusion that outflow (X2) has changed over time, creating an increasingly unnatural flow pattern, the 2010 Flow Criteria Report made several comparisons between actual outflow and unimpaired outflow over various time periods: 1956–1987, 1988–2009, and 2000–2009 (State Water Board 2010, p. 104).

There are several observations in the 2010 Flow Criteria Report regarding the analysis of Winter-Spring X2 patterns that are particularly relevant and worth reconsidering.

- It is not appropriate or meaningful to average the winter months (January-March) and the spring months (April-June) together for the purpose of identifying trends in outflow. The hydrology between winter and spring is in stark contrast, as are the life stages and biological requirements of the fishes in the two seasons. The inflow and diversion patterns are also quite different in winter compared to spring.

- The time periods selected (1956–1987, 1988–2009, and 2000–2009) for comparative purposes in the 2010 Flow Criteria Report raise a number of concerns. It is unclear how natural hydrology was accounted for in the selection of averaging periods. This lack of clarity is a concern as natural hydrology can skew the results of a data analysis, thereby suggesting changes in water consumption that may not exist. The biological relevance of the time periods selected (1956 and later) is also questionable because these periods represent highly altered physical conditions in the Delta and are, therefore, not related to "natural" or undeveloped conditions. It is also unclear why the entire hydrologic record was not used in the analysis.

- As mentioned previously and as discussed in more detail below, unimpaired flows are a calculation of artificial conditions. The Delta and the fishes within the Delta have never experienced unimpaired outflow. It is, therefore, inappropriate to compare the artificial unimpaired flow calculation to actual historical outflow conditions and conclude that a change has occurred.

- By averaging two entirely different seasons over several decades, the trends in the position of X2 are obscured. The analysis considers data at several different scales and then asserts that differences in the calculated X2 locations are the proximate cause.

When January-June data are considered over the entire hydrologic record, an eastward movement of the X2 line does appear to have occurred through time (Figure 15). This outcome is expected because one of the historic purposes of the reservoirs was to capture and store water in the winter and spring (thereby reducing outflow) and to facilitate releases of freshwater in the summer and fall.

Figure 15 Calculated X2 location in January through June 1922–2010 showing X2 trending eastward over time due to construction and operation of reservoirs designed to capture winter and spring flows to reduce flooding and to store water for release later in the year.

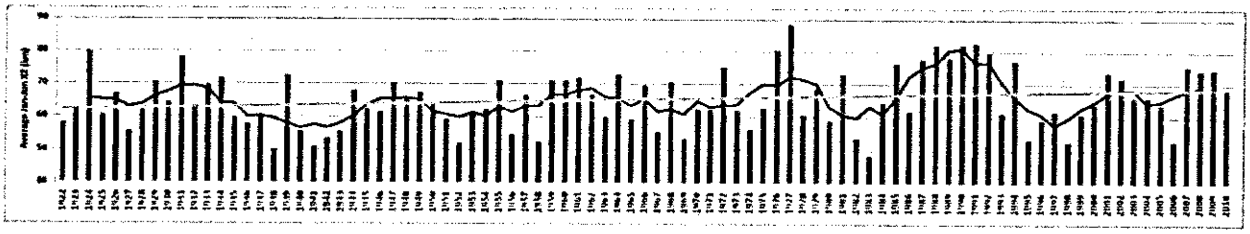
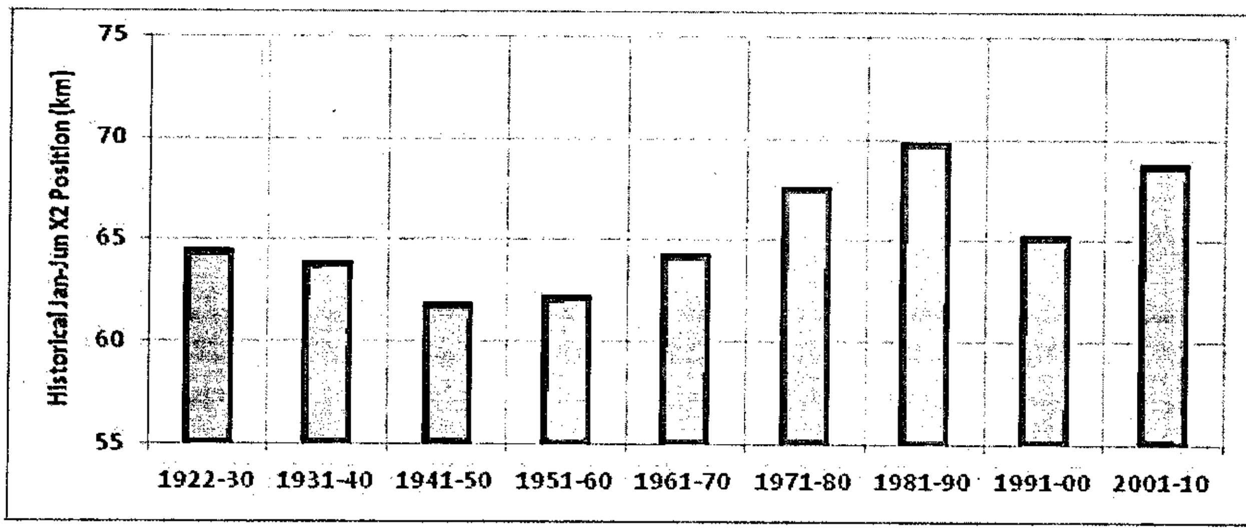


Figure 16 Calculated X2 location in January through June by decade (1922–2010). Calculated X2 location moved eastward after major reservoirs were constructed in the 1940s and 1950s; however, the increase has not been steady over time.



Figures 15 and 16 are mirroring the gross scale of the 2010 Flow Criteria Report, which makes identifying seasonal trends difficult. Therefore, this analysis also considers changes in the calculated X2 location by month. As spring is generally considered the most biologically important season for fishes, Figures 17 through 19 show the monthly X2 location for April, May, and June. The April data show that the calculated X2 location in 2001–2010 was comparable to the decades 1971–1990, but more easterly than 1991–2000. Data from the more recent two decades shows May and June to be fresher than they were in the immediately prior three decades (1971–1990) and are comparable to the decade 1961–1970.

Figure 17 **Calculated X2 location in April 1922–2010. Calculated X2 location in 2001-2010 was comparable to the decades 1971-1990, but more easterly than 1991-2000.**

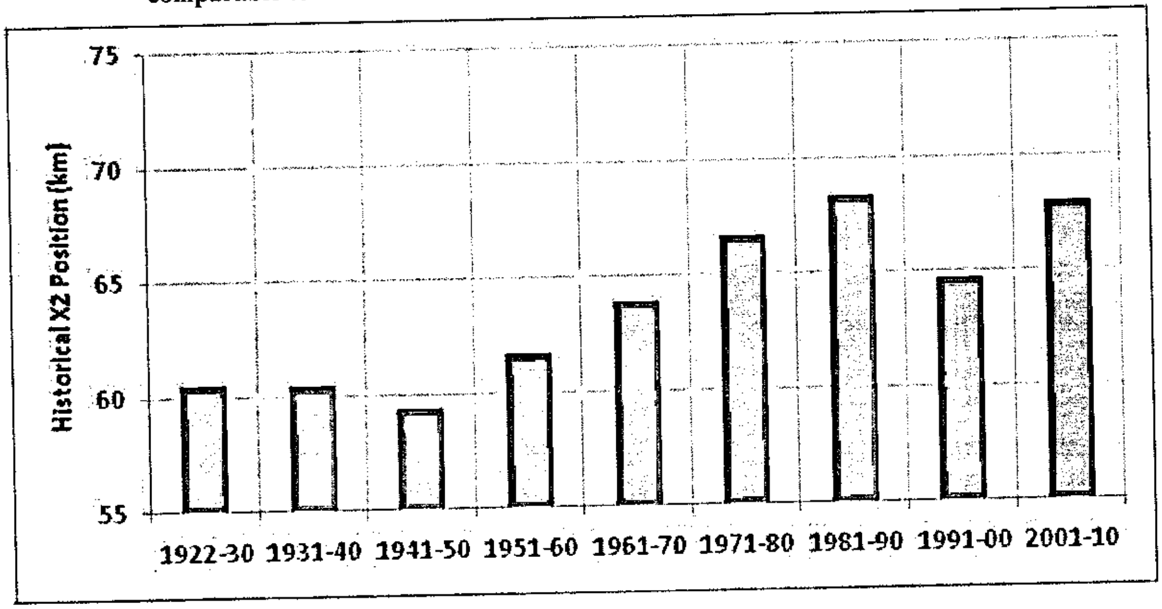


Figure 18 **Calculated X2 location in May 1922–2010. The most recent two decades (1991-2010) were fresher than the immediately prior three decades (1971-1990) and were comparable to the decade 1961—1970.**

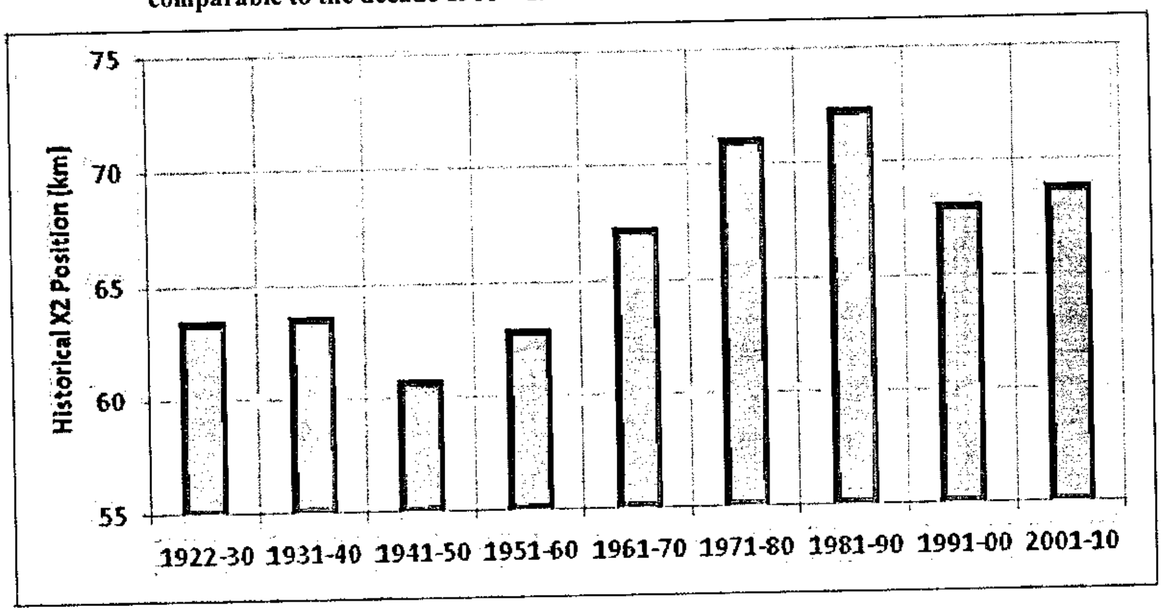
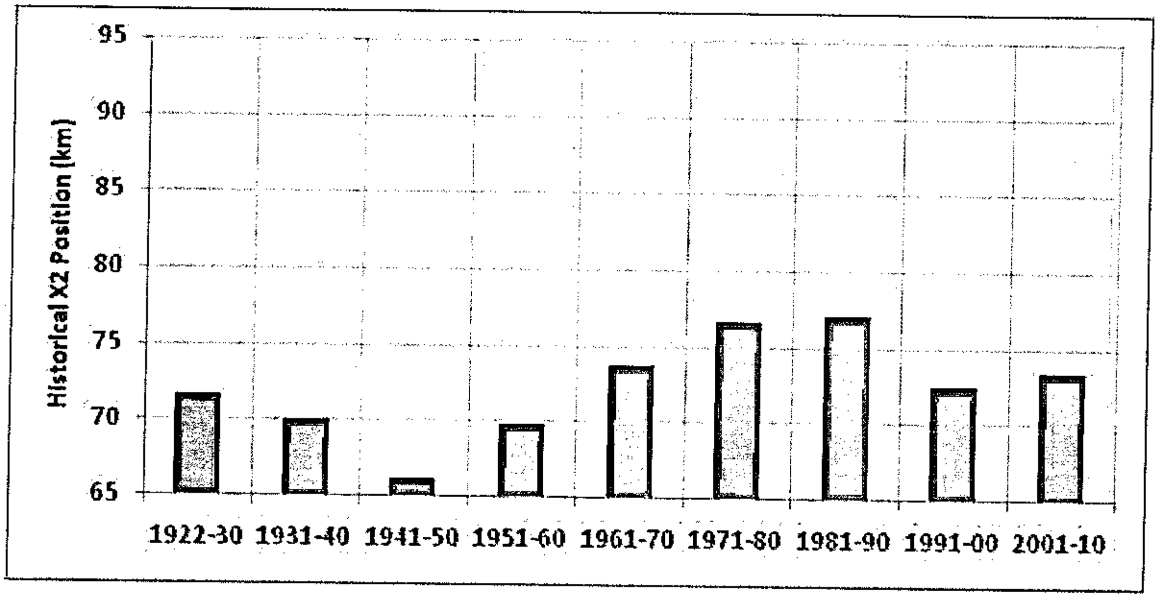


Figure 19 Calculated X2 location in June 1922–2010. The most recent two decades (1991-2010) were fresher than the immediately prior three decades (1971-1990) and were comparable to the decade 1961-1970.



Figures 20 through 22 show the monthly X2 location for January, February, and March. In these months, the most recent decade (2001–2010) is most comparable to the decade 1981–1990. In the most recent decade (2001–2010) X2 has on average been further upstream than in the prior decade (1991–2000).

Figure 20 Calculated X2 location in January 1922–2010. The most recent decade (2001-2010) is most comparable to the decade 1981-1990. In the most recent decade (2001-2010) X2 was further upstream on average than in the prior decade (1991-2000).

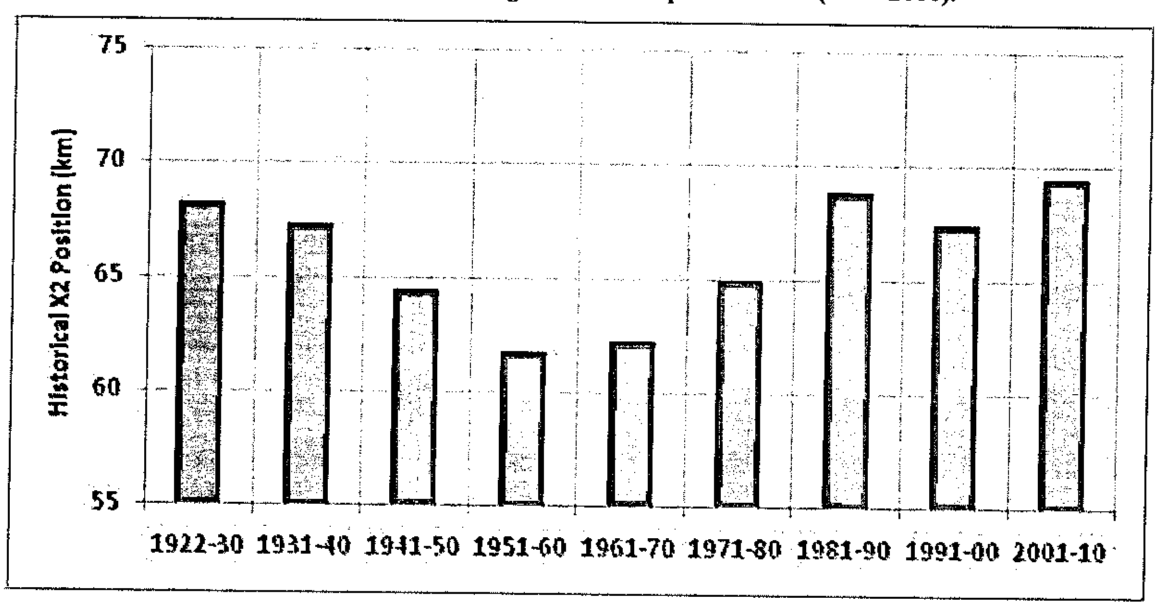


Figure 21 Calculated X2 location in February 1922–2010. The most recent decade (2001-2010) is most comparable to the decade 1981-1990. In the most recent decade (2001-2010) X2 was further upstream on average than in the prior decade (1991-2000).

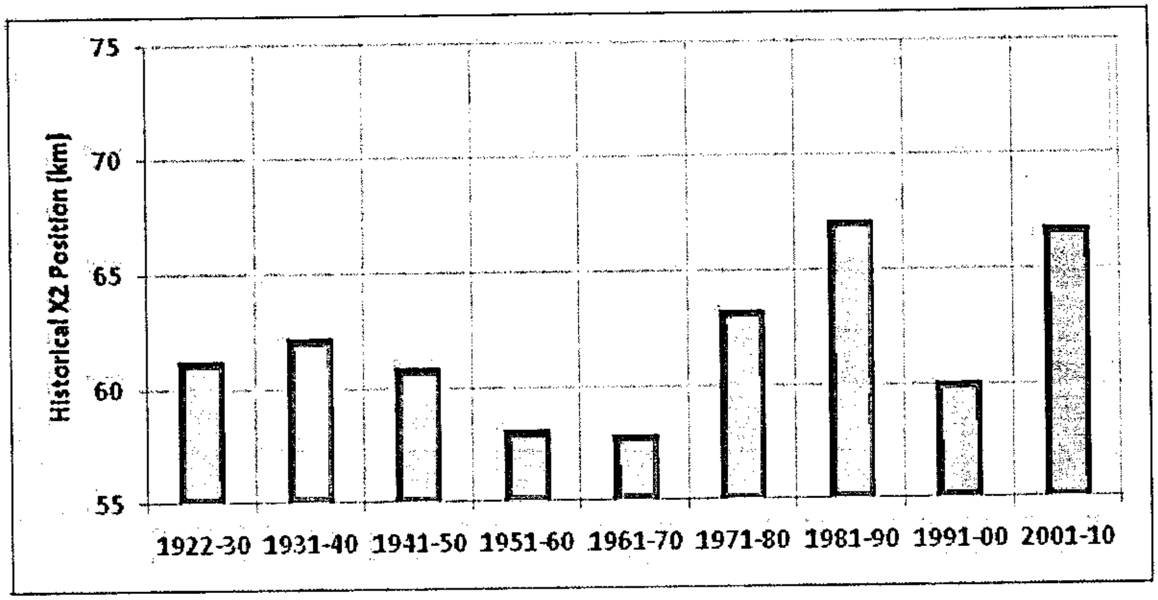
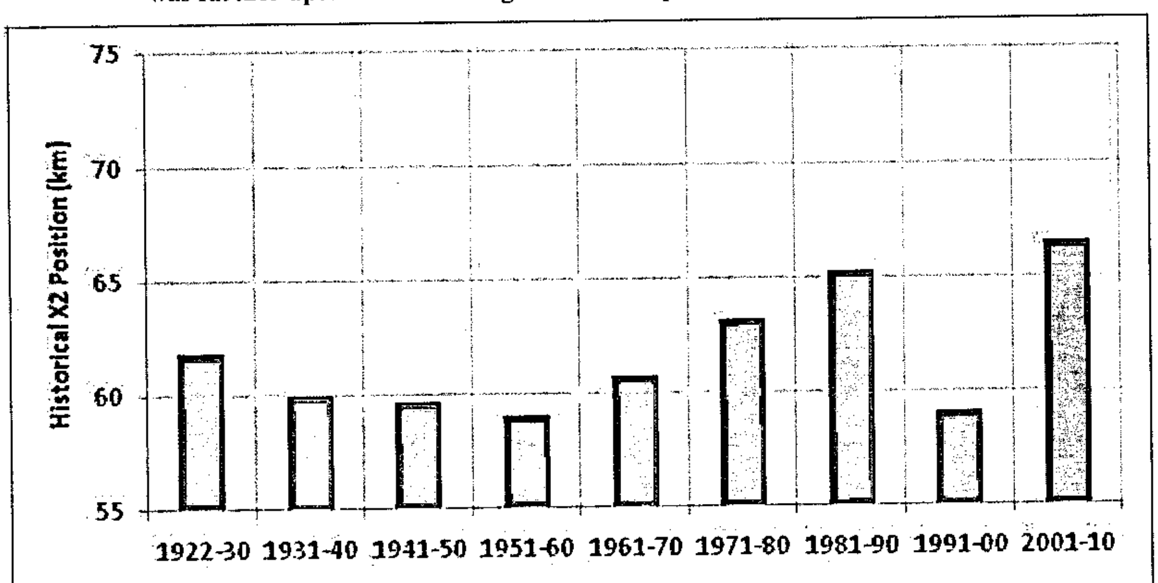


Figure 22 Calculated X2 location in March 1922–2010. The most recent decade (2001-2010) is most comparable to the decade 1981-1990. In the most recent decade (2001-2010) X2 was further upstream on average than in the prior decade (1991-2000).



Figures 16 through 22 show that the calculated X2 has been greater each month (January -June) in the decade 2001–2010 than it was in the prior decade 1991–2000. To understand the reason for this difference in the X2 location, Figures 23 and 24 compare changes in inflows and water diversions between the decades 1991–2000 and 2001–2010. These figures show that the increase in X2 is due primarily to dryer hydrology. As hydrologic and diversion patterns are different in winter compared to spring, the changes are identified by season winter (January - March) and spring (April-June).

Figure 23 identifies the hydrologic factors that drive the decrease in winter (January-March) outflow from the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is explained in large part by the difference in unimpaired outflow (*i.e.*, the reduction in unimpaired outflow [red bar at 6,273 TAF/year] accounts for the majority of the reduction in outflow (blue bar at 6,745 TAF/year]). Thus, the outflow reduction between decades is primarily the result of dryer hydrologic conditions. Water management also contributed to the outflow reduction. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. The horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, CVP/SWP operation (434 TAF/year) is the next most significant hydrologic factor in explaining the decrease in winter outflow between the 2 decades. In other words, Figure 23 shows that 93% of the outflow difference (6273 TAF v. 6745 TAF) is due to changes in unimpaired flow (drier hydrologic conditions) and that CVP/SWP operations comprise only 6% of the difference (434 TAF v. 6745 TAF).

Figure 23 Contribution to decrease in January- March Delta outflow (1991–2000 compared to 2001–2010). Changes in unimpaired flow (drier hydrologic conditions) explain 93% of the difference in outflow between these decades. CVP/SWP operations explain only 6% of the difference.

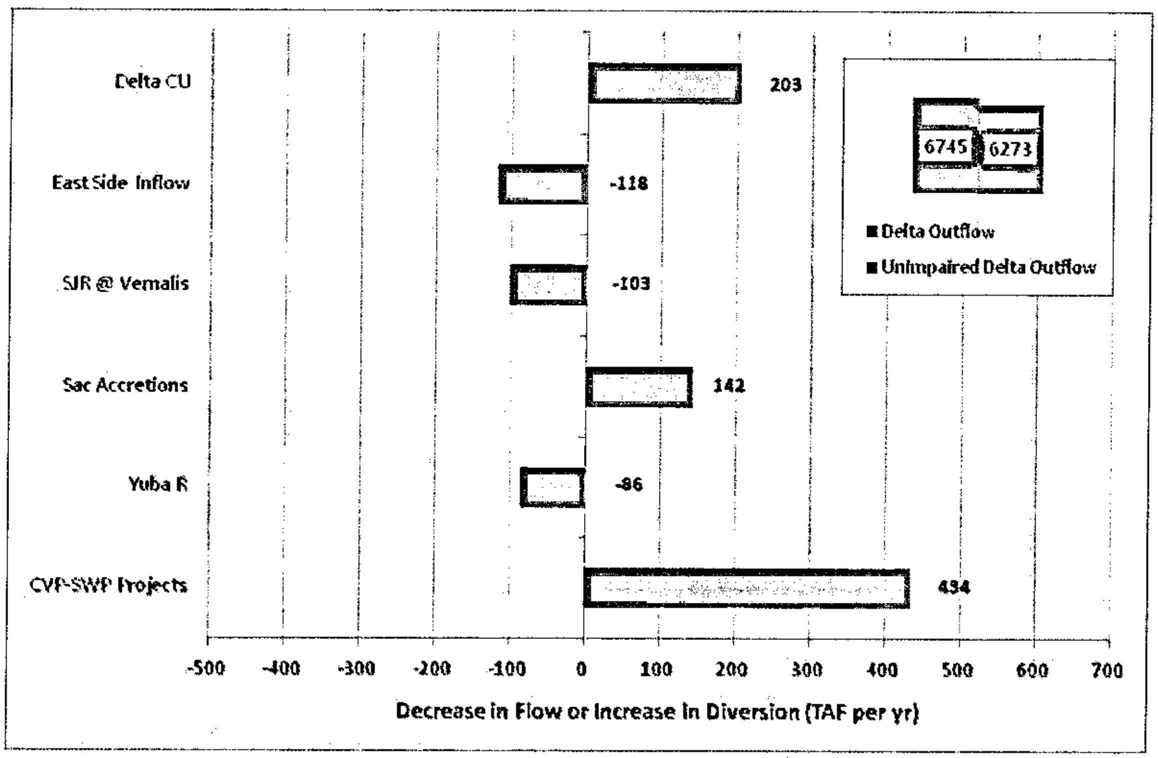
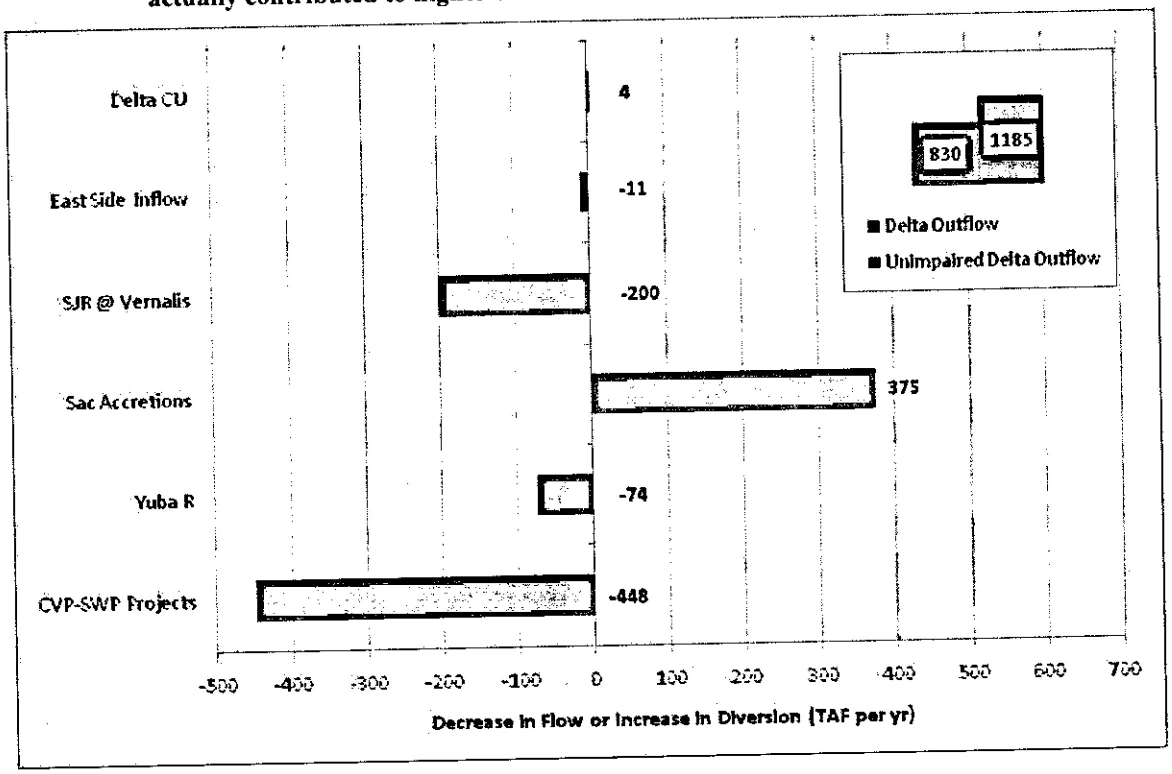


Figure 24 identifies the hydrologic factors that drive the decrease in spring (April-June) outflow from the prior decade (1991–2000) to the most recent decade (2001–2010). The vertical bar chart inset in the top right-hand corner of the figure demonstrates that the difference in outflow is less than is explained by the difference in unimpaired outflow (*i.e.*, the reduction in unimpaired outflow [red bar at 1,185 TAF/year] is larger than the reduction in outflow [blue bar at 830 TAF/year]). In other words, drier hydrologic conditions can explain all of the reduction in outflow between decades. The horizontal blue bars in the main body of the figure represent normalized contributions by individual hydrologic drivers towards the decrease in annual outflow between decades. These horizontal blue bars sum to the difference between the vertical bars. The horizontal blue bars in the main body of the document represent changes in outflow other than hydrology. The figure shows that, after reduction in unimpaired outflow, reduction in Sacramento Valley accretions (375 TAF/year) is the next most significant hydrologic factor contributing to decrease in winter outflow between the 2 decades. The CVP-SWP Projects (-448 TAF/year) and San Joaquin River flows at Vernalis (-200 TAF/year) actually contributed to higher outflow.

Figure 24 Contribution to decrease in April-June Delta outflow (1991–2000 compared to 2001–2010). The difference in outflow between the decades is less than the difference in unimpaired outflow; therefore drier hydrologic conditions can explain all of the reduction in outflow. The CVP/SWP Projects and San Joaquin River flows at Vernalis actually contributed to higher outflow.



3.1.6 Calculation of predevelopment outflow

In the 2010 Flow Criteria Report, and in presentations by certain stakeholders in the ongoing Delta Plan review workshops, a percent of the unimpaired hydrograph approach has been proposed as a method of regulating future Delta inflows and outflow. The fundamental assumption underlying the percent of the unimpaired hydrograph approach is that the unimpaired flow is a valid or otherwise useful estimator of predevelopment or "natural" flows. It is not. The term "unimpaired" outflow leads many to wrongly believe it means "natural" or pristine.

Unimpaired inflows is a calculation intended to represent flow entering the Delta through existing leveed river channels absent storage operations and downstream uses. These flows are assumed to be routed through the existing system of channels and bypasses into the Delta and the Bay, without any losses or modifications on the way and with no recognition of the natural interaction of water with the land, the original incubator of native species (DWR, 2007).

If restoring a more "natural" flow patterns is the goal, regulations based on unimpaired outflow are not going to be effective. The obvious question therefore is what is a valid approach to estimate natural or predevelopment outflow? The Public Water Agencies have been considering that question. They have explored ways to estimate the variability in natural flow, and those next step modeling efforts are described below.

3.1.6.1 Natural flows

The physical structures of the historic Delta (land covers and channel configurations) were very different than exist today. As the physical aspects of the Delta changed over time, local hydrodynamics, hydraulics and flow changed as well. In large portions of the existing Delta, the land and the water are disconnected from each other by levees, native vegetation has been replaced by agriculture, and the once meandering rivers have been channelized. Any estimate of natural flows, including outflows, must account for the fact that the physical environment was dramatically different under natural conditions because those historic structures heavily influenced outflow patterns.

Under natural conditions, the Central Valley functioned as a series of side-stream reservoirs, located alongside the major streams, rather than at the headwaters of the streams. These stream-side reservoirs filled and drained every year. Thus, the natural rim inflows did not flow unimpeded through river channels into the Delta and the Bay. Rather, they spilled over elevated natural levees into side-stream reservoirs, where they were retained, diminished and ultimately returned to the channel.

Under natural conditions, the channels of the major rivers were not adequate to carry normal winter rainfall runoff and spring snowmelt (Grunsky, 1929). They overflowed their banks into vast natural flood basins flanking both sides of the Sacramento and San Joaquin Rivers (Hall, 1880). Water flowed over the levees in thin sheets, until the water level on the non-river side of the levees rose and joined with the water surface in the channel. When this happened, all visible trace of a channel was lost and the area took on the appearance of a large inland sea (Grunsky, 1929, p. 796). In the San Joaquin Valley in July 1853, for example, engineers surveying a route for a railroad, reported:

> The river [San Joaquin] had overflowed its banks, and the valley was one vast sheet of water, from 25 to 30 miles broad, and approaching within four to five miles of the hills.

(Williamson, 1853, p. 12). The filling and emptying of these flood basins had the effect of delaying the transmission of flood flows down the major rivers, reducing peak flows and velocities (TBI, sec. IV.B.1 and Grunsky, 1929). Some of the water in these flood basins gradually drained back into the main river channels after the floods subsided, through a complex network of sloughs. Some basins drained relatively rapidly while others retained flood waters through the summer or year round (Grunsky, 1929, p. 793 and 796; McGowan, 1961; Thompson, 1961, Olmstead and Davis, 1961, pp. 25-27). These flood basins also contained vast tracts of tule marsh, which retarded the drainage of the basins and evapotranspired residual flood waters (Babtist *et al.*, 2007). The resulting delayed transmission and reduced volume of flood and other natural flows is not reflected in unimpaired flows. Thus, setting monthly flow standards based on a percentage of monthly unimpaired flows is not relevant to the original landscape that nurtured the species the State Water Board seeks to protect.

The main river channels were lined by wide levees that were built up over time from sediment deposited as rivers spread out over the floodplain. These levees were much larger and more developed along the Sacramento River than along the San Joaquin River (Hall, 1880, part II, p. 51). Along the Sacramento, the natural levees rose from 5 to 20 feet above the flood basins and ranged in overall width from about 1 to 10 miles, averaging 3 miles (Thompson, 1961, p. 297). The southern reaches of the San Joaquin River developed natural levees only poorly due to low sediment loads (Hall, 1880, part II, p. 51), and only as the river entered the valley floor (Warner and Hendrix, 1985, pp. 5.15-5.16), sustaining large freshwater marshes still found there today (Katibah, 1984 and Garone, 2011, p. 79). However, natural levees did form along the major northern San Joaquin River tributaries -- the Tuolumne, Stanislaus, Merced, Mokelumne, Cosumnes, and northern San Joaquin (Warner and Hendrix, 1985, p. 5.15). Lush riparian forests occupied these levees.

The flood basins also received flow from sources other than flood flows spilling over the natural levees. These included upland runoff and west- and east-side streams, e.g., Stony, Cache, Putah. These were blocked from reaching the main river channels by the natural levees. They spread out over the valley floor, pooling in expansive sinks of tule marsh and connecting to the main rivers only by subsurface flow (Garone, 2011, p. 23; Thompson, 1961, p. 299). Further, breaches or "crevasses" in the natural levees and percolation of water through the relatively coarse, porous levees permitted excess waters to escape the main streams and spread over the low flood plains (Thompson, 1960, pp. 352-353).

This highly productive system was completely replumbed to control floods, facilitate the irrigation of the valley, and for navigation. The channels were dredged and rip-rapped, the levees were raised, the flood basins were drained, bypasses installed, and head-stream reservoirs were built to replace the side-stream storage and generate electricity.

The Sacramento and San Joaquin Rivers discharged into the Delta, which is a product of its topography. As the rivers descended from the mountains toward sea level near their confluence, their gradients decrease dramatically, reducing their velocity and ability to incise their channels. Thus, they distributed their flow into numerous sloughs that meandered across the landscape (Garone, 2011, p. 27) to a common mouth into Suisun Bay. Shoals were present at the mouth of the rivers, one notably opposite Collinsville, which was an obstruction to the escape of flood waters from the Sacramento River (Hall, 1880, part II, p. 23). An appreciable amount of Sacramento River water below Sacramento was originally (and continues to be) routed through the Georgiana and Three-Mile sloughs into the San Joaquin River (Hall, 1880, p. 47).

Under natural conditions, these rivers were braided together in the Delta in a complex arrangement of channels weaving through flat, low-lying islands with elevations at or below sea level. These islands were submerged for much of the year, with water levels fluctuating with the tides and river flood stages. The islands' outer margins had small natural levees while the interior sections were marsh. When river flows were high in spring, the historical Delta was a morass of flooded island and marshes. In late summer, when river flows were low, the islands and marshes, protected by low natural levees, were often surrounded by saline water pushed upstream by tides. Nearly 50% of the Delta was originally submerged by daily tides (Thompson 1957, p. 21; Thompson 1961, p. 299). Dominant vegetation in the saucer-shaped islands included tules and on higher levee ground, coarse grasses, alder, walnut, and cottonwood (Thompson, 1957, chapters 1-2, pp.135-136; Thompson, 1961, p. 299; Hall 1880, part II, Moyle, 2002, p. 32). By the 1930s, these vast areas of Delta tidal wetlands and riparian vegetation were diked, drained, and converted into islands of farmland surrounded by high levees, now highly subsided; the sloughs were replumbed and deepened; and sand bars were removed, completely altering the natural hydrodynamics and its rich and diverse habitat for native species (Thompson, 1957, Lund *et al.*, 2010, Ch. 2, 3, and 5).

Finally, under natural conditions, groundwater moved generally from recharge areas along the sides of the valley towards topographically lower areas in the central part of the valley, where it discharged primarily as evapotranspiration from marshes and riparian forests (TBI, Sec. IV.B.2; Bertoldi *et al.*, 1991, pp. A17, A23, Fig. 14A; Williams, 1989, p. D33; Davis, 1959, p. 86). Groundwater was near the surface in much of the Valley (Bryan, 1915, p. 19 and plate 11; Kooser *et al.,* 1961, pp. 265 and 278). The U. S. Geological Survey estimated that under natural conditions, the groundwater table was less than 10 feet below the surface over about 62% or 8,000 square miles of the Central Valley (Williamson *et al.*, 1989, P. D40). The groundwater system was in a state of dynamic equilibrium. Natural recharge was balanced by natural discharge. This has been recently confirmed for the San Joaquin Valley (excluding the Tulare Basin) using a physically based, surface-subsurface numerical model (HydroGeoSphere) (Bolger *et al.,* 2011, pp. 322-330). The natural groundwater system has been extensively altered by pumping for irrigation and other uses, resulting in widespread overdraft and land subsidence.

3.1.6.2 Estimation of pre-development land cover

There is general agreement within the scientific community regarding the nature of the physical environment that existed in the pre-development era. A recent San Francisco Estuary Institute ("SFEI") study further collaborates the natural flow description provided above (see SFEI Report at http://www.sfei.org/news_items/press-delta-historical-ecology-report). However, there is yet to be general agreement on how many acres of each land cover type existed and the land cover's cumulative consumptive water use.

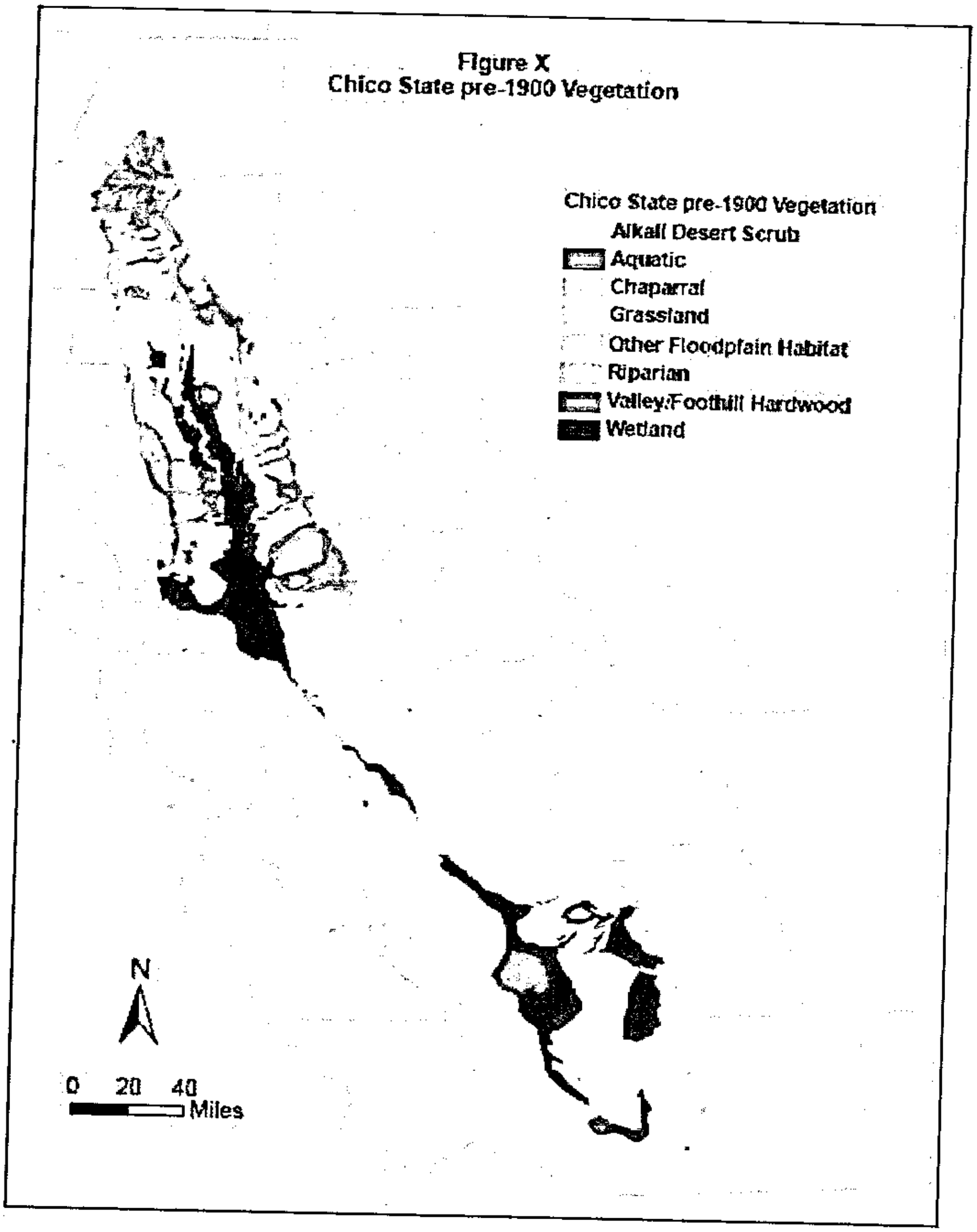
In 2003, California State University-Chico ("Chico") completed a historic mapping effort to determine the acreages of the various types of native vegetation that once covered the Delta and its watershed. The Chico effort mapped four different time periods, with the "pre-1900" map being of particular interest for purposes of calculating predevelopment (pre-1900) outflow.[4] To

[4] Chico (2003) has been referenced in at least two published works: Bolger et al. 20011 and Barbour *et al.* 2007.

create its maps, Chico reviewed and digitized approximately 700 historic maps, searching numerous collections of historic maps in public libraries. For this report, Dr. Phyllis Fox confirmed the accuracy of the Chico State pre-1900 map using several sources, including: Hall (1887); Küchler (1977); Roberts *et al.* (1977); Dutzi (1978); and Fox (1987). These archival maps and others were scanned (400-dpi full color scanner), the scanned versions were georeferenced[5] using various data layers (e.g., county, township), and the map features were digitized by hand using editing features in ArcMap. ArcMap's geoprocessing tools were used to determine areas of the various types of vegetation.

[5] Transforming scanned images into maps with reference coordinates.

Figure 25 Chico (2003) pre-1900 map.

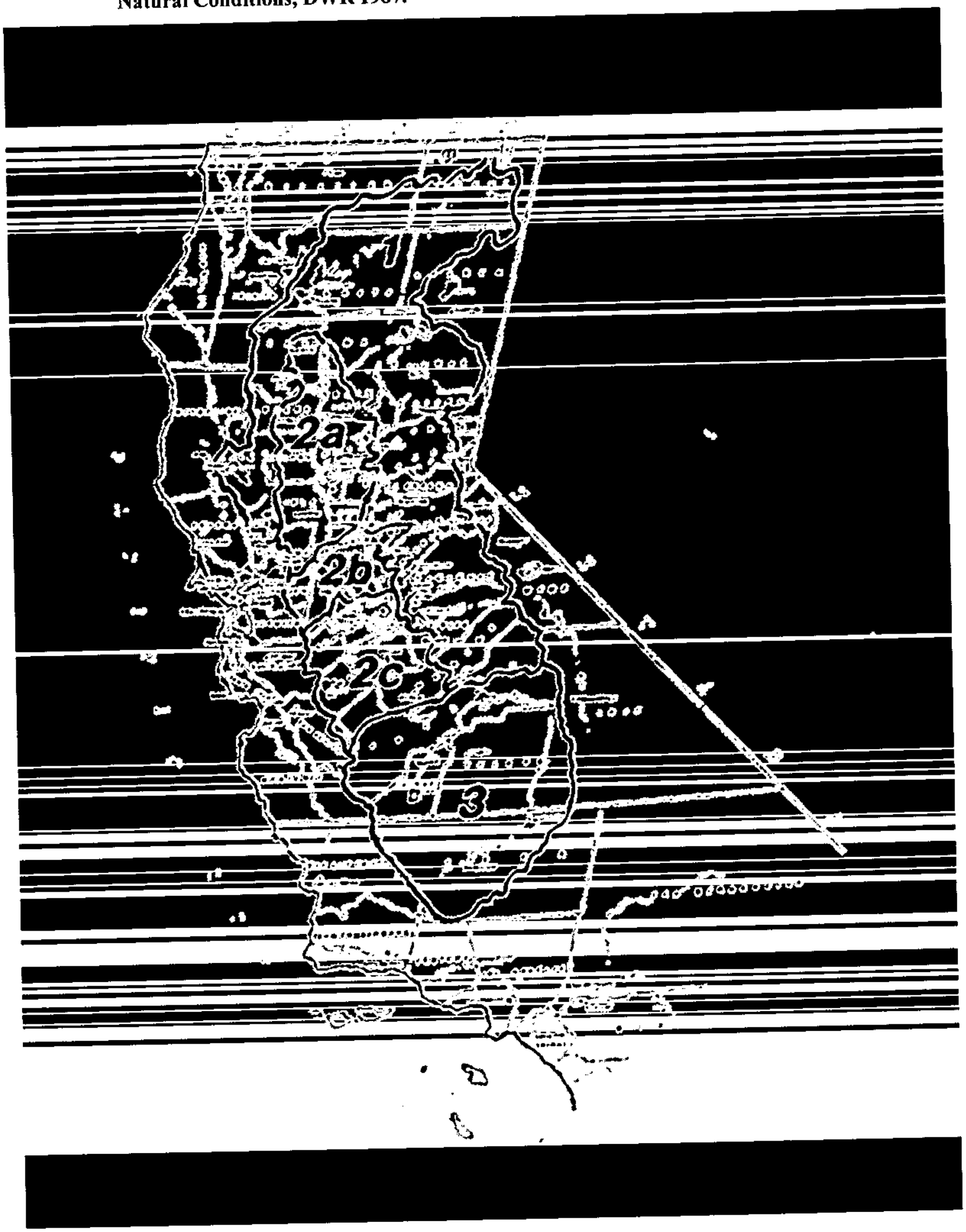


Chico (2003) estimated land cover throughout the Central Valley. We divided the area that drains into the Bay into upper, middle and lower region to correspond with DWR's hydrologic units, as defined by DWR in California Central Valley Unimpaired Flow Data, Second Edition, February 1987.[6] The DWR drainage area encompasses the Sacramento Valley (Area 2a), the Delta and upslope areas (Area 2b), and the San Joaquin Valley Area (Area 2c). These three

[6] DWR has updated its designation of basins and boundaries since the 2nd edition, and future estimates will reflect that new information.

areas define the rim of the valley where the unimpaired flows are gauged. See Figure 26, DWR hydrologic units.

Figure 26 Hydrologic Units Used in Calculating Freshwater Inflow to San Francisco Bay Under Natural Conditions, DWR 1987.



We estimated acreages of each type of vegetation by drainage basin based on Chico pre-1900 map using ArcMap's "Calculate Geometry" feature. The results of this analysis, by drainage basin, are summarized in Table 2 discussed below for each vegetation type.[7]

Table 2 Natural Vegetation Land Area (acres), Chico (2003)

Vegetation	Sacramento Basin (2a) (Acres)	Delta (2b) (Acres)	San Joaquin Basin (2c) (Acres)	Totals (Acres)
Aquatic	32,616	18,319	9,242	60,177
Grassland	1,591,415	615,799	2,263,714	4,470,928
Other Flood Plain Habitat	474,743	117,101	572,291	1,164,135
Riparian	443,852	54,930	72,192	570,974
Valley/Foothill Hardwood	639,650	197,656	9,268	846,574
Wetland	529,814	395,354	86,497	1,011,665
Total	3,712,090	1,399,159	3,013,204	**8,124,453**

It is unknown if Chico's estimates accurately depict "pre-development" conditions as significant modifications to the physical environment and large scale farming had already began by the turn of the 20th century. The earliest resource map used by Chico is 1874 (Chico, 2003, Table 1). To the extent Chico's estimates reflect early development, Chico underestimates natural land cover, and as a result, underestimates natural evapotranspiration.

There is some uncertainty regarding Chico's land cover estimates, primarily because of the various assumptions associated with using numerous archival resources, with varying degrees of accuracy, that cover a range of years. Nevertheless, it appears that the Chico estimates are consistent with findings of other similar research efforts, as discussed below.

3.1.6.2.1 Description of historic grasslands

The plains were smooth and nearly level lands that were formed as flood waters spread over them, leaving behind thick deposits of silt. The vegetation in the grasslands was prairie, as variously defined by Heady (1988), Küchler (1977), and Bartolome et al (2007). The original grassland no longer exists. What it once looked like and contained can never be known with certainty as early eye witness accounts are vague. The best guess by experts is that it was dominated by two species of needlegrass (*Stipa cernua* and *S. pulchra*).

Vernal pools (or "hog wallows") were present within the grasslands but were not separately mapped by Chico. These are seasonal ephemeral wetlands that fill and dry out each year. They

[7] "Chaparral" was removed from the land cover estimates as it was insignificant, totaling a few hundred acres.

are shallow depressions underlain with an impermeable layer of soil. In winter, the hardpan soils underlying these pools prevent water from penetrating, saturating the upper soil and filling the basin with water, thus forming pools and small lakes. Rainfall collects in the depression, stands through early spring, then evaporates as temperatures rise and rainfall declines. The soil remains moist through April and May and then desiccates (Solomeshch, 2007). However, this does not imply they do not contribute to water losses.

The Central Valley vernal pools appear to be supported by perched aquifers. Seasonal surface water and perched groundwater connect uplands, vernal pools and streams (Rain *et al.*, 2006). Thus, these aquifers may contribute significantly to evapotranspiration. These vernal pools have not been mapped and evapotranspiration from this vegetation type has been treated by Chico (2003) as standard grassland, a likely underestimate.

Most vernal pools are densely vegetated seasonally, primarily with native annual grasses, forbs, and pool-bed algae. They support a rich variety of plants including annual forbs, grasses, rushes, and succulents; cryptophytic perennial herbs, perennial grass and forb halophytes, perennial rushes, cryptophytic perennial forbs, and small subshrubs (Solomeshch *et al.*, 2007, p. 398). Rings of vegetation form as the rainfall stops and temperatures rise in late spring. These vernal pools were present throughout the Central Valley under natural conditions, but were most abundant in Fresno, Madera, Merced, Placer, Sacramento, Tehama, and Yuba counties (Solomeshch *et al.*, 2007, p. 398). Most pools are less than 0.02 acres (100 m^2) in area, but a few covered tens of acres up to 300 acres and were temporary lakes (Solomeshch *et al.* 2007, p. 398; Barbour *et al.*, p. 83). Under natural conditions, vernal pools may have covered 1 percent of the State's area (Barbour *et al.*, pp. 81-83; Crampton, 1974, p. 30), but they were not separately mapped by Chico.

3.1.6.2.2 Description of wetlands

Chico (2003) described its wetland category as, "Wetland (perennial) – Also considered Freshwater Marsh." Wetlands are among the most productive wildlife habitats in California. They occur on virtually all exposures and slopes provided the depression or basin is periodically flooded. Characteristic species include various species of Cattails (*Typha spp.*), Bullrushes or Tules (*Scirpus spp.*), Rushes (*Juncus spp.*), and Sedges (*Carex spp.*).

The Chico map describes about 1 million acres of perennial wetland. This estimate is confirmed by a number of primary sources, including the federal surveys done pursuant to the Arkansas Swamp Act of 1850, comparable California surveys, independent surveys by the California State Engineer, and technical summaries based upon surveys. One of the most significant of these reports confirming the extent of the tule marshes was prepared by Professor Hilgard, generally regarded as the father of modern soil science and the first director of the Agricultural Experiment Station at the University of California, Berkeley. His report was prepared for the 1880 U.S. Census. It separately listed the area of tule lands in each county, showing a total of 1.2 million acres tributary to the Bay. Another authoritative source, Marsden Manson, assistant to California's first State Engineer, published an estimate of about 1.0 million acres tributary to the Bay in a refereed and archival journal, based on State Engineer surveys. Thus, the value returned by the Chico pre-1900 map is consistent with historical surveys.

3.1.6.2.3 Description of floodplain habitat

This is the second largest category of native land areas, comprising 1.2 million acres, or slightly more than perennial wetlands. "Other Floodplain Habitat" is a category used by Chico to designate areas that are a mixture of wetlands, grasslands, and riparian forest that have not been previously differentiated on historic maps. Our analysis indicates some of the area classified by Chico as "other floodplain habitat" was classified by Dutzi as oak woodlands and savanna. Further, a comparison of the Chico pre-1900 map with early maps based on surveys indicates that much of this land has been mapped as tule marsh by others.

3.1.6.2.4 Description of valley/ foothill hardwood

In the Central Valley, "valley/foothill hardwood" vegetation as mapped by Chico primarily consists of three hardwood areas dominated by oaks: (1) the open woodland around the rim of the Central Valley; (2) savannas with trees widely spaced and scattered over grasslands, and (3) the densely wooded, thickly canopied oak riparian areas on the upper edge of levees along rivers (valley oak riparian forest) (Barbour and Major, 1988, pp. 387-405, 425-55; Allen-Diaz *et al.* 2007; Shelton 1987; Dutzi 1978; Pavlik *et al.* 1991, p. 9 and 63-64; Anderson 2006, pp. 30-32). The divisions between these three categories are somewhat arbitrary; gradations of communities exist between the savanna and riparian types.

The Chico map returned 847,000 acres of this vegetation type in the study area. Of this, 640,000 acres was in the Sacramento basin (basin 2a); 198,000 acres in the Delta (basin 2b); and 9,000 acres in the San Joaquin basin (basin 2c). This estimate is within the range of estimates by others. Shelton (1987) estimated 494,000 acres of "valley oak savanna," a subset of valley/foothill hardwood area mapped by Chico, reporting none in either the Delta or San Joaquin. Dutzi (1978) estimated 1.5 million acres of "valley oak woodland and savanna" in the Sacramento Valley, which includes all three categories mapped by Chico.

3.1.6.2.5 Description of riparian

Riparian vegetation was found along all of the low-velocity waterways in the Central Valley, but the largest areas occurred on the rivers with the largest natural levees. The riparian forest extended from the banks to the edge of the moist soil zone, and, in many cases, as far as the hundred-year flood line, up to 4 to 5 miles on each side on the lower Sacramento River, where natural levees were widest (Garone 2011, pp. 24-25; Katibah 1984, p. 24). They were also present along tributaries of the main rivers and the upper San Joaquin River (Roberts *et al.* 1977, Figure 2; Warner and Hendrix 1985, pp. 5.10 - 5.11; Williamson 1853, p. 12).

The Chico map describes 571,000 acres, of which 444,000 acres are in the Sacramento Valley (basin 2a); 55,000 in the Delta (basin 5b); and 72,000 acres in the San Joaquin Valley (basin 2c). Chico's estimate for the Sacramento Valley (444,000 acres) is about equal to Dutzi's (1979) estimate for this area (438,000 acres), which is not surprising as Chico relied on Dutzi for its pre-1900 mapping. The difference is primarily due to differences in the boundary of the Sacramento Valley.

However, Chico's estimate for the study area (571,000 acres) is low compared to estimates by others including Küchler 1977 (874,000)[8]; Roberts *et al.* 1977 (937,900 acres)[9]; Katibah 1984 (921,000 acres); and Warner and Hendrix (1985). Warner and Hendix comprehensively reviewed estimates available through 1985 and concluded that "the present 'best estimate' of pre-settlement riparian wetlands vegetation in the Central Valley is at least 1,600,000 acres...". Chico mapped areas shown by others as riparian forest as grasslands or other floodplain habitat, which use less water. Further, Chico separated out the riparian oak fringe of the riparian zone in some areas, which is generally included in most estimates of riparian acreage. Barbour *et al.* (1993), for example, estimated 900,000 acres of riparian forest, which they described as including the fourth zone, or the valley oak forest (Barbour *et al.* 1993, pp. 74-75).

3.1.6.2.6 Description of aquatic

Chico defined "aquatic" as including major water bodies, including lakes, reservoirs, and estuaries. Under natural conditions, the Central Valley contained open water surfaces, including lakes, sloughs, and overflow basins. The open water surface area was determined from historic sources to be about 68,000 acres (SWC, 1979). This compares favorably with the Chico (2003) estimate of aquatic areas of 60,000 acres. Water surface evaporation was calculated using the historic area and annual average pan evaporation data (5.6 ft/yr). The pan data was measured at Gerber. It was supplied by DWR and is used in their CalSim 3.0 model (Cheng, 2012).

3.1.6.3 Estimation of evapotranspiration of natural vegetation

To estimate consumptive use of native vegetation in the pre-development era, the evapotranspiration ("ET") rate (acre-feet per year) for each vegetation type must be identified and calculated (acre-feet per year).

ET is the sum of water lost by evaporation from the soil and open water surface plus loss from interception by vegetative cover and transpiration from plants. Transpiration is the loss of water from plants in the form of vapor that occurs primarily through stomates, microscopic holes in the leaves through which water is lost and carbon dioxide enters for growth. Lesser amounts are lost through the cuticle and lenticels in the bark (Kramer and Boyer, 1995). A leaf that facilitates the uptake of carbon dioxide (CO_2) and thus growth is also favorable for the loss of water. Thus, transpiration is related to canopy size, plant size, density, leaf area, etc. (Cowan, 1982, pp. 535-562; Devitt *et al.* 1994, pp. 452-457). These are important considerations here as the native vegetation was consistently described in eye witness accounts as large, immense, and lush. The evaporation component, on the other hand, is controlled by climatic conditions.

Generally, there are several methods to determine evapotranspiration. These include lysimeters, soil water balance, bowen ratio, eddy covariance, remote sensing energy balance, and sap flow measurements, among others. All of these methods contain degrees of error. We have used two methods in this report to estimate the ET rate of native vegetation: literature review of field

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[8] As reported by Shelton 1987.

[9] The Roberts et al. 1977 map was digitized and the area determined using the "Calculate Geometry" feature in ArcMap returning 638,451 acres in the Sacramento Valley (basin 2a), 131,931 acres in the Delta (basin 2b), and 114,862 acres in the San Joaquin Valley (basin 2c).

experiments and climate based assessment calculations. This analysis provides preliminary estimates based on both methods.

3.1.6.3.1 Results of evapotranspiration field experiment literature review

Research on the rate of vegetative evapotranspiration has been going on for decades. The calculated ET values from the literature review provided in Table 10 are used as comparison against the values measured by researchers. The reasons for providing a comparative range is that the science of measuring ET is evolving and many of the published field studies were conducted in locations outside of the Central Valley so the actual vegetation evapotranspiration (ET_c) values may not be accurately represent the pre-development conditions in the Central Valley. However, the purpose of this literature review is to show the variable magnitude f field study measurements.[10] Results of this literature review are presented in Tables 3 through 5, below.

Table 3 Water Use by Tules and Cattails

Locations	Type of Marsh	Annual Water Use (ft/yr)[d]	Reference
King Island, Delta	Freshwater tidal marsh	7.4 – 13.0[a]	Stout (1929-35)
Victorville, CA (Mojave River)	Desert inland marsh	6.5 – 7.0	Young and Blaney (1942)
Mesilla Valley, NM (Rio Grande River)	Freshwater marsh	10.1	Young and Blaney (1942)
Bonner's Ferry, ID	Inland marsh	5.1	Robinson (1952)
Antioch, Delta	Freshwater tidal marsh	5.8[b]	Blaney and Muckel (1955)
Clarksburg, Delta	Freshwater tidal marsh	9.6[c]	DPW (1931b)

a. Value for third year of growth. Range corresponds to two different tank configurations.
b. Calculated based on limited experiments at Joice Island in Suisun Marsh.
c. Experiments conducted in isolated tanks and values adjusted by multiplying by a factor of about 0.5.
d. All values measured in tank experiments in which tanks were set in natural environment unless otherwise stated.

[10] As some early ET studies had various methodical limitations, the American Society of Civil Engineers (ASCE) convened a task force to review the early literature. The 1989 ASCE report identified certain studies as "outstanding research" and contains a complete bibliography of ET studies widely considered reliable. Many of the citations presented herein were characterized by the ASCE as "outstanding," particularly those conducted by Blaney and Young in the Delta and elsewhere in California.

Table 4 Water Use by Native Grassland Vegetation

Vegetation	Annual Water Use (ft/yr)	Location	Reference
Field Studies			
Native brush	1.4 – 1.8	San Bernadino, CA	Young and Blaney (1942)
Native brush	1.5	Muscoy, CA	Young and Blaney (1942)
Native brush	1.2	Claremont, CA	Young and Blaney (1942)
Native brush	1.6	Palmer Canyon, CA	Young and Blaney (1942)
Native grass and weeds	0.8	San Bernadino, CA	Young and Blaney (1942)
Native grass and weeds	1.1-1.25	Cucamonga, CA	Young and Blaney (1942)
Native grass and weeds	1.0	Anaheim , CA	Young and Blaney (1942)
Native grass and weeds	1.1	Ontario, CA	Young and Blaney (1942)
Native grass and weeds	1.1	Wineville, CA	Young and Blaney (1942)
Annual grasses, forbes, and legumes	1.2	Placer County, CA	Lewis (1968)
Grasslands	0.8-1.3 (7/01-6/07)	Lower Sierra Nevada Foothills, Vaira Ranch	Ryu et al (2008) Baldocchi et al. 2004
Tank Studies			
Annual grasses	0.8 - 1.2	Placer County, CA	Lewis (1968)
Grass	1.2	San Luis Rey, CA	Blaney (1957)
Grasslands Grasses	0.9 – 2.9 2.2	Sierra Ancha, AZ Sierra Ancha, AZ	Rich(1951) Rich (1951)

Table 5 Water Use by Common Riparian Vegetation

Vegetation	Annual Water Use (ft/yr)	Location	Reference
Field Studies			
Canyon-bottom, Lower Reach: 82% alder, 8% sycamore, 4% Bay, 3% willow, some maple, oak. Understory grapevine & blackberry.	6.9[a]	Coldwater Canyon, CA	Blaney (1933)
Canyon-Bottom, Upper Reach: 48% alder, 26% Bay, 9% maple, 7% willow, 6% sycamore, some oak, cedar, spruce, etc. Same understory.	5.4[a]	Coldwater Canyon, CA	Blaney (1933)
Moist-land vegetation, including willows, tules and other unspecified vegetation	9.5[b]	Temescal Canyon, CA	Blaney et al. (1933)
River-bottom brush comprising 38% heavy tree cover of willows, alders, cottonwood, sycamore; 19% grass, 20% brush, 6% tule swamp	4.2	Santa Ana River, CA	Troxell (1933)
Tank Studies			
Isolated clump of 7 ft tall red willows	4.4	Santa Ana, CA	Blaney et al. (1933)
Mixture of cottonwoods and willows	5.2 – 7.6[c]	San Luis Rey, CA	Blaney (1957, 1961)
Alders	5.0	Santa Ana, CA	Muckel (1966)
Cottonwoods and willows	7.6, 6.0[c]	Safford Valley, AZ	Gatewood et al. (1950)

a. Reported for the 4-month period May-October 1932 and converted to a 12-month basis using the monthly distribution of water use for willows, by dividing 0.77 [DPW 1931b].

b. Reported for the month of May 1929 and converted to a 12-month basis using the monthly distribution of water use for willows by dividing by 0.11 [DPW 1931b].

c. Range depends on depth to groundwater, which varied from 3 to 4 feet at San Luis Rey and 7 ft at Safford Valley. Variously reported as 7.6 ft/yr in Table 29 for cottonwood and willow and 6.0 ft/yr for cottonwood at 195 and 203.

In the first oak woodland study, Lewis (1968) measured consumptive use for three oak woodland watersheds (12-47 acres) in the Sierra-Nevada Foothills in Placer county. The predominant hardwood was interior live oak (*Quercus wislizenii*) associated with varying amounts of blue oak (*Quercus douglasii*) and black oak (*Quercus morehus*) with some digger pine (*Pinus sabiniana*) and poison oak, annual grasses, legumes and forbes as ground cover. The measure evapotranspiration averaged 1.7 ft/yr and ranged from 1.4 to 2.0 ft/yr over a 10 year period, from 1956-1966.

In 2000, Lewis et al. published another similar study on another similar watershed, in the Sierra-Nevada Foothills in Yuba County. The woodland was dominated by blue oaks (*Quercus douglasii*) and intermixed with interior live oaks (*Q. wislizenii*) and foothills pine (*Pinus sabiniana*); annual grasses and legumes dominated the ground cover. The 17- year average consumptive use for the period 1981-1997 in the Yuba County study was 1.2 ft/yr, with a range of 0.9 to 1.8 ft/yr.

The results of the initial review of ET field studies are summarized in Table 6 as a range of possible ET_c rates.

Table 6 Summary table, evapotranspiration of native vegetation based on field studies

Land Cover	Minimum ET_c (ft. / yr.)	Maximum ET_c (ft. / yr.)
Riparian Forest	4.2	9.5
Wetland	5.1	13
Grassland	0.8	2.9
Valley/Foothill Hardwood	0.9	4

3.1.6.3.2 Climate based assessment (ET rates)

To provide a comparison on the ET rates measured in published field experiments, Dr. Daniel J. Howes from the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo calculated upper limit (or potential) of ET_c rates for Riparian Forest, Wetland, Other Floodplain Habitat, and Open Water. A simplified soil water balance was used to estimate ET_c for Grassland habitat. Dr. Howes' initial ET calculation is as follows:

The potential evapotranspiration rate is limited based on available energy in a natural system and the availability of water to the vegetation. Energy exchange at the vegetative surface governs evapotranspiration and is limited by the amount of available energy (Allen *et al.*, 1998, Allen *et al* 2011). The equation for the energy fluxes of an evaporating surface with a large extensive vegetative surface is $\lambda ET = Rn - G - H$ where:

λET is the latent heat flux (representing evapotranspiration)

Rn is the net radiation

H is the sensible heat flux

G is the soil heat flux.

While the different fluxes can be positive or negative, a positive Rn supplies energy in the form of radiation to the system and positive ET, G, and H remove energy from the system.

A convenient way to examine vegetative water use is to measure local weather parameters and compute a reference evapotranspiration, then to use a vegetation specific coefficient to adjust the reference evapotranspiration to the actual vegetation evapotranspiration. In California, a well watered grass reference surface is used as the basis for the reference evapotranspiration (grass reference evapotranspiration, ETo). Alfalfa is used as a reference in other parts of the U.S. The actual vegetation evapotranspiration (ETc) will differ from ETo depending on available water supply, albedo (reflectance of incoming solar radiation), vegetative cover density, vegetative health, growth stage, aerodynamic properties, and leaf and stomata properties (e.g. canopy resistance) (Allen *et al.* 1998). The coefficient to adjust ETo to ETc is termed a crop coefficient in agriculture but the term ETo Fraction (EToF with "o" denoting a grass reference crop) is used here to limit confusion since natural vegetation is being examined not agricultural crops. ETc can be estimated from ETo and EToF as:

$$ETc = EToF \times ETo \qquad \text{Eq. 1}$$

ETo is computed based on local weather parameters from a specialized weather station that is specifically located in a setting without obstructions from wind surrounded by healthy, well watered vegetation. ETo is computed using the 2005 Standardized ASCE Penman-Monteith equation (PM-ETo) (Allen *et al.,* 2005). Using a clipped grass as the reference, specific known properties of grass, including albedo, aerodynamic resistance, and bulk surface resistance, are used in the PM-ETo equation.

EToF is an adjustment factor based on the vegetation and soil properties to be examined. There are many types of vegetation that have higher potential to evapotranspire water compared to grass, therefore EToF can be greater than 1.0. The limitation of available energy means that EToF has limitation as well. For natural vegetation, that has sufficient available water, with full ground cover, the maximum EToF can be computed as (Allen *et al.*, 1998):

$$EToF_{max} = EToF_h + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad \text{Eq. 2}$$

Where $EToF_h = 1.0+0.1*h$ for vegetation heights less than or equal to 2 meters (~6.5 feet) and equal to 1.2 with vegetation heights greater than 2 meters. RHmin is the minimum relative humidity during the day, u_2 is the wind speed measured at 2 meter above the ground surface, and h is the vegetation height. Where there is standing water with the vegetation (*i.e.* wetlands), a value of 0.05 is added to the $EToF_{max}$ computed with the previous equation to account for additional evaporative losses (Allen *et al.*, 1998).

Daily weather data was obtained from five CIMIS weather station (Durham and Gerber in the Sacramento Valley, Twitchell Island in the Delta, and Modesto and Firebaugh in the San Joaquin Valley) to evaluate the $EToF_{max}$ for applicable habitat in the evaluated in the water balance. The $EToF_{max}$ values were weighted based on daily ETo values over the timeframe analyzed which was 25 years for some station to 13 years for another depending on data availability. The EToF for the Aquatic category was not computed using the previous equation, instead taken directly from Allen *et al.* (1998) for shallow water bodies, because open water does not have the same properties as vegetation. Descriptions of each type of habitat are discussed above.

Table 7 shows the ET_oF_{max} computed from Eq. 2. These values are in agreement with Allen *et al.* (2011) which states that ET_oF should not exceed 1.3- 1.4 in semi-arid climates.

Table 7 Estimated EToFmax based shallow water for aquatic and on Equation 2 for the other categories.

Vegetation	Assumed Maximum Height (ft)	Weighted Annual $EToF_{max}$*		
		Sacramento Valley	Delta	Northern San Joaquin
Aquatic		1.05	1.05	1.05
Other Flood Plain Habitat	6	1.22	1.26	1.22
Riparian	35	1.27	1.35	1.27
Wetland	25	1.30	1.36	1.30

* The $EToF_{max}$ assumes expansive vegetation. In cases where there are small stands of vegetation surrounded by sparse vegetation or dry land, the EToF can be significantly higher (oasis and close line effects). The Chico State pre-1900 vegetation map shows large expanses of these vegetation types so these values should be reasonable.

Grassland ET is highly dependent on available soil moisture. As will be discussed, in some areas the grasses could have access to groundwater. In many grassland habitats, these grasses will be dependent on rainfall to meet their evapotranspiration demands. An initial analysis was conducted to examine a daily soil water balance of rain fed grasslands in each of the three regions. Weather data including ETo and precipitation was obtained from one CIMIS weather station in each region (Gerber in the Sacramento Valley (2006), Twitchell Island in the Delta (2004), and Modesto in the San Joaquin Valley (2001)). Years were selected which had similar precipitation totals as shown in Table 2. Soil type information was estimated for the grassland habitat using NRCS soils map of California.

For the Sacramento Valley, Delta, and San Joaquin Valley north of Fresno the soils were classified on average as silty loam, loam, and loam, respectively. The San Joaquin Valley generally has sandy to fine sandy loam on the east side of the San Joaquin River, and clay loam on the west side. The available water holding capacity for an "average" soil was used which is based on a loam soil. A conservative root zone depth of 3 feet was assumed. The initial analysis resulted in an estimated annual EToF value for grasslands in the Sacramento, Delta, and San Joaquin of 0.3, 0.25, and 0.21, respectively.

No attempt was made to quantify the $EToF_{max}$ for Valley/Foothill Hardwood habitat. It is expected that the ETc within this habitat will be between Other Flood Plain Habitat and grasslands.

The ETo values used were obtained for this preliminary evaluation from the California Department of Water Resources ETo Zone Map. ETo Zones 12 and 14 are within the Sacramento Valley, Zone 14 covers the Delta, and Zones 12, 14, and 15 cover the San Joaquin Valley north of Fresno. The following table shows the long-term average ETo, precipitation, $EToF_{max}$, and the maximum likely ETc for each vegetative habitat within each region.

Table 8 Estimated upper crop evapotranspiration (ETc)

Sacramento Basin Vegetation	Long-Term Average ETo	Precipitation	$EToF_{max}$	Upper Est. ETc
	ft/yr	ft/yr	ft/ft	ft/yr
Aquatic	4.6	1.8	1.05	4.8
Grassland	4.6	1.8	0.3	1.4
Other Flood Plain Habitat	4.6	1.8	1.22	5.6
Riparian	4.6	1.8	1.26	5.8
Valley/Foothill Hardwood	4.6	1.8	0.80	3.7
Wetland	4.6	1.8	1.30	6.0
Delta Vegetation	**Long-Term Average ETo**	**Precipitation**	**$EToF_{max}$**	**Upper Est. ETc**
	ft/yr	ft/yr	ft/ft	ft/yr
Aquatic	4.8	1.2	1.05	5.0
Grassland	4.8	1.2	0.25	1.2
Other Flood Plain Habitat	4.8	1.2	1.27	6.0
Riparian	4.8	1.2	1.35	6.4
Valley/Foothill Hardwood	4.8	1.2	0.80	3.8
Wetland	4.8	1.2	1.36	6.5
San Joaquin Basin Vegetation	**Long-Term Average ETo**	**Precipitation**	**$EToF_{max}$**	**Upper Est. ETc**
	ft/yr	ft/yr	ft/ft	ft/yr
Aquatic	4.7	1.0	1.05	4.9
Grassland	4.7	1.0	0.21	1.0
Other Flood Plain Habitat	4.7	1.0	1.22	5.7
Riparian	4.7	1.0	1.27	5.9
Valley/Foothill Hardwood	4.7	1.0	0.80	3.7
Wetland	4.7	1.0	1.30	6.1

The upper ETc estimates shown in Table 8 are based on annual computations for average ETo within each basin. A more detailed evaluation is planned in the near future to examine long-term average weather parameters for multiple weather stations within each basin to refine these estimates. Additional refinements include possibly subdividing each basin by localized weather conditions (precipitation and ETo) and using remote sensing of actual evapotranspiration to examine the relative ETc rates for vegetative habitat that might be similar to what would have been found in pre-development. Through these refinements the Upper and Lower ETc estimates in the following section could change especially the Lower ETc estimates which are conservatively low for some vegetation such as grasslands.

3.1.6.4 Calculation of natural outflow

Natural flows are those that would have occurred before the Central Valley was altered by colonial and American development. The primary reason natural flows are lower than unimpaired flows is water use by natural vegetation is not accounted for in the unimpaired flow calculation. To get a truer estimate of natural flows, an estimate may be calculated by subtracting natural vegetation water use from the total supply using a simple water balance around the portion of the Central Valley that drains to the Bay:

Delta Outflow = Water Supply – Water Use by Native Vegetation

The water balance was calculated for the portion of the Central Valley that drains to the Bay as defined by DWR's unimpaired flow calculations. The results of the natural outflow calculation are summarized in Table 10. This calculation adjusts DWR's estimate of unimpaired Delta outflow to account for consumptive use by native vegetation to provide a more accurate estimate of natural annual Delta outflow assuming average climatic conditions over water years 1922-2010.

Water supply was set equal to the sum of DWR's unimpaired Delta inflow and DWR's estimate of precipitation on the valley floor. Natural inflow to the Delta watersheds is assumed to be equal to DWR's unimpaired rim inflow, reported as "Delta Unimpaired Total Inflow" for the period 1922-2010 from the most recent version of DWR's impaired flow calculations. The annual average is 29.2 MAF/yr. Precipitation on the Valley floor estimated using the most recent long-term, annual average (1922-2008) calculated by DWR for use in their C2VSIM groundwater model based on PRISM data (Kadir, 2012). The results of this analysis are summarized in Table 9.

Vegetation water use was determined by multiplying ET_c for each vegetation type by the number of acres in each region. Because of the uncertainties described previously in determining the actual ET_c values from predevelopment vegetation, an upper and lower estimate of ET_c was used to calculate a range of vegetation water use. The lower end of the ET range for riparian forest, wetland, and grassland is as described in Table 6, and is based on reports from field studies.

Other Floodplain Habitat as described by Chico 2003 is a mix of grassland, wetland and riparian land cover. The lower end of the range was determined using best professional judgment. The lower end ET of grassland is 0.8 ft/yr, wetlands is 5.1 ft/yr, and riparian forest is 4.2 ft/yr and so a ET for Other Floodplain Habitat should fall within the above stated range. Historical references indicate that land cover was predominantly dense riparian forest rather than grassland, and therefore it is appropriate to select an ET similar to Valley/Foothill Hardwood (4.0). Using best professional judgment the lower end ET for Valley/Foothill Hardwood is 3.5 ft/yr.

The lower end of the range for Valley/Foothill Hardwood was increased from 0.9 to 2 in order to reflect the historical studies indicating dense riparian forest. The 0.9 field study was based on areas with large grasslands and few trees.

The natural flow calculation presented here is not an estimate of a realized annual Delta outflow, i.e., it is not an estimate of actual flow in an individual year such as 1900 or 1850. Rather, the natural flow calculation is a long-term annual average, presented to demonstrate that unimpaired flows are natural flows and are an improper basis from which to establish objectives intended to restore the health of the estuary, which evolved in an entirely different flow environment.

Table 9 Valley Floor Precipitation (1922-2008)

Region	ValleyFloor Area (Acres)	Long-Term Average Precipitation (in/yr)	Precipitation (ac-ft/yr)
Sacramento Basin	3,712,090	21.3	6,588,960
Delta	1,399,159	14.5	1,690,650
San Joaquin Basin	3,013,204	11.7	2,937,874
Total			**11,217,484**

Table 10 Estimated Delta Outflow Under Predevelopment Conditions

Water Supply				Long-Term Average Annual Water Supply (MAF/Yr)	
Unimpaired Rim Inflow				29.20	
Precipitation on the Valley Floor				11.22	
Total Water Supply				**40.42**	
ETc Outflow					
Sacramento Basin	**Lower ETc**	**Upper ETc**	**Area**	**Lower ETc**	**Upper ETc**
Vegetation	**ft/yr**	**ft/yr**	**1,000 Acres**	**MAF/yr**	**MAF/yr**
Aquatic	4.4	4.8	33	0.14	0.16
Grassland	0.8	1.4	1,591	1.32	2.19
Other Flood Plain Habitat	3.5	5.6	475	1.66	2.66
Riparian	4.2	5.8	444	1.86	2.57
Valley/Foothill Hardwood	2.0	3.7	640	1.28	2.35
Wetland	5.1	6.0	530	2.7	3.17
Delta Basin	**Lower ETc**	**Upper ETc**	**Area**	**Lower ETc**	**Upper ETc**
Vegetation	**ft/yr**	**ft/yr**	**1,000 Acres**	**MAF/yr**	**MAF/yr**
Aquatic	4.5	5.0	18	0.08	0.09
Grassland	0.8	1.2	616	0.50	0.73
Other Flood Plain Habitat	3.5	6.0	117	0.41	0.71
Riparian	4.2	6.4	55	0.23	0.35
Valley/Foothill Hardwood	2.0	3.8	198	0.4	0.75

Wetland	5.1	6.5	395	2.02	2.55
San Joaquin Basin	**Lower ETc**	**Upper ETc**	**Area**	**Lower ETc**	**Upper ETc**
Vegetation	**ft/yr**	**ft/yr**	**1,000 Acres**	**MAF/yr**	**MAF/yr**
Aquatic	4.4	4.9	9	0.04	0.05
Grassland	0.8	1.0	2,264	1.80	2.22
Other Flood Plain Habitat	3.5	5.7	572	2.00	3.26
Riparian	4.2	5.9	72	0.3	0.43
Valley/Foothill Hardwood	2.0	3.7	9	0.02	0.03
Wetland	5.1	6.1	86	0.44	0.53
Total Vegetation Water Use				**17.20**	**24.80**
				Upper Bound	**Lower Bound**
				MAF/yr	**MAF/yr**
		Natural Flow Condition		**23.21**	**15.61**

The current outflow based on 2011 level of development as reported by DWR in its SWP Delivery Reliability Report is 16 MAF/yr. The result of this analysis is that current outflow is within this initial estimate of predevelopment annual average outflow. In addition, unimpaired outflow, based on SOURCE, is 28 MAF. The unimpaired outflow estimate is nearly 80% higher than the low estimate of natural outflow and 17% higher than the high estimate. The most important conclusion to be gleaned from this analysis is that unimpaired outflow is not an accurate or meaningful estimate of natural outflow.

3.1.6.5 Description of analysis to refine predevelopment outflow calculation

The Public Water Agencies are developing a simple spreadsheet model that estimates natural Delta inflows and outflows that would have occurred prior to colonial and American settlement (*i.e.*, pre-development conditions). The purpose of this further analysis is to estimate inter- and intra- annual variability in predevelopment or "natural" outflow that was not included in the initial analysis contained above.

Pre-development Delta inflows and outflows will be developed for an 88-year hydrologic period (1922-2009) assuming a monthly time step. The spreadsheet model will allow the user to easily perform sensitivity analysis by changing key input assumptions.

Calculations of pre-development Delta inflows and outflow will modify unimpaired flow calculations undertaken and published by DWR. Specifically, DWR's estimates of unimpaired flows will be modified to account for: (1) valley floor depletion of water supplies through evapotranspiration of native vegetation and riparian lands; (2) bank overflow and detention storage in low-lying areas within the Valley floor; and (3) seasonal variation in groundwater storage. In contrast to DWR's unimpaired flow estimates, pre-development accretions within the valley floor will be calculated using a land use based approach. Valley floor depletions will be calculated using estimates of pre-development land use and a simple one-dimensional root zone soil moisture model. Bank overflows and detention storage will be estimated using a hydraulic model of the Sacramento and San Joaquin river system and hydrologic routing of overflows through detention basins. Seasonal variation in groundwater storage will be estimated based on a review of historical literature and depletion by natural vegetation.

Development of Delta inflows and outflows under natural conditions will be undertaken in a series of steps as follows:

- Obtain unimpaired outflows from the mountain and foothill watersheds from published DWR reports and data
- Determine historical accretions within the valley floor
- Adjust historical accretions to account for land use change within the floor of the Central Valley.
- Route unimpaired flows through the stream system, accounting for bank overflow and detention storage
- Determine Delta outflow from Delta inflows and in-Delta depletions

It is anticipated that this model will be completed in early 2013. The Public Water Agencies anticipate having further discussions with State Water Board as the model is finalized and vetted with the scientific community.

4. Tools to Assess the Effect of Changes on Aquatic Species

4.1 Life cycle modeling

Lifecycle models integrate the effects of multiple stressors across multiple life stages to evaluate impacts of actions at population scales. Lifecycle models offer the prospect of evaluating the effect of multiple stressors on the ultimate survival or abundance of the species. (NRC, 2011.)

Quantitative life-cycle models are tools that fish biologists use to determine, among other things, which of the various environmental factors that surround the species are statistically linked to its population over time. In order to perform this analysis, life-cycle models use long-established statistical techniques to determine the degree to which changes in environmental variables explain changes in the population growth rate of the species (the rate at which the population increases or decreases.) Note, however, that while lifecycle models provide statistical support (or non- support) for various hypotheses about what factors may influence populations, they do not provide proof of cause and effect. Additional study is generally required to identify the potential biological mechanisms and/or to demonstrate whether the specific factors identified in lifecycle models are indeed causally related to abundance.

Life-cycle models are powerful tools for studying complicated ecosystems like the Delta where there are a large number of interconnected variables. As the National Research Council explained:

> Nonlinear and compensatory relationships between different life-history traits exhibits significant patterns of autocorrelation, such that changes in one life-history trait induce or cause related changes in others. These patterns can most effectively be understood through integrated analyses conducted in a modeling framework that represents the complete life cycle.

(NRC 2010.) Courts have also recognized the use of life cycle models as the best available science, finding that: "It is undisputed that application of a quantitative life cycle model is the preferred scientific methodology." (Wanger, 2010.)

4.1.1 Delta Smelt Life Cycle Models

4.1.1.1 Description of Maunder Deriso Delta Smelt Life Cycle Model

The Maunder Deriso life cycle model ("M-D Life Cycle Model") is a published state-space multistage life-cycle model that analyzes delta smelt populations at several life stages using data from multiple seasonal surveys of delta smelt abundance (Maunder and Deriso, 2011).[11] The state-space approach was recommended as a useful next step by both Thomson *et al.* 2010 ("A state-space approach would provide a more continuous life history model that linked the abundances of each life stage would provide a more continuous

[11] Maunder and Deriso (2011) provides a detailed discussion of the M-D Life Cycle Model, and a copy of that study has been provided to the State Water Board as part of the Public Water Agencies submittal on analytical tools.

picture of the delta smelt population and would capitalize more fully on available data.") and MacNally *et al.* 2010 ("A broader life-history model with a more general state-space approach to modeling the pelagic species decline should be more informative.").

The model is able to test multiple factors or covariates (including factors relating to environmental conditions and mortality rates based on entrainment) for their influence on the survival and stock-recruit relationships. Thus, each factor represents a hypothesis about what conditions or events make a difference for smelt survival and recruitment. Those factors can then be objectively evaluated by the model against the data for the smelt through its various life stages year over year. The M-D Life Cycle Model can concurrently evaluate a variety of factors. For example, the model can evaluate potential mortality factors, like entrainment, predation, toxicity, temperature, and food availability. It can consider potential fecundity factors, like adult size and temperature. It can also consider potential abundance bottlenecks, like area of spawning beds, habitat volume, area, or length. To determine which factors are important for explaining changes in delta smelt survival and recruitment multiple covariates and multiple combinations of covariates were tested. The model attempts to identify the factors affecting abundance trends over time.

The Maunder-Deriso Lifecycle Model represents different life-cycle stages of the species (adult, larval, juvenile) and how population abundance changes between these stages.

Figure 27 Illustration of the delta smelt life cycle.

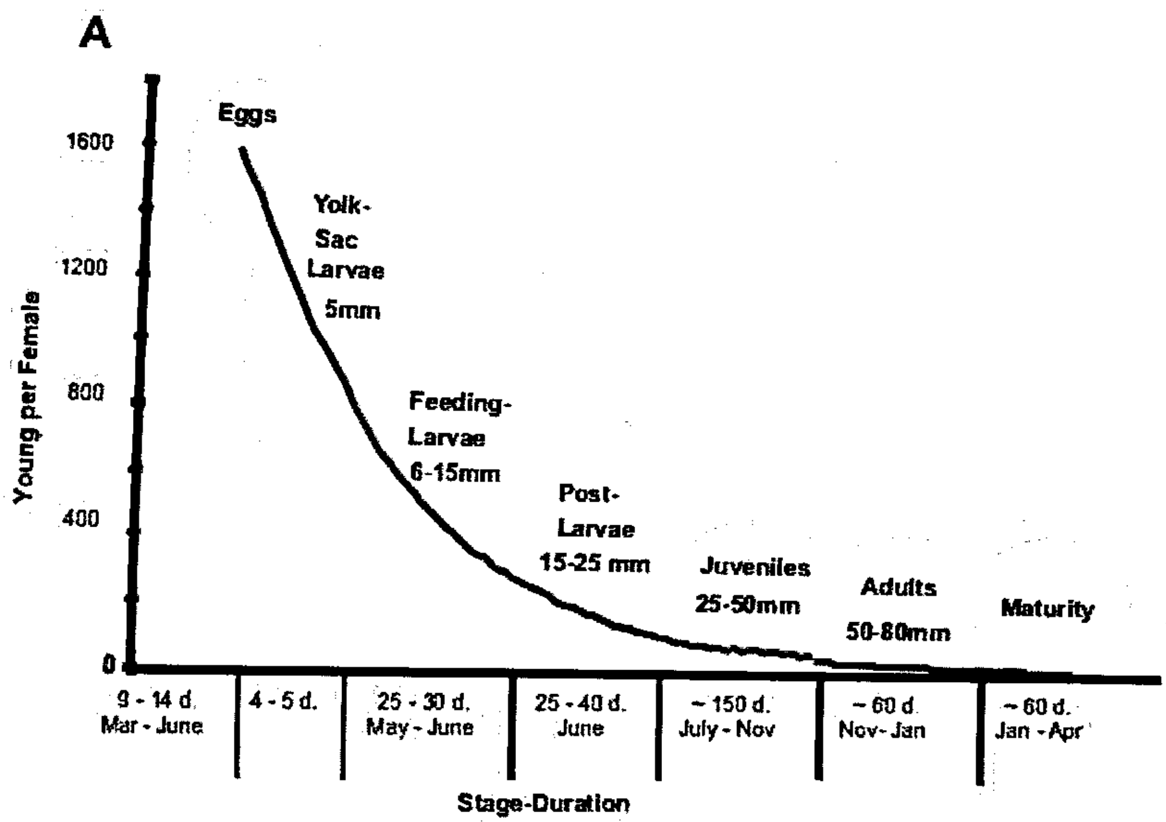

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Figure 27, Conceptual model of delta smelt life history with approximate life stage durations (Source: Bennett 2005).

The M-D Life Cycle Model evaluates survival from one life stage to the next, as well as the stock-recruit (*i.e.*, parent-offspring) relationship. The delta smelt life cycle is broken into three life stages. The model stages are associated with the timing of the three main surveys, 20-millimeter trawl (20 mm), Summer Townet Survey (STN), and the Fall Midwater Trawl (FMWT), and roughly correspond to the life stages larvae, juveniles, and adults, respectively. The reason for associating the model stages with the surveys is that the surveys are the only abundance data available for much of the period of record. Environmental variables were then created to look at possible abundance linkages for the periods between these lifestages.

For simplicity and to be consistent with the predominant dynamics of delta smelt, the model assumes an annual life cycle, although it is recognized that a small portion of the population survives into a second year (Bennett 2005). Within a year, the number of individuals in each life stage is a function of the number in the previous life stage. The number of individuals in the first life stage is a function of the number in the last life stage in the previous year (i.e., the stock-recruitment relationship), except for the numbers in the first life stage in the first year, which is estimated as a model parameter. The functions describing the transition from one life stage to the next are modeled using covariates. A state-space model (Newman 1998; Buckland *et al.* 2004, 2007) was used by Maunder and Deriso (2011) to allow for annual variability in the equation describing the transition from one life stage to the next.

4.1.1.2 Covariates evaluated by the model

Multiple factors were chosen for inclusion in the delta smelt life cycle model. The environmental factors were those proposed by Manly (2010b). The entrainment mortality rates were calculated based on Kimmerer (2008); the rates were obtained by fitting a piecewise linear regression model of winter Old and Middle River (OMR) flow to corresponding adult entrainment estimates. Larval- juvenile entrainment estimates were fitted to a multiple linear regression model with spring OMR flow and spring low salinity zone (as measured by X2). The values from Kimmerer (2008) were used for years in which they are available, and the linear regression predictions were used for the remaining years.

Manly (2010b) provided several variables as candidates to account for the changes in delta smelt abundance from fall to summer and summer to fall. The fall-to-summer covariates could influence the adult and larvae stages, while the summer-to-fall covariates could influence the juvenile stage. The factors proposed by Manly (2010b) are those that were considered to act directly on delta smelt. There are many other proposed factors that act indirectly through these factors. Secchi depth was included as a covariate for water turbidity-clarity, because it was identified as a factor by Thomson *et al.* (2010). Exports also were identified as a factor and were assumed to be related to entrainment. However, the model development used direct measures of delta smelt entrainment. Interactions among the factors were not considered in the model. However, some of the covariates implicitly include interactions in their definition and construction. Akaike information criterion (AICc) values and weights were calculated for all possible combinations of density dependence (DD) that included no density dependence (No), a Beverton-Holt model (BH), a Ricker model (R), and estimation of both b and y (DD)

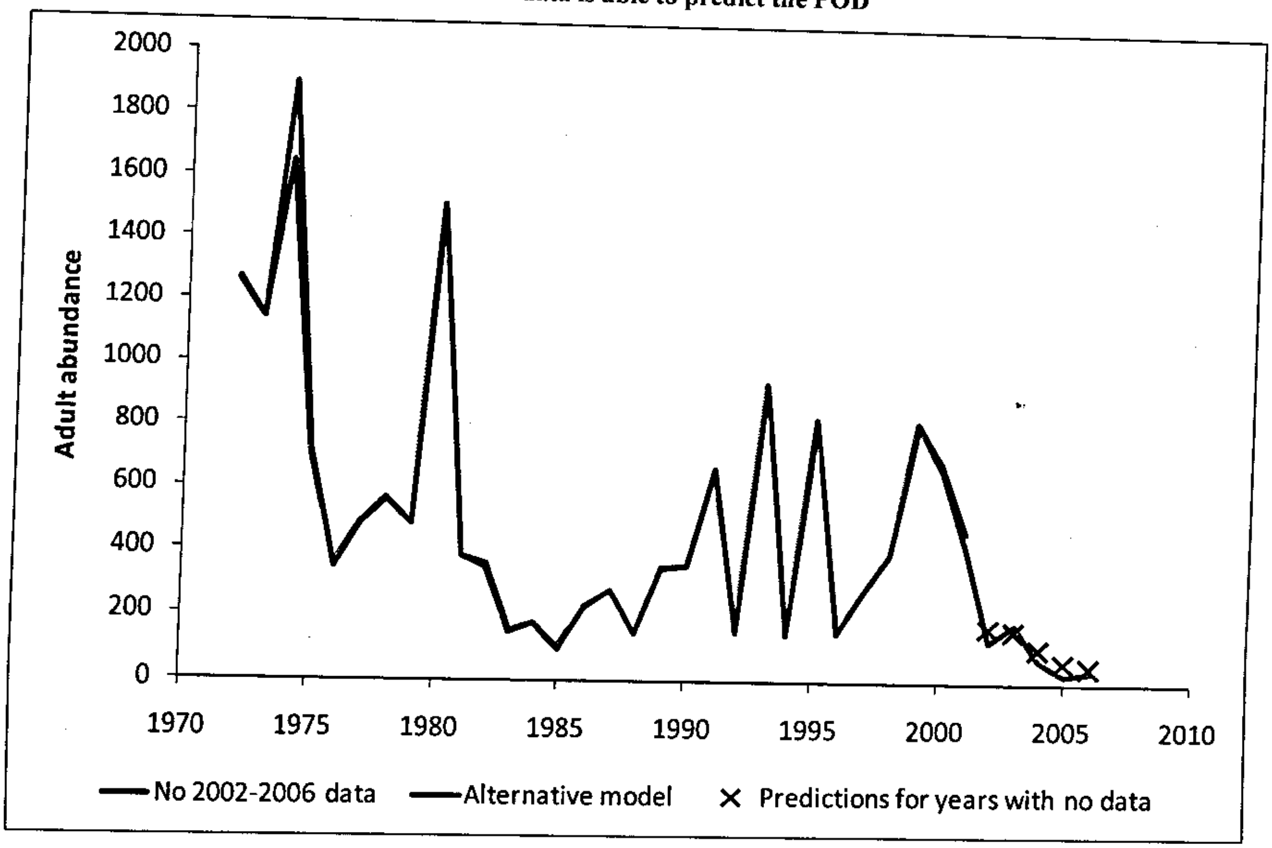
Covariates (hypotheses) are tested by using AICc ranking. The AIC_c is a measure of the relative goodness of fit of a statistical model. The AICc is useful for ranking alternative hypotheses when multiple covariates and density-dependence assumptions are being considered. A better model fit is one with a smaller AICc score. AICc weights are often used to provide a measure of the relative support for a model and to conduct model averaging (Hobbs and Hilborn 2006). AICc weights are essentially the rescaled likelihood penalized by the number of parameters, which is considered the likelihood for the model (Anderson *et al.* 2000).

4.1.1.3 Maunder Deriso Delta Smelt Life Cycle Modeling Results

Maunder and Deriso (2011) reported that the "best" fit model, meaning the model with the lowest AICc ranking, included spring and summer *Eurytemora* and *Pseudodiaptomus* densities, spring and summer water temperature, and predation (predator abundance and water clarity). The model also indicated that density dependence was an important factor. An alternative model which also included Secchi depth and adult delta smelt entrainment generated a similar AIC_c score and thus could not be excluded.

The M-D Life Cycle Model fits the data fairly well. Drs. Maunder and Deriso have tested their model to determine if it can predict recently observed trends. Using data from 1972-2001, the M-D Life Cycle Model was able to predict the recent pelagic organism decline.

Figure 28 Model created with 1972-2001 data is able to predict the POD



Since publication of the model, Drs. Maunder and Deriso have completed further investigations using their model. The fall X2 covariate was evaluated, but fall X2 did not have significant explanatory power and was rejected from inclusion in the model.

Since publication, the M-D Life Cycle Model has been updated with data through 2010, which is the most current data available. Updating the data did not change the initial model results for the "best" model. However, the additional years did cause the alternative model, which included Secchi depth and adult smelt entrainment to score more poorly. Thus, this model can be excluded.

Drs. Maunder and Deriso are planning further modeling run intended to test additional hypotheses using different covariates and data sets. Results of these additional modeling exercises will be provided to the State Water Board.

4.1.1.4 Other Life Cycle Models

There are at least three other published models that have been used to evaluate factors potentially effecting delta smelt abundance. Each of these models use different data sets and different methods. Mac Nally *et al.* (2010) used a multivariate autoregressive modeling to analyze the effects of a number of different environmental covariates, including X2, on several Delta fish species. Thomson *et al.* (2010) used a Bayesian change point analysis, to explore abrupt changes in population or population trends. Miller *et al.* 2012 applied a series of regression equations, testing hypotheses using a hierarchial approach, where factors potentially directly effecting smelt are evaluated first. Factors potentially having direct effects included, but were not limited to, entrainment, predation, fecundity, contaminants, disease, temperature, and extent of spawning habitat. All three of these analyses considered Fall X2 as a covariate, and none found that Fall X2 has a statistically significant effect on species abundance. As the NRC observed, "When multiple models [with different structures and assumptions] agree, the confidence in their predictions is increased" (NRC (2010) at 26).

4.1.2 Longfin Smelt Life Cycle Models

Drs. Deriso and Maunder are in the latter stages of developing a state–space multistage life cycle model for longfin smelt that allows for an evaluation of density dependence and environmental factors on different life stages of the species.

Abundance indices fitted with the model are based on a scaled average of the Bay Study bottom (otter) trawl and midwater trawl catch data. Use of the Bay Study survey data have several advantages over the Fall Midwater Trawl and other data sets, including that:

(1) The Bay Studies use two trawl gears which have been consistently applied since 1980, thus providing vertical distribution data over a 30-year + period;

(2) The Bay Studies collect longfin smelt and other fish year-round throughout the bulk of the range of longfin, including in San Francisco, San Pablo and Suisun Bays, as well as in the Delta; and

(3) Fish collected in the Bay Studies are separated by estimated age, which permits the model to establish abundance indices for the life stages of juvenile, late age 0 –early age 1, and late age 1- age 2+.

Consistent with the conceptual model developed for the DRERP process (Rosenfeld 2010) and results of longfin smelt analyses that proposed assessing a broad range of potentially explanatory variables when evaluating Delta fish declines (Rosenfeld and Baxter 2007, McNally et al. 2010, Thomson et al. 2010), the Deriso/Maunder longfin life cycle model will evaluate density dependence and a number of covariates in an effort to determine their relative significance in explaining longfin smelt abundance trends. The categories of covariates that may be evaluated include, but are not limited to: food, water temperature, secchi depth, flow, ammonium, and predators.

The longfin model development, including analysis of example covariates, is expected to be fully completed in the next several months.

4.1.3 Salmon Life Cycle Modeling

Analytical tools are available now that can be used to evaluate the relative benefits of various management actions on the population dynamics and survival of salmonids. These tools can assess the effects of various flows, route selection during migration, entrainment losses, and other stressors to the species. These tools allow comparative cost/benefit assessments for management actions. These tools can also be used to assess the relative importance of a stressor on the overall population dynamics of a species and provide a framework for identifying and evaluating potential management actions.

The ability to flexibly respond to current in-river and reservoir conditions, through coldwater pool management of Shasta Reservoir and, application of near-real time monitoring results, has improved conditions for salmonids over the last three decades. Improvements in monitoring technology and analytical tools have also helped to address uncertainty in evaluating the response of juvenile salmonids to factors such as route selection, behavior, survival, and flow changes (including river flow, Delta tidal hydrodynamics, and export operations).

The Instream Flow Incremental Method (IFIM) and other analytical tools have been developed and applied to Central Valley rivers for use in evaluating instream flow schedules that meet the requirements of the various lifestages of salmonids. Acoustic tag technology (Figure 6-3) has been used to develop detailed information on juvenile salmon and steelhead migration through the Delta. The technology is continuing to be refined and improved to provide better signal transmission, longer battery life, smaller tag size and the ability to successfully tag smaller salmonids. There have also been marked improvements in technologies designed for tracking and mapping juvenile salmonid movement in three dimensions.

Data obtained from application of these new and improved technologies can be analyzed in conjunction with information about local flow patterns to improve habitat and passage conditions for juvenile salmonids. The technologies can also be used to analyze the benefits of fish guidance projects, such as non-physical barriers (*e.g.*, the "bubble curtains" tested in the San Joaquin River at the Head of Old River and on the Sacramento River at Georgiana Slough).

Data generated using these improved monitoring technologies are now being integrated into analytic tools designed to improve our understanding of salmon biology, the response of juvenile salmonids to flows and other environmental conditions, and the role of predation in juvenile salmonid mortality. The predictive capacity of models and other tools has also improved, particularly in their integration into life cycle modeling efforts. The rapid development of these new tools has only recently begun and these efforts are continuing to expand and provide new information that will be directly applicable to informing management decisions in the future. For example, NMFS and others are currently conducting a large-scale acoustic tag study of juvenile hatchery and wild salmonids migrating through the upper Sacramento River and its tributaries downstream through the Delta, however results of this large-scale study are not expected to be available for several years.

These circumstances suggest that the science should be allowed to develop further, and maximum flexibility in management and operations should be retained to allow nimble response to improved scientific data. The imposition of minimum or specific instream flows may simply impede progress being made in improving salmon stocks by restricting flexibility.

Additional information on river flows and hydrologic conditions in the Central Valley rivers is presented in the SWC (2012) comments submitted in conjunction with the State Board's workshop on Ecosystem Changes.

4.1.3.1 Life cycle modeling

It has been acknowledged for some time that modeling can play a powerful role in evaluating the interrelationships among individual factors that give rise to broad patterns in population dynamics, and that understanding the processes that produce such patterns is key to developing principles of management (Levin 1992). Ruckelshaus et al. (2002) even go so far as to say that using better models in making management decisions is one obvious way to change how risks to salmon populations are managed.

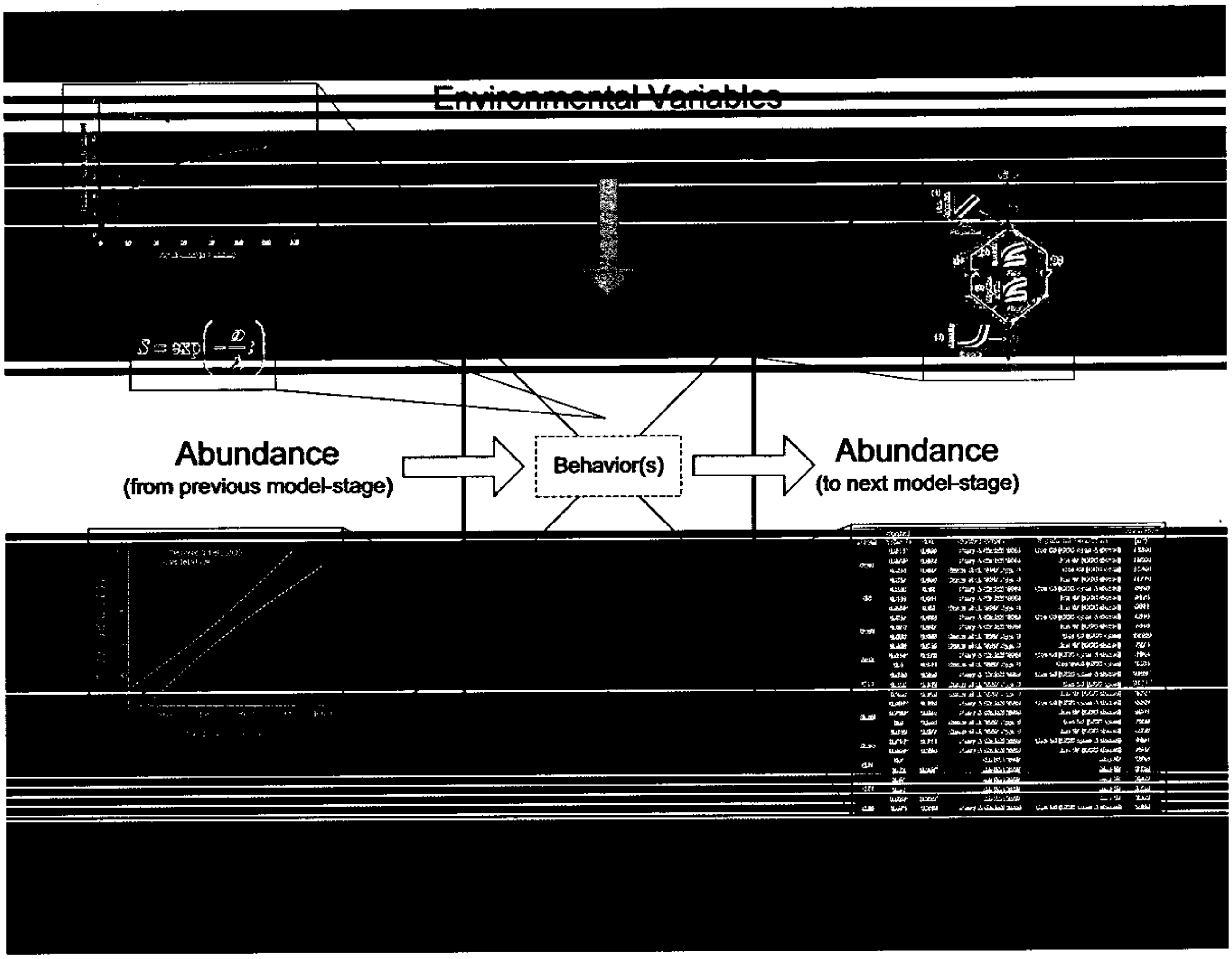
Multiple efforts have been undertaken to develop effective models for Central valley salmon. Williams (2006) classifies these models into two general categories: estimation models, which estimate parameter values by directly fitting the model to available data; and simulation models, which take parameter values from literature or other sources. An example of an estimation model is the Bayesian hierarchical state-space model developed by Newman and Lindley (2006), which incorporates multiple data sources to roughly predict juvenile out-migration based on data for juveniles from the preceding year. An example of a simulation model is the SALMOD model (Bartholow *et al.* 1997; Bartholow 2004), which combines information regarding run timing with fine-scale data regarding spatial and temporal variations in flow and temperature to define computational units which are then used to assess the effects of river flow and water temperatures on the production of Chinook salmon in the upper Sacramento River.

While the results of such models have provided valuable insights, their narrow focus and limited geographic area reduce their utility in assessing the relative impact on overall population viability of actions at specific locations or affecting specific life stages. A framework is needed for organizing the body of information regarding the impact of changes in environmental variables (e.g., flow, temperature, exports, harvest, and physical habitat), for quantifying the effects of these changes on the abundance of salmon at each life stage (e.g., development, migration, and maturation), and for evaluating the resulting impact on overall population viability. Life-cycle models provide such a framework. Both scientists and managers have increasingly recognized the utility of lifecycle models for evaluating salmon population responses to management actions (Ruckelshaus *et al.* 2002), and a recent review of salmon recovery efforts in California's Central Valley recommended their use (Good *et al.* 2007). The Interactive Object-oriented Simulation (IOS) model is currently the only Central Valley Chinook salmon life-cycle model that has been published in the peer reviewed scientific literature (Zeug *et al.* 2012).

4.1.3.2 Modeling framework

Life-cycle models enable, to the extent allowed by available data, the integration of information drawn from a wide breadth of sources regarding each stage of the salmon life cycle. Thus, life-cycle models are essentially integrated accounting frameworks which track how the various pieces of information regarding behaviors, environmental variables, and abundance relate to one another by synthesizing data, equations, and sub-models into quantitative functional relationships. These functional relationships are then grouped into model-stages which are defined by a specific spatial context and are arranged sequentially to account for the entire life cycle of the fish, from eggs to returning spawners. Figure 29 illustrates how the various components are used to construct a model-stage.

Figure 29 Generic model-stage illustrating the synthesis of data, equations, and sub-models into functional relationships.



The specific functional relationships for each model-stage—and the arrangement of model stages necessary to account for a complete life cycle—are determined by the unique combination of the modeled species' behaviors, the environmental variables interacting with those behaviors, and the geographic areas in which these interactions occur. Thus, both the model-stages and their arrangement are specific to each life-cycle model.

4.1.3.2.1 IOS life cycle model

The Interactive Object-oriented Simulation (IOS) model is the only life-cycle model that has been specifically designed to incorporate life stages, geographic areas, and influencing factors at a scale closely matching that affected by alternative water management actions. The model was developed by Cramer Fish Sciences to simulate the interaction of environmental variables with all life stages of winter-run Chinook salmon in the Sacramento River, Sacramento-San Joaquin Delta, and Pacific Ocean. IOS has undergone extensive development and interagency review, and has now been peer reviewed and published (Zeug *et al.* 2012). IOS is the first, and to date only, Central Valley Chinook salmon life-cycle simulation model which has been published and which has been actively used to help plan and evaluate several important projects. Fish behaviors modeled by IOS include Emergence (eggs to fry), Rearing, Migration, and Maturation (ocean phase). The IOS model dynamically simulates responses of salmon populations across these model-stages to changes in environmental variables or combinations of environmental variables in the geographical areas specified for each model-stage, and enables scientists and managers to investigate the relative importance of specific environmental variables by varying a parameter of interest while holding others constant; an approach similar to the testing of variables in a laboratory setting. The IOS life-cycle model estimates adult escapement, which is the primary key to population viability over time.

Although there have been many studies and monitoring efforts focused on the ecology of salmon at the individual and population level, many of these data relate only to a single life stage, habitat type or environmental variable. This has made it difficult to integrate these data into a traditional statistical framework to estimate inter-annual population dynamics or to identify specific bottlenecks to population recovery. The IOS life-cycle model uses a systems dynamics modeling framework, a technique that is used for framing and understanding the behavior of complex systems over time (Costanza *et al.* 1998; Ford 1999). The IOS model integrates into this framework available time-series data as well as values taken from laboratory studies and other sources to parameterize model relationships, thereby utilizing the greatest amount of data available to dynamically simulate responses of populations across multiple life stages to changes in environmental variables or combinations of environmental variables at specified times and locations. However, there are ecological relationships that are not modeled in IOS because sufficient information on them does not exist (*e.g.,* predation, disease).

IOS is not a static model, but rather a flexible life-cycle simulation framework which incorporates the best available data. IOS is built on the GoldSim platform, which enables the simulation of complex processes through creation of simple object relationships and allows users to view model functions and easily make changes to functional relationships as new data or hypotheses become available. IOS model details and calculations are thus transparent to the user, and knowledge of C++, FORTRAN, or other computer languages is not required to understand or update the model.

(a) **Application of IOS**

The results of IOS life-cycle model simulations are dependent upon the assumptions and information used to build the model, as well as the quality of the data which the model integrates. Model results should be viewed as one source of information, part of a suite of information which should be considered when making management decisions. The use of formal simulation models such as the IOS life-cycle model is especially important when analyzing the interactions of fish populations and environmental variables in complex systems such as the Delta, where management actions often have unexpected results.

IOS results should not be interpreted as predictions of the future since factors which are not included in the model or which cannot be altered by management actions may influence long-term population viability. Instead, IOS results should be used to compare the relative impacts of different operational scenarios on fish survival and abundance. For example, sufficient flow is thought to be key for the survival of delta smelt during the fall season, but releasing water to increase Delta flow in the fall may result in insufficient cold water supply the next summer and fall for the survival of winter-run Chinook salmon. The IOS life-cycle model can be used to test the relative impact of alternative flow standards on short-term survival and long-term population viability for winter-run Chinook, and thus enable managers to set standards likely to be protective of both species. The IOS life-cycle model can also be used to investigate the impact of different combinations of management actions, or to investigate trade-offs between them, by varying the parameter or parameters being investigated while holding others constant. For example, the IOS model can be used to investigate relative impacts from restricting south Delta exports versus managing Delta inflows.

The IOS life-cycle model was originally developed to evaluate potential effects and design alternatives for the proposed North of Delta Offstream Storage (NODOS) project. It has since been used to analyze the effects of water exports in the Biological Assessment for the National Marine Fisheries Service (NMFS) 2009 Salmon BiOp, and to evaluate water management alternatives for the Bay Delta Conservation Plan (BDCP). IOS results for the BDCP are available in Appendix E8 of the BDCP effects analysis (Cavallo *et al.* 2011), and Zeug *et al.* (2012) provides a detailed description of the model.

(b) IOS Model Overview

The IOS model is composed of six model-stages that are defined by a specific spatiotemporal context (Figure 30) and are arranged sequentially to account for the entire life cycle of winter-run Chinook salmon, from eggs to returning spawners. In sequential order, the IOS model-stages are:

1) *Spawning*, which models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds,

2) *Early Development*, which models the impact of temperature on maturation timing and mortality of eggs at the spawning grounds,

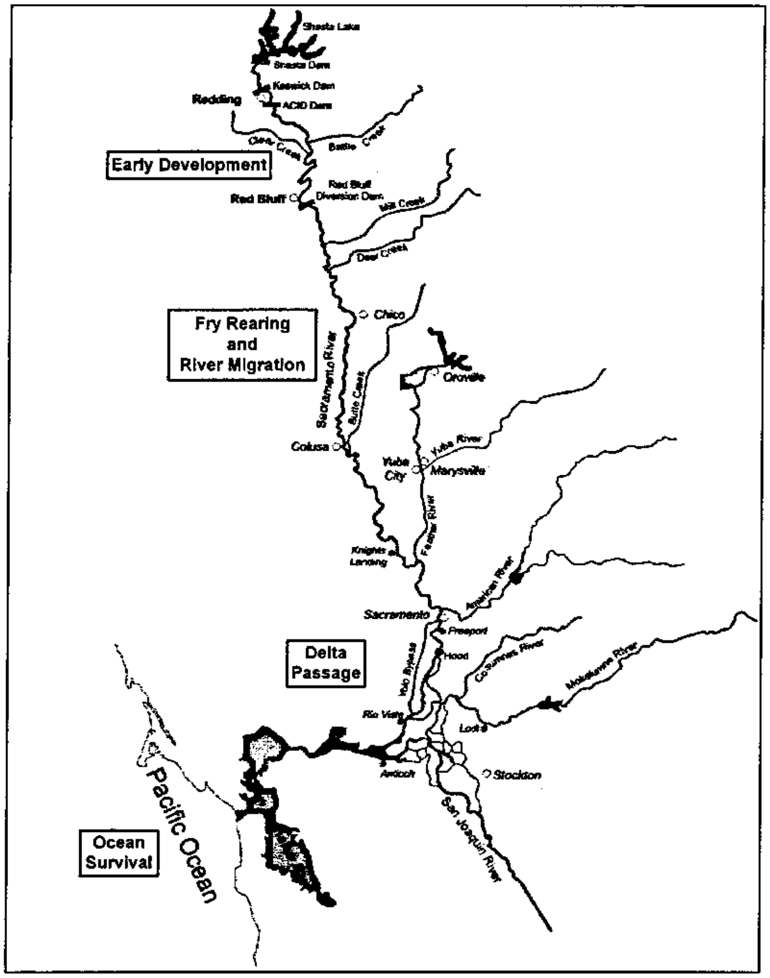
3) *Fry Rearing*, which models the relationship between temperature and mortality of fry during the river rearing period,

4) *River Migration*, which estimates mortality of migrating smolts in the Sacramento River between the spawning and rearing grounds and the Sacramento-San Joaquin Delta,

5) *Delta Passage*, which models the impact of flow, route selection and water exports on the survival of smolts migrating through the Sacramento-San Joaquin Delta to San Francisco Bay, and,

6) *Ocean Survival*, which estimates the impact of natural mortality and ocean harvest to predict survival and spawning returns by age.

Figure 30 Map of the Sacramento River and the Sacramento-San Joaquin Delta, including approximate areas defined by model-stages.



For the first four simulation years, the model is seeded with a fixed number of female spawners. In each subsequent simulation year, the number of female spawners is determined by the model's probabilistic simulation of survival to this life stage. To ensure that developing fish experience the correct environmental conditions during each year, spawn timing mimics the observed arrival of salmon on the spawning grounds as determined by 8 years of carcass surveys (2002-2009) conducted by the United States Fish and Wildlife Service (USFWS). In each year of the simulation, one of the 8 spawning distributions is chosen at random. The daily number of female spawners is calculated by multiplying the daily proportion of the total carcasses observed during the USFWS surveys by the total Jolly-Seber estimate of female spawners (Poytress and Carillo 2008). Then, in order to better match the timing of carcass observations to the deposition of eggs, the date of egg deposition is shifted 14 days before the carcasses were observed (Kevin Niemela, USFWS, personal communication).

Eggs deposited on a particular date are treated as cohorts which experience temperature and flow on a daily time step during the *Early Development* model-stage. To obtain an estimate of juvenile production, a Ricker stock-recruitment curve (Ricker 1975) is fit between the number of emergent fry produced each year and the number of female spawners as estimated by CDFG screw trap sampling (juveniles) and USFWS carcass surveys (spawners) for years (1996-1999, 2002-2007). In the IOS model, this linear relationship is used to predict values for mean fry production along with the confidence intervals for the predicted values. These values are then used to define a normal probability distribution, which is randomly sampled to determine the annual fry production. Although the Ricker model accounts for mortality during egg incubation, the data used to fit the Ricker model were from a limited time period (1996-1999, 2002-2007) when water temperatures during egg incubation were too cool (< 14°C) to cause temperature-related egg mortality (USFWS 1999). Thus, additional mortality is imposed at higher temperatures not experienced during the years used to construct the Ricker model. In order to calculate this additional mortality, data from three laboratory studies were used to estimate the relationship between temperature, egg mortality and development time for higher temperatures (Murray and McPhail 1988; Beacham and Murray 1989; USFWS 1999). Due to limited sample size from the study by the USFWS (USFWS 1999), the appropriate statistical analyses to test for the effects of temperature on mortality (e.g., a general additive model) could not be performed. However, in order to acquire predicted values for the IOS model, an exponential relationship was fitted between observed daily mortality and observed water temperatures (USFWS 1999). In the IOS model, each day the mean mortality rate of the incubating eggs is predicted from the daily temperature measured at Bend Bridge on the Sacramento River using the exponential function. The predicted mean mortality rate along with the confidence intervals of the predicted values are used to define a normal probability distribution, which is then randomly sampled to determine the daily egg mortality rate.

For the *Fry Rearing* model-stage, data from USFWS (USFWS 1999) was used to model fry mortality during rearing as a function of water temperature. Again, due to a limited sample size from the study by the USFWS (USFWS 1999), it was not possible to run statistical analyses to test for the effects of temperature on rearing mortality. However, to acquire predicted values for the model, an exponential relationship was fitted between observed daily mortality and observed water temperatures (USFWS 1999). In the IOS model, each day the mean proportional mortality of the rearing fish is predicted from the daily temperature using the exponential relationship; the predicted mean mortality along with the confidence intervals of the predicted values are used to define a normal probability distribution, which is then randomly sampled to determine the daily mortality of the rearing fish. Temperature mortality is applied to rearing fry for the 60 days that is the approximate time required for fry to transition into smolts (USFWS 1999) and enter the *River Migration* model-stage.

In the *River Migration* model-stage, survival of smolts from the spawning and rearing grounds to the Delta is a normally distributed random variable with a mean of 23.5 % and a standard error of 1.7%. Mortality in this stage is applied only once and occurs on the same day that a cohort of smolts enters the model-stage—rather than being applied daily as in the *Early Development* stage—because there is insufficient data to support a relationship with flow or temperature. Smolts are then delayed from entering the next model-stage to account for travel time. Mean travel time (20 days) is used along with the standard error (3.6 days) to define a normal probability distribution, which is then randomly sampled to determine the total travel time of migrating smolts. Survival and travel time means and standard deviations were acquired from a study of late-fall run Chinook smolt migration in the Sacramento that employed acoustics tags and several monitoring stations (including Freeport) between Coleman and the Golden Gate Bridge (Michel 2010).

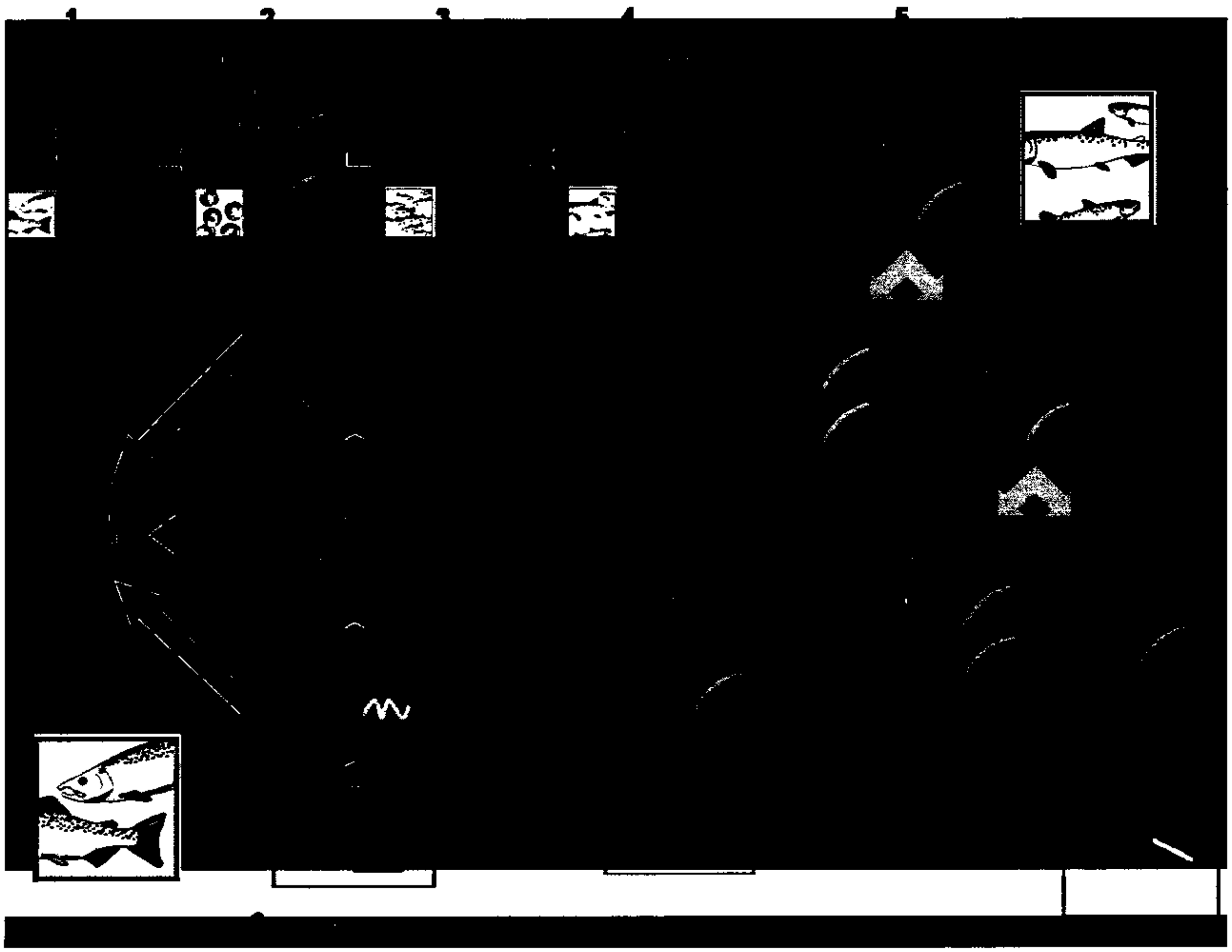
Smolt migration in the *Delta Passage* model-stage is evaluated using the Delta Passage Model (described below), and is based on four major functional relationships: 1) Delta entry timing, in which daily cohorts of smolts enter the first reach of the Delta on a day of the year determined by timing in the previous model stages; 2) route selection by smolts at river junctions, which is a function of the proportion of flow entering each route; 3) migration speed, which is a function of reach-specific flow; and 4) survival, which for a specific reach is a function of flow, exports, or a probability distribution. As each cohort of smolts exits the final reaches of the Delta they continue to accumulate until all cohorts from that year have exited the Delta. After all smolts have arrived, they enter the *Ocean Survival* model-stage as a single cohort and the model begins applying mortality on an annual time step.

The *Ocean Survival* model-stage utilizes a set of equations for smolt-to-Age 2 mortality, winter mortality, ocean harvest, and spawning returns to predict yearly survival and escapement numbers (i.e., individuals exiting the ocean to spawn). The IOS model relies on ocean harvest, mortality, and returning spawner data from Grover et al. (2004), and uses a uniformly distributed random variable between 96% and 98% mortality for winter-run Chinook from ocean entry to Age 2 to develop functional relationships to predict ocean survival and returning spawners for Age 2 (8%), Age 3 (88%), and Age 4 (4%), assuming that 100% of individuals which survive to Age 4 return for spawning. Harvest mortality is represented by a uniform distribution that is bounded by historical levels of harvest. Age-2 survival is multiplied by a scalar that corresponds to the value of the Wells Index of ocean productivity. This metric was shown to significantly influence over-winter survival of age two fish (Wells et al. 2007). The value of the Wells Index is a normally distributed random variable that is resampled each year of the simulation. Adult fish designated for return to the spawning grounds are assumed to be 65% female and are assigned a pre-spawn mortality of 5% to determine the final number of female returning spawners (Snider *et al.* 2001).

(c) **Illustrative Example of IOS**

To help illustrate the series of operations performed by the IOS model, Figure 31 depicts the life cycle of a population of winter-run Chinook salmon spawning in the Sacramento River and migrating downriver to the ocean before later returning to spawn again. The number and timing of eggs deposited in the Spawning model-stage (1), along with the rates of maturation and mortality in the Early development model-stage (2), determines the abundance of fry emerging to rear in the Fry rearing model-stage (3). The number of fry which undergo river migration (4) is a function of mortality in the prior stage. As fish encounter junctions in the Delta they are routed down various paths with different associated migration speeds and survival rates (4, 5), depending on the proportion of flow entering each downstream reach. Some fish remain in reaches in the northern Delta (Yolo Bypass, Sac1, SS, Sac2, Sac3, Sac4), and some enter the interior Delta through the GEO/DCC reach. As fish enter Delta reaches, their reach survival and migration speed (and therefore travel time) is calculated on the day they enter the reach. During all subsequent days that fish are migrating through a given reach, they are not exposed to mortality, nor are their migration speeds adjusted. For reaches where data are available to inform a relationship with flow, reach survival (Sac1, Sac2, Sac3, Sac4, SS, and Interior Delta) and migration speed (Sac1, Sac2, Geo/DCC) are calculated as a function of the flow on the initial day of reach entry. Likewise, where data are available to inform a relationship with south Delta exports (Interior Delta), reach survival is calculated as a function of south Delta exports as fish enter that reach. Overall survival through the Delta is a combination of survival in each route and the proportion of fish that enter each route. Once fish successfully migrate through the Delta and enter the ocean (6), a proportion survive and mature until Age 2. Those fish that survive to Age 2 either return to spawn or continue maturing. Those remaining in the ocean are subjected to natural mortality and harvest, with a large proportion of survivors returning to spawn at Age 3. Fish that do not return at Age 3 are again subjected to natural mortality and harvest before all of the remaining fish return to spawn at Age 4.

Figure 31 Conceptual diagram depicting the life cycle of a winter-run Chinook population in the IOS model, with the IOS model-stages and environmental influences on survival and development of winter-run Chinook at each stage. Red = temperature, blue = flow, green = water exports, pink= ocean productivity.



4.1.3.2.2 Delta Passage Model

The Delta Passage Model (DPM) is a stochastic simulation model which was developed by Cramer Fish Sciences to evaluate the impacts of water management actions and conservation measures on the survival of Chinook salmon smolts as they migrate through the Delta. The DPM is not a life-cycle model, but is incorporated as a sub-model in the IOS life-cycle model (described above), comprising the *Delta Passage* model-stage. A detailed description of the

DPM is included in the peer reviewed paper on the IOS life-cycle model (Zeug *et al.* 2012). The DPM is also used as a stand-alone model to analyze Delta survival and routing.

The DPM simulates migration of Chinook salmon smolts entering the Delta from the Sacramento River, Mokelumne River, and San Joaquin River, and estimates survival through the Delta to Chipps Island. The model can also provide survival estimates for specific reaches or life stages. The DPM can be used to inform which management actions likely have the most benefit for improving smolt survival, as well as locations in the Delta where such actions are likely to have the most benefit—a level of detail which aggregated estimates of survival through the Delta cannot provide. The development of the DPM has been made possible by the results of acoustic tagging studies, which have demonstrated repeatable migration routing patterns at junctions as well as different survival rates among routes.

The DPM utilizes the best available empirical data to parameterize model relationships and inform uncertainty, thereby utilizing the greatest amount of data available to dynamically simulate responses of smolt survival to changes in model inputs or parameters in the model. The DPM is primarily based on studies of late-fall and San Joaquin basin fall run Chinook, but it has been applied to winter-run, spring-run, late-fall run, Sacramento fall-run, Mokelumne River fall-run and San Joaquin fall-run Chinook salmon by adjusting emigration timing and by assuming that all migrating Chinook salmon smolts respond similarly to Delta conditions.

Although studies have shown considerable variation in emigrant size, with Central Valley Chinook salmon migrating as fry, parr, or smolts (Brandes and McLain 2001; Williams 2006), the DPM relies predominantly on data from acoustic tagging studies of large (>140 mm) smolts. Unfortunately, survival data is limited for small (fry-sized) juvenile emigrants due to the difficulty of tagging such small individuals. Therefore, the DPM should be viewed as a smolt survival model only, most applicable to large smolts (>140 mm), with the fate of pre-smolt emigrants not incorporated in the model.

The DPM is not a static model, but rather an adaptable simulation framework that can be changed as more data or new hypotheses regarding smolt migration and survival become available. It is built on the GoldSim platform, which allows users to view every function in the model and easily make changes to incorporate new data and functional relationships. The DPM is thus transparent to the user, and differs in this respect from models written in C++, FORTRAN, or other computer languages.

(a) Application of Delta Passage Model

Survival estimates generated by the DPM are not intended to predict future outcomes since factors which are not included in the model or which cannot be altered by management actions may influence long-term population viability. Instead, the DPM provides a simulation tool that can compare the effect of different water management scenarios and model formulations on smolt migration and survival, with accompanying estimates of uncertainty. Thus, the DPM can help management agencies and stakeholders understand how competing management alternatives may influence both short-term survival of migrating smolts and long-term viability of Chinook populations.

As a sub-model incorporated in the IOS life-cycle model, the DPM has been used to analyze the effects of water exports in the Biological Assessment for the National Marine Fisheries Service (NMFS) 2009 Salmon BiOp and to evaluate effects and design alternatives for the proposed North of Delta Offstream Storage (NODOS) project. The DPM has also been used— both as a stand-alone model and as part of IOS—to evaluate water management alternatives for the Bay Delta Conservation Plan (BDCP).

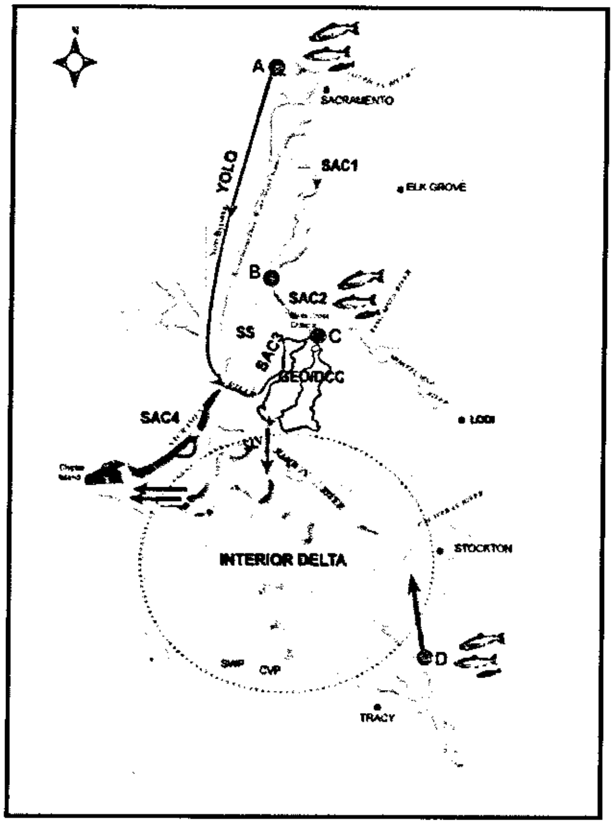
The DPM has undergone substantial revisions based on comments received through Bay Delta Conservation Plan (BDCP) anadromous team meetings and in particular by feedback received during a workshop held on August 24th, 2010, and a two-day workshop held on June 23-24, 2011. A detailed description of the DPM is included in the peer reviewed paper on the IOS life-cycle model (Zeug *et al.* 2012).

(b) Overview of Delta Passage Model

The DPM is based on a detailed accounting of migratory pathways and reach-specific survival as Chinook salmon smolts travel through a simplified network of reaches and junctions. The biological functionality of the DPM is based upon the foundation provided by acoustic telemetry data (Perry 2010) and coded wire tag (CWT) based studies (Newman and Brandes 2010; Newman, personal communication). Uncertainty is explicitly modeled in the DPM by incorporating environmental stochasticity and estimation error whenever available.

The DPM is composed of eight reaches and four junctions (Figure 32) selected to represent primary salmonid migration corridors where fish and hydrodynamic data were available. Smolts can enter the model in 3 separate locations: 1) immediately upstream of Fremont Weir on the Sacramento River (Sacramento runs), 2) the head of the North and South Forks of the Mokelumne River (Mokelumne Fall-run, and 3) immediately upstream of the head of Old River on the San Joaquin River (San Joaquin River fall-run). For simplification, Sutter Slough and Steamboat Slough are combined as the reach SS and the forks of the Mokelumne River and Georgiana Slough are combined as Geo/DCC. Due to lack of data informing specific routes through the Interior Delta, or tributary-specific survival, the DPM treats the entire Interior Delta region as a single model reach. However, survival varies within the Interior Delta reach depending upon whether smolts enter from the Mokelumne River, the San Joaquin River or Old River, as informed by different survival data sources.

Figure 32 Map of the Sacramento-San Joaquin Delta showing the modeled reaches and junctions of the Delta applied in the DPM. Bold headings label modeled reaches and red circles indicate model junctions. Salmon icons indicate locations where smolts enter the Delta.



The DPM operates on a daily time step using simulated daily average flows and south Delta exports as model inputs. The DPM does not attempt to represent sub-daily flows or diel salmon smolt behavior in response to the interaction of tides, flows and specific channel features. The DPM is intended to represent the net outcome of migration and mortality occurring over days, not three-dimensional movements occurring over minutes or hours (e.g., Blake and Horn 2006).

The major model functions in the DPM are: 1) *Delta Entry Timing*, which models the temporal distribution of smolts entering the Delta for each race of Chinook salmon, 2) *Fish Behavior at Junctions*, which models fish movement at river junctions, 3) *Migration Speed*, which models reach-specific smolt migration speed and resulting travel time, and 4) *Survival*, which models survival in a specific reach of the river as a function of flow, exports or a probability distribution.

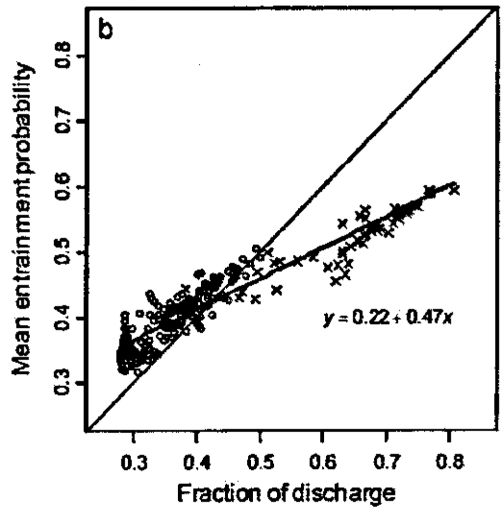
Recent sampling data on *Delta entry timing* of emigrating juvenile smolts for six Central Valley Chinook salmon runs (Table 11) were used to inform the daily proportion of juveniles entering the DPM for each run.

Table 11 Sampling gear used to create juvenile Delta entry timing distributions for each Central Valley run of Chinook salmon. Agencies that conducted sampling are listed: U.S. Fish and Wildlife Service (USFWS), East Bay Municipal District (EBMUD), and California Department of Fish and Game (CDFG).

Run	Gear	Agency	Brood Years
Sacramento River Winter-Run	Trawls at Sacramento, CA	USFWS	1995-2009
Sacramento River Spring-Run	Trawls at Sacramento, CA	USFWS	1995-2005
Sacramento River Fall-Run	Trawls at Sacramento, CA	USFWS	1995-2005
Sacramento River Late-Fall Run	Trawls at Sacramento, CA	USFWS	1995-2005
Mokelumne River Fall-Run	Rotary Screw Trap at Woodbridge, CA	EBMUD	2001-2007
San Joaquin River Fall-Run	Kodiak Trawl at Mossdale, CA	CDFG	1996-2009

Acoustic tagging data are used to inform *fish behavior at junctions*. Perry (2010) found that acoustically tagged smolts arriving at Delta junctions exhibited movement patterns in relation to the flow being diverted. For junction B (Sacramento River-Sutter/Steamboat Sloughs), Perry (2010) found that smolts consistently entered downstream reaches in proportion to the flow being diverted. Therefore, smolts arriving at junction B in the DPM move proportionally with flow. Similarly, with data lacking to inform the nature of the relationship, the DPM uses a proportional relationship between flow and fish movement for junction D (San Joaquin River-Old River). For Junction A, smolts are assumed to enter Yolo Bypass in proportion to flow movement into the bypass. When available flow data includes Fremont weir spill, proportions are calculated as flow passing over Fremont Weir divided by flow passing over Fremont Weir plus Sacramento River flow at Freeport. When flow data includes only flows within the bypass, all fish enter the Sacramento until flow in the bypass exceeds 500 cfs, then fish enter each route proportional to flow as described above. The 500 cfs threshold accounts for flows into the bypass from west side tributaries (Putah and Cache creeks). For junction C (Sacramento River-Georgiana Slough/DCC), Perry (2010) found a linear, non-proportional relationship between flow and fish movement (Figure 33).

Figure 33 Figure from Perry (2010) depicting the mean entrainment probability (proportion of fish being diverted into reach Geo/DCC) as a function of fraction of discharge (proportion of flow entering reach Geo/DCC). In the DPM, this linear function is applied to predict the daily proportion of fish movement into Geo/DCC as a function of the proportion of flow movement into Geo/DCC. A circle indicates when the DCC gates were closed and X indicates when the DCC gates were open.



With the exception of exports at the SWP and CVP pumping plants, flow though the Delta is modeled using daily (tidally averaged) flow output from the hydrology module of the Delta Simulation Model II (DSM2-HYDRO; http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/). Exports at the CVP and SWP pumping plants are modeled using monthly flow output from the hydrologic simulation tool CALSIM II (Ferreira *et al.* 2005) that is "disaggregated" into mean daily exports based on historical patterns.

The DPM assumes a net daily movement of smolts in the downstream direction. Smolt *migration speed* in the DPM affects the timing of arrival at Delta junctions and reaches which can affect route selection and survival as flow conditions or water exports change. Smolt migration and travel time in all reaches except Yolo Bypass and Interior Delta for Sacramento or Mokelumne fish is a function of reach-specific length and migration speed as observed from acoustic tagging results (Table 12).

Table 12 **Reach-specific migration speed and sample size of acoustically-tagged smolts released during December and January for three consecutive winters (2006/2007, 2007/2008, and 2008/2009; Perry 2010) and associated flow data (gauging station ID; http://cdec.water.ca.gov/) used to develop a logarithmic relationship between migration speed and flow.**

Reach	Gauging Station ID	Release Dates	Sample Size	Speed (km/day)			
				Ave.	Min	Max	SD
Sac1	FPT	12/05/06-12/06/06, 1/17/07-1/18/07, 12/04/07-12/07/07, 1/15/08-1/18/08, 11/30/08-12/06/08, 1/13/09-1/19/09	452	13.32	0.54	41.04	9.29
Sac2	SDC	1/17/07-1/18/07, 1/15/08-1/18/08, 11/30/08-12/06/08, 1/13/09-1/19/09	294	9.29	0.34	10.78	3.09
Sac3	GES	12/05/06-12/06/06, 1/17/07-1/18/07, 12/04/07-12/07/07, 1/15/08-1/18/08, 11/30/08-12/06/08, 1/13/09-1/19/09	102	9.24	0.37	22.37	7.33
Sac4	GES[a]	12/05/06-12/06/06, 1/17/07-1/18/07, 12/04/07-12/07/07, 1/15/08-1/18/08, 11/30/08-12/06/08, 1/13/09-1/19/09	62	8.60	0.36	23.98	6.79
Geo/DCC	GSS	12/05/06-12/06/06, 1/17/07-1/18/07, 12/04/07-12/07/07, 1/15/08-1/18/08, 11/30/08-12/06/08, 1/13/09-1/19/09	86	14.20	0.34	25.59	8.66
SS	FPT-SDC[b]	12/05/06-12/06/06, 12/04/07-12/07/07, 1/15/08-1/18/08, 11/30/08-12/06/08, 1/13/09-1/19/09	30	9.41	0.56	26.72	7.42

a = Sac3 flow is used for Sac4 because no flow gauging station is available for Sac4
b = SS flow is calculated by subtracting Sac2 flow (SDC) from Sac1 flow (FPT).

Survival through a given route (individual reach or reaches combined) is calculated and applied the first day smolts enter the route. For routes where literature or available tagging data showed support for responses to environmental variables, survival is influenced by flow (Sac1, Sac2, Sac3 and Sac4 combined, SS and Sac4 combined, Interior Delta via San Joaquin River, and Interior Delta via Old River) or south Delta exports (Interior Delta via Geo/DCC). For these routes, daily flow or south Delta exports occurring the day of route entry are used to predict survival through the entire route (Table 13). For all other routes (Geo/DCC, Yolo, Sac4 entering from Yolo), survival is uninfluenced by Delta conditions and is informed by means and standard deviations of survival from acoustic tagging studies (Table 13).

Table 13 **Route-specific survival functionality for each Chinook salmon run. For routes where survival is uninfluenced by Delta conditions, mean survival and associated standard deviation (in parenthesis) observed during acoustic tagging studies (Perry 2010) are used to define a normal probability distribution that is sampled from the day smolts enter a route to calculate route survival.**

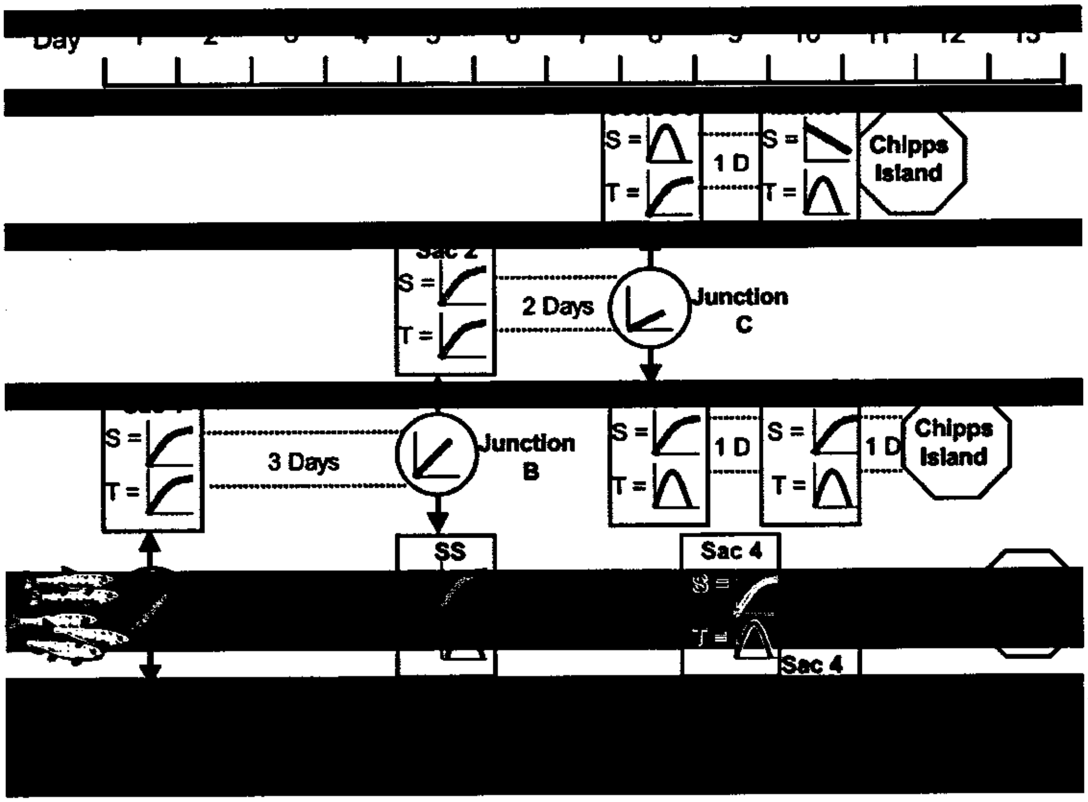
Route	Chinook Salmon Run	Survival
Sac1	All Sacramento runs	function of flow
Sac2	All Sacramento runs	function of flow
Sac3 and Sac4	All Sacramento runs	function of flow
SS and Sac4	All Sacramento runs	function of flow
Yolo	All Sacramento runs	0.8
Sac4[a]	All Sacramento runs	0.698 (0.153)
Geo/DCC	Mokelumne Fall-run	0.407 (0.209)
	All Sacramento runs	0.65 (0.126)
Interior Delta	Sacramento runs and Mokelumne Fall-run	function of exports
	San Joaquin Fall-run via Old River	function of flow
	San Joaquin Fall-run via San Joaquin River	function of flow

a = Although flow influences survival of fish migrating through the combined routes of SS - Sac4 and Sac3 - Sac4, flow does not influence Sac4 survival for fish arriving from Yolo.

(c) Illustration of Delta Passage Model

To help illustrate the series of operations performed by the DPM model, Figure 34 depicts the "migration" of a single daily cohort of salmonid smolts entering from the Sacramento River and migrating through the DPM. It is important to remember that cohorts of differing numbers of smolts enter the Delta each day during the migration period of each salmon run. As fish encounter junctions in the Delta they are routed down one of two paths, depending on the proportion of flow entering each downstream reach. In some cases (Junctions A and B) fish routing is directly proportional to flow, while in other cases (Junction C) fish routing, although linear, is not directly proportional to flow. As fish enter Delta reaches, their reach survival and migration speed (and therefore travel time) is calculated on the day they enter the reach. During all subsequent days that fish are migrating through a given reach, they are not exposed to mortality, nor are their migration speeds adjusted. For reaches where data are available to inform a relationship with flow, reach survival (Sac1, Sac2, Sac3, Sac4, SS, and Interior Delta via San Joaquin River) and migration speed (Sac1, Sac2, Geo/DCC) is calculated as a function of the flow on the initial day of reach entry. Likewise, where data are available to inform a relationship with south Delta exports (Interior Delta), reach survival is calculated as a function of south Delta exports as fish enter that reach. Because portions of a single cohort of fish migrate through different routes in the Delta, portions of the cohort will experience differing overall survival rates, differing migration rates, and differing arrival times at Chipps Island. Overall survival through the Delta for the cohort is then the combination of survival in each route and the proportion that enters each route.

Figure 34 Conceptual diagram depicting the "migration" of a single daily cohort of smolts entering from the Sacramento River and migrating through the Delta Passage Model. Day of the model run is indicated at the top of the diagram. Circles indicate Delta junctions, where the proportion of fish moving to each downstream reach is calculated, and rectangles indicate Delta reaches. The shape of the relationship for each reach-specific survival (S), reach-specific migration speed (T), and proportional fish movement at junctions are depicted. Relationships that are influenced by flow (x variable) are colored blue, relationships influenced by south Delta exports are colored red, and relationships that are calculated from a probability distribution (and not influenced by flow or south Delta exports) are colored black. Dotted lines indicate migration time through the previous reach, and the Chipps Island icons indicate when fish from each route exited the Delta.



4.1.3.2.3 SALMOD and OBAN Life-cycle Models

Additional life-cycle models which have been applied to Central Valley salmonids include SALMOD and OBAN. Both of these models have significant differences with the IOS life-cycle model.

(a) SALMOD Model

SALMOD simulates the effects of habitat changes on freshwater salmon population dynamics. It was developed to link fish production with flow, as described by the Physical Habitat Simulation System (PHABSIM) model. SALMOD was used in the Biological Assessment (BA) for the National Marine Fisheries Service 2009 Salmon BiOp, and is described in the BA as follows:

> "SALMOD simulates population dynamics for all four runs of Chinook salmon in the Sacramento River between Keswick Dam and RBDD. SALMOD presupposes egg and fish mortality are directly related to spatially and temporally variable microhabitat and macrohabitat limitations, which themselves are related to the timing and volume of streamflow and other meteorological variables. SALMOD is a spatially explicit model in which habitat quality and carrying capacity are characterized by the hydraulic and thermal properties of individual mesohabitats, which serve as spatial computation units in the model. The model tracks a population of spatially distinct cohorts that originate as eggs and grow from one life stage to another as a function of water temperature in a computational unit. Individual cohorts either remain in the computational unit in which they emerged or move, in whole or in part, to nearby units. Model processes include spawning (with redd superimposition), incubation losses (from either redd scouring or dewatering), growth (including egg maturation), mortality due to water temperature and other causes, and movement (habitat and seasonally induced). SALMOD is organized around physical and environmental events on a weekly basis occurring during a fish's biological year (also termed a brood year), beginning with adult holding and typically concluding with fish that are physiologically "ready" to begin migration towards the ocean. Input variables, represented as weekly average values, include streamflow, water temperature, and number and distribution of adult spawners." (BOR 2008, p.9-25)

SALMOD does not simulate the influence of environmental variables on salmonid population dynamics during the river migration, Delta migration, or ocean maturation phases of the salmonid life cycle. Thus, SALMOD is not used to estimate adult escapement; the primary key to population viability over time. It should be noted that the life stages and geographic areas addressed by SALMOD are contained and described in the IOS life-cycle model using similar functional relationships.

(b) OBAN Model

The Oncorhynchus Bayesian Analysis (OBAN) is a statistical model developed by Hendrix (2008) and used to quantify uncertainties in potential outcomes and long-term population viability due to variations in environmental conditions, but not to compare population effects at the spatial and temporal scale of specific management actions. OBAN is described in a recent NMFS review of salmon life-cycle models (NMFS 2012a) as follows:

> "OBAN is statistical life cycle model that includes life stages based on a Beverton-Holt function. OBAN defines the transformation from one life stage to the next in terms of survival and carrying capacity. Unlike the mechanistic models, it does not consider the timing of movement between stages or habitats.

> Additionally, the survival and carrying capacity parameters are determined by a set of time varying covariates. There is no specific mechanistic relationship between the parameters and the survival and carrying capacity. The weighting terms for the influence of environmental covariates on the Beverton-Holt functions are established by fitting the model to spawner recruit data." (NMFS 2012a, p.5)

Unlike the IOS life-cycle model, OBAN does not compare population effects at the spatial and temporal scale of specific management actions. Also, the OBAN model has not been published in a peer reviewed scientific journal, and no detailed description of model relationships or coefficients is currently available.

4.1.3.3 NMFS Life Cycle Model

The National Marine Fisheries Service (NMFS) has recently proposed the development of a new life-cycle model for Central Valley salmonids. After holding a June, 2011 Independent Panel Workshop in which existing life-cycle models were reviewed, NMFS concluded that none of the existing models were sufficiently well suited for their use in supporting the OCAP and BDCP Biological Opinions. An important consideration in this decision was the perceived need for complete ownership and control of the model (NMFS 2012, p.17). To that end, NMFS proposed the development of their own life-cycle model for winter-run Chinook. The proposal was completed in February 2012 and conveyed to the Bureau of Reclamation and the California Department of Water Resources in March 2012. The initial model is to be completed and available for use by NMFS to evaluate OCAP RPA actions by December 2013. NMFS' approach to the new life-cycle model is summarized in the proposal as follows:

> The NMFS life-cycle model needs to be able to translate the effects of detailed water project operations into population effects. There are at least two ways this might be approached: 1) a brand-new coupled physical and individual-based biological simulation model or 2) linking existing physical models to a population-level stage-structured life-cycle model through state-transition parameters that are a function of the environment (as described by the physical models). We are pursuing the latter strategy because we are more certain it will yield useful products in time for the OCAP and BDCP processes, and because it will be easier to analyze, understand and explain model outputs.

Our work will proceed on four fronts—development and refinement of the life-cycle modeling framework; application, improvement and integration of physical models; development of linkages between physical model outputs and stage-transition parameters; and assembly of data sets needed to determine the physical-biological couplings and assess overall model performance. Periodically, we will integrate work in these four areas to produce assessment tools ("life-cycle models") that can address increasingly complex management scenarios. Along the way, we will work with interested parties (especially agency staff responsible for the BiOps) to guide development, through periodical workshops and webinars. We will deliver working models, analyses of select scenarios, documentation, and peer-reviewed publications." (NMFS 2012, p.3)

At this time, the NMFS life-cycle model is simply a proposal; even an initial model is at least a year or more from completion. The use of available models such as IOS is necessary for the current evaluation and planning of management actions, and to provide important feedback for the development and use of future models such as the proposed NMFS life-cycle model.

4.2 Delta Turbidity Forecasting Tools

Flows in Old and Middle River ("OMR") have been used by the FWS and NMFS minimize entrainment in the SWP and CVP Delta facilities. When OMR is used for this purpose, it is not measuring a degradation of water quality. Nevertheless, several parties have raised concerns about OMR and entrainment in the SWP and CVP facilities during these workshops. For this reason, the Public Water Agencies addressed entrainment and OMR in Workshop 2, explaining that current entrainment of smelt and salmonids in the SWP and CVP Delta facilities is very low. The Public Water Agencies further explained that entrainment by the SWP and CVP has never been shown to have a population level effect, nor has there ever been shown to be a statistically significant relationship between entrainment and species abundance. However, the Public Water Agencies recognize that adult delta smelt entrainment can often be minimized by managing operations in response to natural turbidity events. In this workshop, the Public Water Agencies are describing new modeling capabilities that allow SWP and CVP operators to forecast turbidity events as part of real time operations to minimize entrainment.

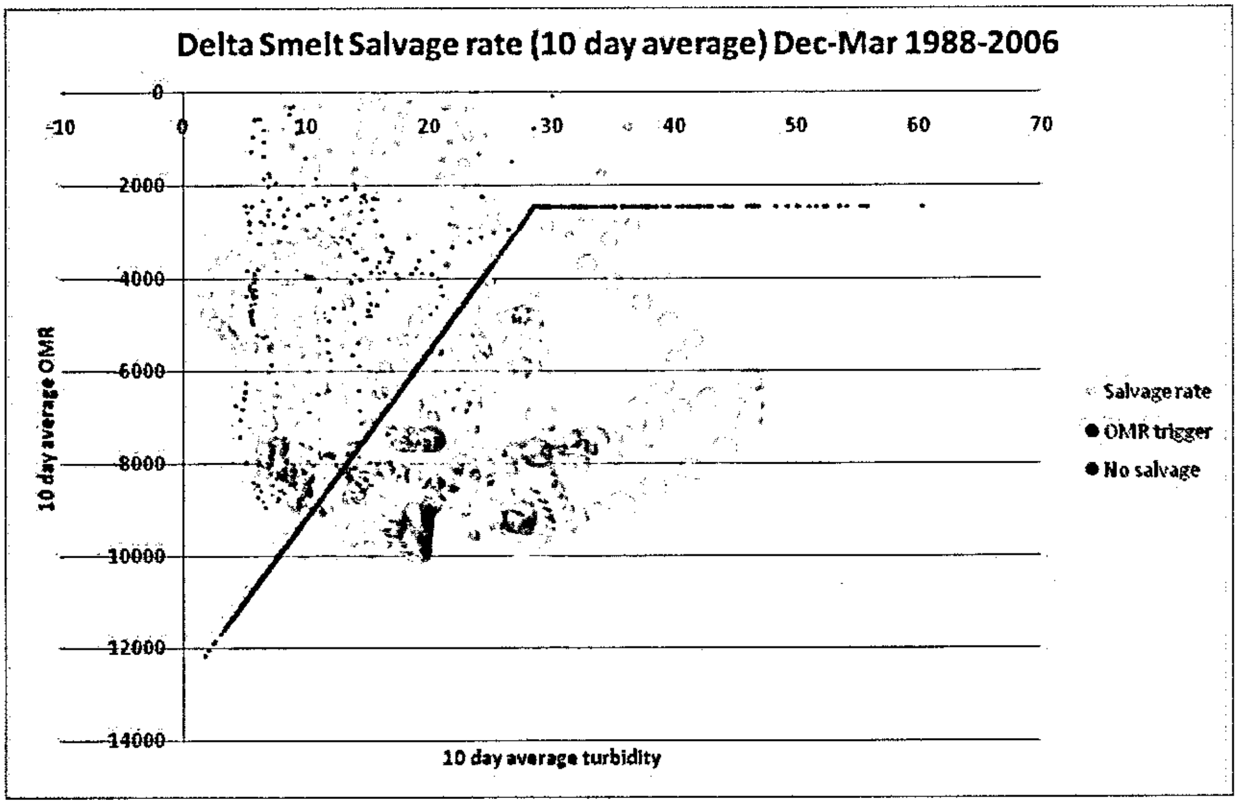
4.2.1 Background

There is little disagreement that turbidity is a factor affecting entrainment in the CVP/SWP facilities. The distributions of pre-spawning adult delta smelt are typically observed to shift from Suisun Bay into the Delta sometime in late December or January. This shift in distribution appears to be triggered by land-derived turbidity plumes associated with the first major winter rainfall-runoff event, the so-called "first-flush". It is hypothesized that, if these turbidity plumes move from the Sacramento River into the OMR corridor, adult delta smelt will follow the resulting turbidity "bridge" upstream and become more vulnerable to entrainment at the south Delta pumping facilities. While delta smelt entrainment has been characterized as at most "sporadically significant" (Kimmerer 2008), no year-to-year or long-term population level effects have been observed (Kimmerer 2008; Maunder and Deriso 2010). However, to minimize entrainment events modeling tools have been developed and are available to adaptively manage operations in response to turbidity.

In an effort to model salvage as a function of turbidity as well as OMR flows, Manly (2010) developed equations that estimate adult delta smelt salvage in December and January of each water year. His equations were derived from flow data spanning December 1993 to January 2009 and estimated biweekly salvage as a function of OMR flows, Sacramento River at Freeport flows (representing turbidity during storm events), the fall mid-water trawl index (representing overall population size), and other flows. A variety of equations were explored consisting of one, two, or three flow terms. A two-flow-term equation (including OMR and Sacramento River flows) proved to be the best compromise in terms of number of parameters and variation explained (> 80%).

Deriso (2010) developed a statistical relationship between adult delta smelt salvage rate (normalized for previous fall midwater trawl), OMR flows, and turbidity in Clifton Court Forebay. Model parameters were estimated by non-linear least-squares minimization for each ten-day time period that lies within the months of December through March of 1988-2006. His model suggests that the relationship between salvage and OMR flow is strongest when Clifton Court turbidity is high and that salvage events are unlikely when Clifton Court turbidity is low, irrespective of OMR flow levels. Figure 35 shows a bubble plot in which the OMR "trigger" is shown as a function of turbidity along with observed salvage rates. Most of the higher salvage rates (denoted by the bubble size) lie in the region partitioned by the OMR trigger. The higher salvage rates correspond to OMR flows more negative than the OMR trigger for a given level of turbidity. Figure 36 also illustrates that the relationship between entrainment and OMR is not linear.

Figure 35 Deriso Bubble Plot Illustrating the Relationship Between Salvage Rates, OMR Flows and Delta Turbidity



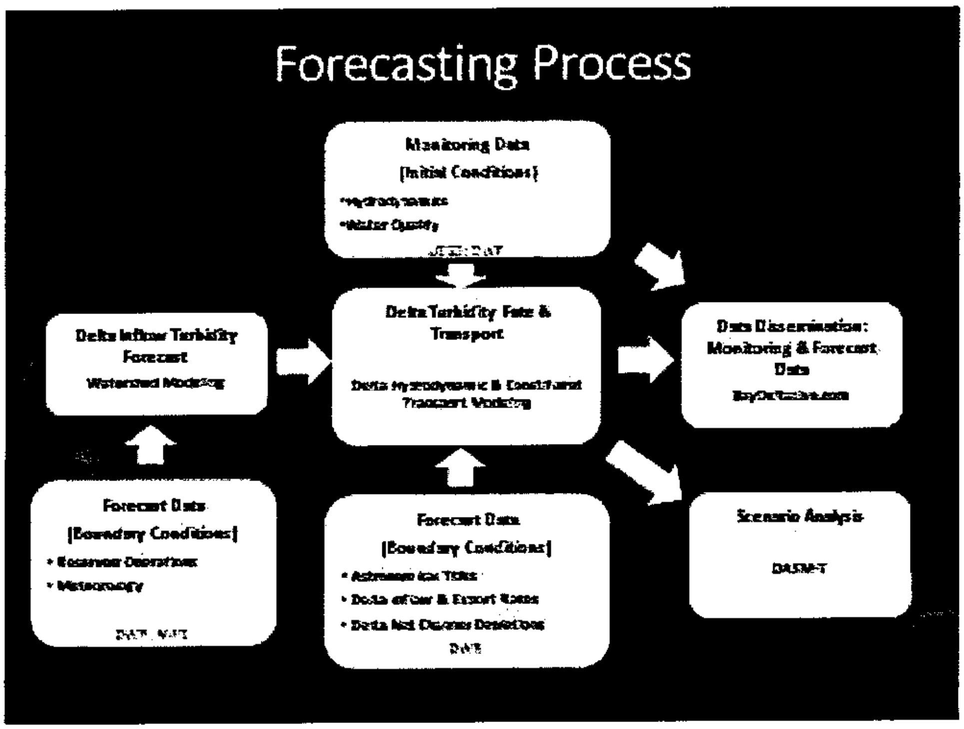
4.2.2 Forecasting Tools Suite

A decision support system is being developed to forecast Delta turbidity. It integrates DWR's hydrology and operations forecasts, computer simulation models, and real-time data to generate forecasts on a weekly basis during winter months. To compliment this decision support system, a fast and easy-to-use tool with a spreadsheet-based user interface was developed for scenario analysis as well as for long-term water supply planning. Employing artificial neural network technology, this tool is being designed and calibrated to mimic the flow-turbidity relationships as modeled in DSM2. This tool, by allowing for rapid evaluation of Delta turbidity response under alternative pumping and watershed loading scenarios, shouldprovide scientists, regulators and operators insights for developing cost-effective management strategies.

4.2.2.1 Framework

Real-time turbidity data assist with understanding water quality conditions in the Delta and the quality of water flowing into the Delta. Additionally, modeling tools are available that simulate how conditions change over time within the dynamic tidal environment of the Delta. The framework for integrating these real-time data and modeling tools into a forecasting procedure is depicted in Figure 37.

Figure 36 Forecasting Framework



Over a short forecasting window (1-3 days), real-time data provides much of the information needed to forecast turbidity loads entering the Delta. But over longer time horizons, a model is needed to forecast these conditions. Watershed models are used within the proposed framework to forecast turbidity entering the Delta. The key data inputs to these models are meteorology (i.e. precipitation and temperature) and reservoir operations forecasts.

Delta hydrodynamic and water quality models simulate the fate and transport of turbidity throughout the Delta channels, particularly at key compliance locations. In addition to forecast information from the watershed models, the Delta models require key input on Delta hydrology, hydrodynamics, and project operations. The Delta models can also be used to simulate adult smelt behavior through particle tracking.

Finally, monitoring data and forecast information produced by the Delta models can be disseminated in a timely manner to interested parties through email, web-based applications, etc. Forecast information can also be used as input into other decision support tools such as the previously described salvage models developed by Manly and Deriso.

4.2.2.2 Key Modeling Assumptions and Limitations

Key assumptions and limitations associated with the proposed forecasting methodology are outlined below:

- Turbidity measures the light scattering effect of suspended solids in water. Materials that contribute to this effect generally include land-derived materials (e.g. clay, silt) and waterborne organisms (e.g. plankton). Although turbidity is not a material, it is directly related to suspended sediment concentration and is assumed to be governed by advective and dispersive processes.
- The watershed models simulate fate and transport of suspended solids. Simple relationships between suspended solids and turbidity provide the translation needed to generate input to the Delta models.
- The Delta models assume that turbidity settling behavior follows a first-order decay mechanism. The assumed decay rates are channel specific and are not related to flow velocity or sediment properties. Sediment re-suspension driven by wind and waves is not modeled.
- The forecasting methodology should not be used outside the approximate period of December through February. This restriction acknowledges that:
    - The salvage relationships described by Manly have the greatest statistical significance in December and January, are degraded in February, and are not significant beyond February, and
    - The modeling assumptions are most reliable in emulating turbidity loading associated with rainfall-runoff events. As the year progresses, turbidity measurements tend to become less representative of land-derived materials and more representative of waterborne organisms.

4.2.2.3 Real-Time Monitoring Data

The USGS has installed a network of real-time turbidity monitoring stations in the Delta and at an upstream location at Verona. These data are useful for first-flush action compliance as well as for turbidity model calibration and validation. These data would also be useful in support of a real-time forecasting system.

4.2.2.4 Delta Modeling

An RMA transport model simulates the distribution of turbidity in the Delta and a particle tracking model simulating a habitat-seeking behavior for adult delta smelt. The particle tracking model uses conductivity and turbidity gradients as well as hydrodynamics to drive delta smelt movement, simulating their hypothesized turbidity-seeking behavior and their potential to become salvaged in the SWP and CVP export locations.

Although turbidity is an easily measured indicator of water clarity and automated devices have been installed in many Delta locations in recent years, turbidity transport cannot be modeled directly using numerical models. In comparison, suspended sediment is more difficult and expensive to measure and sampling is generally not automated, however there are governing equations for mass conservation and force balance for sediment. Calculations from a numerical model of suspended sediment transport can be used to estimate turbidity by establishing empirical relationships between the suspended sediment measurements and turbidity measurements at a given location. Unfortunately, the data requirements for developing suspended sediment model boundary conditions and model parameters are numerous and these data are not yet available in the Delta. Until these data sets are developed, transport models of turbidity distributions using a decay-coefficient approach are being used to estimate turbidity in the Delta. As discussed elsewhere (RMA 2010, 2011a, 2011b, 2012a), the RMA turbidity model has provided useful results in the interim.

Based on the limited turbidity data available for model calibration, the original turbidity transport model used a single decay coefficient to estimate in-Delta turbidity. With the inclusion of numerous turbidity data collection sites starting in late 2009, the initial calibration was modified to improve the representation of Delta turbidity fate and transport. The recalibration of the turbidity model resulted in a multi-parameter decay coefficient regime that better estimated turbidity in the single coefficient regime. The decay rates in the new calibration are about a factor of two higher than the initial calibration rates throughout much of the Delta. The new calibration was tested by running simulations assuming the Delta hydrology, water quality and operations associated with several recent years (RMA 2011b).

A recent version of the DSM2 model was calibrated to simulate turbidity within the Delta (DWR 2011). Similar to the approach adopted by RMA, turbidity was simulated as a non-conservative constituent governed by advection-dispersion and first-order decay due to settling. The model was calibrated for the wet season of 2010, using detailed turbidity data available at a number of locations at 15-minute intervals, and using variable decay rates through the Delta (varying in space, but constant in time). Model-simulated turbidity at 15-minite intervals and daily average values compared well with observed values at a number of locations including the Sacramento River at Rio Vista, Decker Island, Prisoner's Point, Holland Cut, San Joaquin River at Jersey Point, Garwood, Mossdale, Brandt Bridge, and Old River at Bacon Island, and Victoria Canal.

4.2.2.5 Watershed Modeling

The Watershed Analysis Risk Management Framework (WARMF) is a watershed modeling platform. WARMF, a GIS based watershed model originally designed for TMDL analysis, is a public domain model and is publically available from the U.S. EPA website. WARMF is a mature model that is compatible with other watershed models contained in the EPA BASINS suite. It is well documented (Chen et. al. 2001), peer reviewed (Keller, 2000, 2001, Driscoll, Jr. et al. 2004), and includes a user's manual (Herr et al. 2001).

Sacramento and San Joaquin River WARMF applications are used to dynamically simulate flow and water quality within their respective watersheds on a daily or hourly time step. The Sacramento River application of WARMF includes tributaries on the east side of the Delta including the Cosumnes River, Dry Creek, Mokelumne River, Calaveras River, and French

Camp Slough. The watershed has been calibrated for flow and water quality parameters including turbidity (Systech 2011a, Systech 2011b). The San Joaquin River WARMF application is designed to simulate the watershed from Friant Dam to Vernalis and has also been calibrated for flow, turbidity, and other water quality parameters (Systech 2011c).

In the process of simulating the watersheds, the WARMF models determine the sources and fates of pollutants. Many chemical and physical parameters are simulated in both models including temperature, nitrogen species, phosphorus, major ions, organic carbon, dissolved oxygen, suspended sediment, turbidity, phytoplankton, and electrical conductivity. The models have been used for a variety of purposes including phytoplankton study and management, organic carbon and salinity source identification, and tracking nitrate and salinity.

The WARMF models simulate the Central Valley watersheds to the downstream locations where they enter the Delta, but do not simulate the tidal flow and pollutant transport within the Delta. The WARMF models provide time series of flow and concentration for many chemical and physical parameters at these interface points including the Sacramento River, Yolo Bypass, Mokelumne River, Cosumnes River, Calaveras River, and San Joaquin River.

Both the Sacramento and San Joaquin River applications have been calibrated using historical data. Watershed management alternatives are typically simulated in a "historical" mode. This is done by modifying historical data to simulate proposed watershed management alternatives. This type of simulation is used for long-term watershed management and determining total maximum daily load (TMDL) of pollutants allowable in the watershed. The WARMF models can also be utilized in a real-time forecasting mode. In forecast mode, the models simulate conditions right up to the time the simulation is run and then continue into the near future. Predicted meteorology, reservoir releases, diversions, and point source discharges are used to drive the models. Flow and water quality predictions can then be used to make real-time management decisions. WARMF was first tested as a forecasting tool to predict the effect of eliminating San Luis Drain discharge on water quality in the San Joaquin River at Vernalis (Herr and Chen 2007). The process of generating time series model inputs for forecasting applications has recently been streamlined and applied to Delta turbidity forecasts (Systech 2011d, 2012, RMA 2012b).

4.2.2.6 Scenario Analysis

Simulating fate and transport of Delta turbidity using the RMA or DSM2 models requires considerable user expertise and computational time to run, hence limiting its accessibility. As a practical matter, there is a need for a tool that can be used to provide rapid predictions of turbidity in two situations:

- For near-term operations planning, where there is a need to estimate turbidity expected in the following days under a variety of possible operating scenarios, and

- For long-term water supply planning, where there is a need to estimate turbidity-related export constraints in water operations models (e.g. CalSim) run over multi-year periods.

For these situations, running the RMA or DSM2 models is generally not computationally feasible. To fit this need for generating rapid predictions of Delta turbidity, Artificial Neural Network (ANN) technology was employed as an alternative mathematical approach to conventional statistical methods and mechanistic models. ANNs use simple elements (neurons) and connections between elements using a range of functional forms to represent complex real-world data. The ANN methodology was inspired by biological nervous systems (Demuth and Beale, 2002) and has found broad application in the prediction and control of complex systems. An ANN can be trained to perform a particular function through adjusting values that form the connections between elements (weights). In this context, the term training is analogous to parameter estimation used in statistical and mechanistic models. ANNs offer several advantages over alternative statistical methods: 1) they can include non-linear functions and represent a broad range of functional forms, and 2) they can be set up to approximate relatively complex problems, such as the hydrodynamics in the Delta. In recent years, ANNs have also become popular in the water resources field: recent literature reviews identified more than 300 peer-reviewed applications of ANNs to water resources problems worldwide (Maier and Dandy, 2000; Maier et al., 2010). Although the majority of applications of ANNs to water resources are related to flow, some applications have focused on water quality (Maier et al. 2010).

The ANN approach has been integrated into DWR-USBR state-wide operations model CalSim (DWR 2001). The salinity ANN is trained on DSM2 results that may represent historical or future conditions, through taking into account individual flow components and operational parameters as model inputs. In this sense, the ANN model has the advantage as previous approaches are based on historical measurements alone and cannot account for potential future changes in the Delta hydrology. The current version of DWR's ANN model predicts flow-salinity relationships at nine locations in the Delta including Emmaton, Jersey Point, Old River at Rock Slough, Collinsville, Chipps Island, Antioch, Central Valley Project intake (Jones pumping plant), Clifton Court Forebay intake (Banks pumping plant), and Los Vaqueros intake at Old River. This version of the ANN model also calculates the position of X2 in the estuary.

A Delta turbidity scenario analysis tool, DASM-T, is now available. The model is Excel-based and includes a user-interface that was designed in consultation with state and federal resource agency staff. Key model inputs include three flow variables (north Delta inflow, east side tributary inflow, and OMR flow) and three water quality variables (north Delta turbidity, east side turbidity, and San Joaquin River turbidity).

The Public Water Agencies maintain that regulation of OMR for entrainment minimizations is not a relevant topic for the State Water Board's 2006 Bay Delta Plan review since it is not related to a degradation of water quality. However, because several parties have raised concerns about OMR and entrainment in the SWP and CVP facilities during these workshops, this analysis shows that better tools are available to minimize entrainment events than simple OMR flow models. The modeling tools described here allow SWP and CVP to adaptively manage operations in response to natural turbidity events to minimize entrainment from already low levels to eve lower levels.

5. Conclusion

Any change to the 2006 Bay Delta Plan could have unintended effects on each beneficial use of water, including fish and wildlife as well as agricultural and urban uses. The Public Water Agencies have provided information on three categories of analytical tools: (1) tools to assess the effect of changes on fish; (2) tools to assess the effect of changes on water supply and hydrology; and (3) tools to address uncertainty. The State Water Board should consider these tools and others when assessing the potential effects of any future revision to the 2006 Bay Delta Plan.

6. References

Allan, C., and G.H. Stankey. 2009. Editors. Adaptive Environmental Management. A Practitioner's Guide. Springer. CSIRO Publishing. Collingwood, Australia.

Allen, R. G., I.A. Walter, R.L. Elliott, T.A. Howell, D. Itenfisu, D., M.E. Jensen, and R.L. Snyder. 2005. Editors. The ASCE Standardized Reference Evapotranspiration Equation. Reston, Virginia, ASCE.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irr. & Drain. Paper 56. UN-FAO, Rome, Italy. Available at: www.kimberly.uidaho.edu/ref-et/fao56.pdf

Allen, R.G., L.S. Pereira, T.A. Howell, and M.E. Jensen. 2011. Evapotranspiration information reporting: I. Factors governing measurement accuracy. Agricultural Water Management, 98:899-920.

Allen-Diaz, B, R. Standiford, and R.D. Jackson. Oak Woodlands and Forests, Chapter 12. In: M.G. Barbour and others (Eds.). Terrestrial Vegetation of California, 3rd Ed.

Anderson, J., F. Chung, M. Anderson, L. Brekke, D. Easton, M. Ejeta, R. Peterson, and R. Snyder. 2008. Progress on incorporating climate change into management of California's water resources. Climatic Change. Volume 89, Supplement 1, March 2008, pg 91-108.

Anderson, J., R. Kneib, S. Luthy, and P. Smith. 2010. Report of the 2010 Independent Review Panel (IRP) on the Reasonable and Prudent Alternative (RPA) Actions Affecting the Operations Criteria and Plan (OCAP) for State/Federal Water Operations. Prepared for the Delta Stewardship Council, Delta Science Program. December 9, 2010.

Anderson, J.L., R.W. Hilborn, R.T. Lackey, and D. Ludwig. 2003. Watershed restoration: Adaptive decision making in the face of uncertainty. In: Wissmar, R.C., and P.A. Bisson (eds.) Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems. Bethesda, MD: American Fisheries Society.

Anderson, M.K. 2006. Tending the Wild. Native American Knowledge and the Management of California's Natural Resources. University of California Press.

Argent, R.M. 2009. In: Allan and Stankey. Components of Adaptive Management.

Baldocchi, D.D, L. Xu, and N. Kiang. 2004. How Plant Functional-type, Weather, Seasonal Drought, and Soil Physical Properties Alter Water and Energy Fluxes of an Oak-Grass Savanna and an Annual Grassland. Agricultural and Forest Meteorology, v. 123, pp. 13-39, Table 3.

Baptist, M.J, V. Babovic, Rodriguez, J. Uthurburu, M. Keijzer, R.E. Uittenbogaard, A. Mynett, and A. Verwey. 2007. On Inducing Equations for Vegetation Resistance. Journal of Hydraulic Research, v. 45, no. 4, pp. 435-445.

Barbour, M.G. and J. Major. 1988. Terrestrial Vegetation of California. California Native Plant Society, Special Publication Number 9, Second Edition, 1988 [Chapter 11, written by Griffin, J.R. Oak Woodland, pp. 387-405.].

Barbour, M.G. and J. Major. 1977. Terrestrial Vegetation of California. John Wiley & Sons, New York.

Barbour, M.G., T. Keeler-Wolf, and A.A. Schoenherr. 2007. Terrestrial Vegetation of California, Third Edition, University of California Press, Berkeley, 2007 [Chapter 15, written by Solomeshch, A.I, Barbour, M., Holland, R. F. Vernal Pools; Chapter 16, written by Vaghti, M.G., and Greco, S.E. Riparian Vegetation of the Great Valley, pp. 425-55.].

Barbour, M.G., B. Pavlik, F. Drysdale, and S. Lindstrom. 1993. California's Changing Landscapes. Diversity and Conservation of California Vegetation, California Native Plant Society, Sacramento, CA , pp. 75 and 82-83.

Bartholow, J., J. Sandelin, B. Coughlan, J. Laake, and A. Moos. 1997. SALMOD. A Population Model for Salmonids. User's Manual.

Bartholow. J. 2004. Modeling Chinook Salmon with SALMOD on the Sacramento River, California. Hydroecol. Appl. 14 Vol. 1, pp. 193-219.

Bartolome, J.W., W. J. Barry, T. Griggs, and P.Hopkinson. 2007. Valley Grasslands, Chapter 14 In: Michael G. Barbour, Todd Keeler-Wolf, and Allan A. Schoenheer (Eds.), Terrestrial Vegetation of California, 3rd Ed.

Bennett, W. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science. 3(2), Article 1.

Bertoldi, G.L., R.J. Johnston, and K.D. Evenson. 1991. Ground Water in the Central Valley, California -- A Summary Report, U.S. Geological Survey Professional Paper 1401-A, pp. A17, A23, Fig. 14A.

Blake, A and M.J. Horn. Acoustic Tracking of Juvenile Chinook Acoustic Tracking of Juvenile Chinook Salmon Movement in the Vicinity of the Delta Cross Channel, Sacramento River, California – 2001 Study Results. U.S. Geological Survey Draft Report. Available at: http://www.fishsciences.net/reports/2006/Blake_Horn_3_14_06.pdf

Blaney, H.F, C.A. Taylor, H.G. Nickle, and A.A. Young. 1933. Consumptive Use of Water by Native Plants Growing in Moist Areas in Southern California, In: Water Losses Under Natural Conditions from Wet Areas in Southern California. Part 1, Bulletin No. 44, California Department of Public Works, pp. 65-74.

Blaney, H.F. and D.C. Muckel. 1955. Evaporation and Evapotranspiration Investigation in the San Francisco Bay Area. Transactions of the American Geophysical Union, v. 36, no. 5, pp. 813-830.

Blaney, H.F. Evaporation and Evapotranspiration Studies United States Department of

Agriculture in the Pacific Southwest. Available at: http://iahs.info/redbooks/a040/04005.pdf.

Blaney, H.F. 1957. Monthly Consumptive Use of Water by Irrigated Crops and Natural Vegetation. Presented at the Eleventh General Assembly of International Union of Geodesy and Geophysics, Toronto, Canada, September 1957.

Bolger, B. L, Y.J. Park, A. Unger, and E.A. Sudicky. 2011. Simulating the Pre-development Hydrologic Conditions in the San Joaquin Valley, California. Journal of Hydrology, v. 411, pp. 322-330; p. 327-328.

Brandes, P. and J. McLain. 2001. Juvenile Chinook salmon abundance, distribution and survival in the Sacramento-San Joaquin Estuary. In Brown RL, editor. Fish Bulletin 179: Contributions to the biology of Central Valley Salmonids, Vol. 2. California Department of Natural Resources.

Bryan, Kirk. 1915. Groundwater for Irrigation in the Sacramento Valley, California, U.S. Geological Survey Water-supply Paper 375-A, Plate 11 and p. 19.

Buckland, S.T., K.B. Newman, L. Thomas, N.B. Koesters. 2004. State-space models for the dynamics of wild animal populations. Ecol. Model. 171(1-2):157-175.

Buckland, S.T., K.B. Newman, C. Fernandez, L. Thomas, and J. Harwood. 2007. Embedding population dynamics models in inference. Stat. Sci. 22 (1) 44:58.

California Department of Public Works. 1931. Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, Bulletin 27, p. 69.

Chen, C.W., J. Herr, and L.Z. Weintraub. 2001. Watershed Analysis Risk Management Framework: Update One: A Decision Support System for Watershed Analysis and Total Maximum Daily Load Calculation, Allocation, and Implementation, Electric Power Research Institute, Palo Alto, CA. Topical Report 1005181.

Cheng, R. 2012. DWR. Email to Paul Hutton, MWD, Re: Pan Evap for the Central Valley.

California State University. 2003. The Central Valley Historic Mapping Project.

Costanza, R., D. Duplisea, and U. Kautsky. 1998. Ecological modeling on modeling ecological and economic systems with Stella. Ecological Modelling, 110:1-4.

Cowan, L.R. 1994. Regulation of Water Use in Relation to Carbon Gain in Higher Plants, In: Encyclopedia of Plant Physiology, O.L. Lange and J.D. Bewley (Eds.), Springer-Verlag, v. 12B, 1982, pp. 535-562; D.A. Devitt, R.L. Morris, and D.S. Neuman, Evapotranspiration and Growth Response of Three Woody Ornamental Species Placed under Varying Irrigation Regimes, J. Amer. Soc. Hort. Sci., v. 119, no. 3, pp. 452-457.

Crampton, B. 1974. Grasses in California. University of California Press, Berkeley, p. 30.

Davis, G.H. 1959. Ground-water Conditions and Storage Capacity in the San Joaquin Valley, California, U. S. Geological Survey Water Supply Paper 1469, p. 86.

Demuth, H. and M. Beale. 2002. Neural Network Toolbox for Use with Matlab. User's Guide, Version 4.

Department of Water Resources. 1993. Sacramento-San Joaquin Delta Atlas.

Department of Water Resources. 2001. Methodology for flow and salinity estimates in the Sacramento–San Joaquin Delta and Suisun Marsh, 22nd Annual Progress Report to the SWRCB in Accordance with Water Right Decisions 1485 and 1641, Chapter 7.

Department of Water Resources. 2007. California Central Valley Unimpaired Flow Data, Fourth Edition, Draft, May 2007.

Department of Water Resources. 2011. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 32nd Annual Progress Report to the SWRCB in Accordance with Water Right Decisions 1485 and 1641, Chapter 7.

Department of Water Resources. 2012. The State Water Project DRAFT Delivery Reliability Report. January 2012.

Deriso, R. 2010. Adult Smelt Salvage as a Function of Turbidity and OMR Flows, Prepared for Metropolitan Water District of Southern California.

Devitt, D.A., R.L. Morris, and D.S. Neuman. 1994. Evapotranspiration and Growth Response of Three Woody Ornamental Species Placed under Varying Irrigation Regimes. J. Amer. Soc. Hort. Sci. 119(3):452-457.

Driscoll, Jr. C. T., R.A. Bodaly, O.R. Bullock, Jr., D.P. Krabbenhoft, R.P. Mason, C.D. Pollman, and T. A. Wool. 2004. Report of The Peer Review Panel on the Development of the Watershed Analysis Rish Management Framework (WARMF) Model to Assess Mercury in the Western Lake Superior Basin, Minnesota.University of Minnesota Sea Grant Program, Duluth, Minnesota, Publication No. CT 15.

Dutzi, E.J. 1978. Valley Oaks in the Sacramento Valley: Past and Present Distribution, Master of Arts Thesis in Geography, University of California, Davis, March 23, Figure 11.

Enright, C. and S. Culberson. 2010. Salinity trends, variability, and control in the northern reach of the San Francisco Estuary. San Francisco Estuary and Watershed Science, 7(2).

Ferreira, I.C., S.K. Tanaka, S.P. Hollingshed, and J.R. Lund. 2005. Musings on a model: CalSimII in California's water community. San Francisco Estuary and Watershed Science, 3(1). Ye

Ford, A. 1999. Modeling the environment: an introduction to system dynamics modeling of environmental systems. Washington: Island Press.

Fox, P. Freshwater Inflow to San Francisco Bay Under Natural Conditions, Appendix 2, Figure 3, SWC Ex. 262, 1987.

Garone, Philip. 2011. The Fall and Rise of the Wetlands of California's Great Central Valley, University of California Press, Berkeley, p. 24-25, 27 and 79.

Gatewood, J.S, Robinson, T.W., Colby, B.R, Hem, J.R, and Halpenny, L.C. Use of Water by Bottom-Land Vegetation in Lower Safford Valley, Arizona, U.S. Geological Survey Water Supply Paper 1103, 1950, Table 29 and pp. 195, 203.

Good, T.P., T.J. Beechie, P. McElhany, M.M. McClure, and M.H. Ruckelshaus. 2007. Recovery Planning for Endangered Species Act-listed Pacific Salmon: Using Science to Inform Goals and Strategies. Fisheries, 32(9):426-440.

Gregory, R. and D. Ohlson, J. Arvai. 2006. Deconstructing Adaptive Management: Criteria for Applications to Environmental Management. Ecological Applications 16:6, 2411-2425

Grunsky, C.E. 1929. The Relief Outlets and By-Passes of the Sacramento Valley Flood-Control Project. Transactions of the American Society of Civil Engineers, v. 93, pp. 791-811.

Gunderson, L. 2000. Ecological Resilience in Theory and Application. Annual Review of Ecology and Systematics 31:425-439.

Hall, W.H. 1880. Report of the State Engineer to the Legislature of California, Session of 1880, Part 2, p. 10, 24, 47 and 51.

Hall, W.H. 1887. Topographical and Irrigation Map of the Great Central Valley of California Embracing the Sacramento, San Joaquin, Tulare and Kern Valleys and the Bordering Foothills.

Hobbs, N.T., and R. Hilborn. 2006. Alternatives to statistical hypothesis testing in ecology: a guide to self teaching. Ecol. App. 16(1):5-19.

Heady, H.F. 1988. Valley Grasslands, In Barbour and Major.

Healey, M.C, P.L. Angermeier, K.W. Cummins, T. Dunne, W.J. Kimmerer, G.M. Kondolf, P.B. Moyle, D.D. Murphy, D.T. Patten, D.J. Reed, R.B. Spies, and R.H. Twiss. 2004. Conceptual models and adaptive management in ecological restoration: the CALFED Bay–Delta Environmental Restoration Program. p. 40

Herr, J. and C.W. Chen. 2007. Forecasting Results Report, CALFED Project ERP-02D-P63, Monitoring and Investigation of the San Joaquin River and Tributaries Related to Dissolved Oxygen, Task 6 Model Calibration and Forecasting, Systech Engineering, San Ramon, CA.

Herr, J., L.Z. Weintraub, and C.W. Chen. 2001. User's Guide to WARMF: Documentation of Graphical User Interface, Electric Power Research Institute, Palo Alto, CA. Topical Report.

Holling, C.S. 1978. Editor. Adaptive Environmental Assessment and Management. New York, NY: John Wiley and Sons.

Hutton, P. 2012. Forecasting Delta Turbidity Conditions with Artificial Neural Networks, 7th Biennial Biennial Bay-Delta Science Conference, October 16–18, Sacramento Convention Center.

Jassby, A., W.J. Kimmerer, S.G. Monismith, C. Armor, J.E Cloern, T.M. Powell, J.R. Schubel, and T.J. Vendlinski. 1995. Isohaline Position As A Habitat Indicator For Estuarine Populations. Ecological Applications, 5(1):272-289.

Kadir, Tariq, N. 2012. E-mail to Tom Boardman, July 27, 2012, Re: Long Term Average Precipitation for Valley Floor, Run DWR C2VSIM Run-356.

Katibah, E.F. 1984. A Brief History of Riparian Forests in the Central Valley of California, In: R.E. Warner and K.M. Hendrix (Eds.), California Riparian Forests, University of California Press, Berkeley, pp. 23-29 at Table 1. Available at: http://publishing.cdlib.org/ucpressebooks/view?docId=ft1c6003wp&chunk.id=d0e3419&toc.depth=100&toc.id=d0e3419&brand=eschol.

Keller A. 2000. Peer review of the watershed analysis risk management framework (WARMF): an evaluation of WARMF for TMDL applications by independent experts using USEPA guidelines, Electric Power Research Institute, Palo Alto, CA. Technical Report 1000252.

Keller A. 2001. Peer Review of the Acid Mine Drainage Module of the Watershed Analysis Risk Management Framework (WARMF) – An evaluation of WARMF/AMD using EPA Guidelines, Electric Power Research Institute, Palo Alto, CA. Technical Report 1005182.

Kimmerer, W.J. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento- San Joaquin Delta. San Francisco Estuary Watershed Science. 6(2):1-27.

Kooser, B. P, S. Seabough, , and F.L. Sargent. 1861. Notes of Trips of the San Joaquin Valley Agricultural Society's Visiting Committee on Orchards and Vineyards, Reports of Committees. Committees Nos. 1 and 2 on Farms and Orchards, Transactions of the S.J.V. Agricultural Society, pp. 258 - 298.

Kramer, P.J, and J.S. Boyer. 1995. Water Relations of Plants and Soils, Academic Press, Chapter 7: Transpiration and the Ascent of Sap.

Küchler, A.W. 1977. Natural Vegetation of California, Pocket Map in Michael G. Barbour and Jack Major (Eds), Terrestrial Vegetation of California, 1977 and 1988.

Lee, C.H. 1912. An Intensive Study of the Water Resources of a Part of Owens Valley, California, U.S. Geological Survey Water Supply Paper 294.

Lee, K.N. 1993. Compass and Gyroscope. Integrating Science and Politics for the Environment. Island Press. Washington, D.C.

Lee, K.N. 1999. Appraising Adaptive Management. Conservation Ecology 3(2):3. Available online at http://www.consecol.org/vol3/iss2/art3, accessed February 13, 2003.

Levin, S.A.. 1992. Orchestrating Environmental Research and Assessment. Ecological Applications, 2(2):103-106.

Lewis, D.C. 1968. Annual Hydrologic Response to Watershed Conversion from Oak Woodland to Annual Grassland.Water Resources Research, v. 4, no. 1, pp. 5972.

Lund, J.R, J. Mount, E. Hanak, B. Fleenor, W. Bennett, R. Howitt, and P. Moyle. 2010. Comparing Futures for the Sacramento-San Joaquin Delta, University of California Press, Chapters 2, 3, 5.

Mac Nally, R., J.R. Thomson, W.J. Kimmerer, F. Feyrer, K.B. Newman, A. Sih, W.A. Bennett, L. Brown, E. Fleishman, S. D. Culberson, and G. Castillo. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications. 20(5):1417-1430.

Maier, H.R. and G.C. Dandy. 2000. Neural networks for the prediction and forecasting of water resources variables: a review of modeling issues and applications. Environmental Modeling and Software 15: 101–124.

Maier, H.R., A. Jain, G.C. Dandy, K.P. Sudheer. 2010. Methods used for the development of neural networks for the prediction of water resource variables in river systems: current status and future directions. Environmental Modeling and Software 25: 891–909.

Manly, B.F.J. 2010. Summary of Reports on the Estimation of Delta Smelt Salvage Numbers and the Proportion of Delta Smelt in the Southeast Delta Produced Before December 2010, Technical Report Prepared for Metropolitan Water District of Southern California, December 8.

Maunder, M.N. and R.B. Deriso. 2011. A state-space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*). Can.J. Fish. Aquat. Sci. 68:1285-1306.

McGowan, J, A. 1961. History of the Sacramento Valley, Lewis Historical Pub. Co., Vol. 1.

Michel, C.J. 2010. River and Estuarine Survival and Migration of Yearling Sacramento River Chinook Salmon (*Oncorhynchus Tshawytscha*) Smolts and the Influence of Environment. Thesis submitted University of California, Santa Cruz.

Miller, W.J., B. Manly, D.D. Murphy, D. Fullerton, and R.R. Ramey. 2012. An Investigation of Factors Affecting the Decline of Delta Smelt (*Hypomesus transpacificus*) in the Sacramento-San Joaquin Estuary. Reviews in Fisheries Science, 20:1, pp.1-19.

Moyle, P.B. 2002. Inland Fishes of California, Revised and Expanded.

Muckel, D.C. 1966. Phreatophytes - Water Use and Potential Savings. ASCE Water Resources Engineering Conference Preprint 328, May 16-20, 1966.

National Research Council. 2004. Adaptive Management for Water Resources Project Planning Panel on Adaptive Management for Resource Stewardship, Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning, National Research Council. The National Academies Press, Washington, D.C.

National Research Council. 2011. A Review of the Use of Science and Adaptive Management in California's Draft Bay Delta Conservation Plan. Panel to Review California's Draft Bay Delta Conservation Plan. National Research Council. The National Academies Press, Washington, D.C.

Newman, K.B. 1998. State-space modeling of animal movement and mortality with applied to salmon. Biometrics. 54(4):1290-1314.

Newman, K.B., and P.L. Brandes. 2010. Hierarchical modeling of juvenile Chinook salmon survival as a function of Sacramento-San Joaquin Delta water exports. North American Journal of Fisheries Management, 30:157-169.

Newman, K.B. and S.T. Lindley. 2006. Accounting for demographic environmental stochasticity, observation error and parameter uncertainty in fish population dynamics models N. Am. J. Fish. Manage. 26(3):685-701.

Nichols, J.D. and B.K. Williams. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21(12):668-673.

Olmsted. F.H. and G.H. Davis. 1961. Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley California, U.S. Geological Survey Water Supply Paper 1497, pp. 25-27.

Pavlik, B. M., P.C. Muick, S.G. Johnson, and M. Popper. 1991. Oaks of California. Cahuma Press and the California Oak Foundation, p. 9 and pp. 63-64.

Perry, R. 2010. Survival and migration dynamics of juvenile Chinook salmon (*Oneurhynchus tshawytscha*) in the Sacrament-San Joaquin Delta. Dissertation submitted to the University of Washington.

Poytress and Carillo. 2008. Brood-year 2007 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement. Red Bluff: United States Fish and Wildlife Services.

Rains, M. C, G.E. Fogg, T. Harter, R.A. Dahlgren, and R.J. Williamson. 2006. The Role of Perched Aquifers in Hydrological Connectivity and Biogeochemical Processes in Vernal Pool Landscapes, Central Valley, California, Hydrological Processes, Vol. 20, issue 5, pp. 157-1175.

Resource Management Associates Inc. 2010. Turbidity and Adult Delta Smelt Modeling with the RMA 2-D Models: December 2009 – May 2010, Prepared for Metropolitan Water

District of Southern California.

Resource Management Associates Inc. 2011a. Turbidity and Adult Delta Smelt Modeling with the RMA 2-D Models: December 2010 – February 2011. Prepared for Metropolitan Water District of Southern California.

Resource Management Associates Inc. 2011b. Turbidity and Adult Delta Smelt Modeling with the RMA Delta Models: Simulations for Water Years 2002, 2004, 2008 and 2009, Prepared for Metropolitan Water District of Southern California.

Resource Management Associates Inc. 2012a. Turbidity and Adult Delta Smelt Modeling with the RMA 2-D Models: November 2011 – February 2012, Prepared for Metropolitan Water District of Southern California, DRAFT.

Resource Management Associates Inc. 2012b. RMA/Systech Collaboration to Improve WARMF Model Turbidity Estimates, Prepared for Metropolitan Water District of Southern California, DRAFT.

Rich, L.R. 1951. Consumptive Use of Water by Forest and Range Vegetation. Proceedings of the American Society of Civil Engineers, v. 77, Separate No. 90, pp. 1-14, 1951; Blaney, Table 5.

Ricker, W.E. 1975. Recruitment and stock-recruitment relationships. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191:265-296.

Roberts, W.G,J.G. Howe, and J. Major. 1977. A Survey of Riparian Forest Flora and Fauna in California, In: Riparian Forests in California. Their Ecology and Conservation, Anne Sands (Ed.), A Symposium Sponsored by Institute of Ecology, University of California, Davis and Davis Audubon Society Institute of Ecology Publication No. 15, May 14, Figure 2.

Robinson, T.W. 1952. Phreatophytes and their Relation to Water in Western United States. Transactions, American Geophysical Union, v. 33, no. 1, pp. 57-66.

Rosenfield, J.A. 2010. Life history conceptual model and sub-models for longfin smelt, San Francisco Estuary population. Delta Regional Ecosystem Restoration Implementation Plan. California Department of Fish and Game. Sacramento, CA.

Ruckelshaus, M.H., P. Levin, J.B. Johnson, and P.M. Kareiva. 2002. The Pacific Salmon Wars: What Science Brings to the Challenge of Recovering Species. Annu. Rev. Ecol. Syst. 33:665-706.

Ryu, Y., D.D. Baldocchi, S. Ma, and T. Hehn. 2008. Interannual Variability of Evapotranspiration and Energy Exchange Over an Annual Grassland in California, Journal of Geophysical Research, v. 113.

Shelton, M.L. 1987. Irrigation Induced Change in Vegetation and Evapotranspiration in the Central Valley of California, Landscape Ecology, v. 1, no. 2, pp. 99, 103.

State Water Board. 2011. 2011 Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives. State Water Resources Control Board. Sacramento, CA.

State Water Resources Control Board. 2006. 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. State Water Resources Control Board. Sacramento, CA.

Stout, O.V.P. Use of Water in the Sacramento-San Joaquin Delta, in Sacramento-San Joaquin Water Supervisor's Report for the Years 1929 - 1935, 1929-1935.

Systech Water Resources Inc. 2011a. Task 3 Technical Memorandum: Analytical Modeling of the Sacramento River, Prepared for California Urban Water Agencies and the Central Valley Drinking Water Group, April 4.

Systech Water Resources Inc. 2011b. Analytical Modeling of the Delta East Side Tributaries, Prepared for State Water Project Contractors Authority and Metropolitan Water District of Southern California, April 19.

Systech Water Resources Inc. 2011c. Task 2 Technical Memorandum: Analytical Modeling of the San Joaquin River, Prepared for California Urban Water Agencies and the Central Valley Drinking Water Group, March 25.

Systech Water Resources Inc. 2011d. WARMF Forecasting, Automation, and Technical Support, Prepared for Metropolitan Water District of Southern California, May 26.

Systech Water Resources Inc. 2012. WARMF Forecasting, Water Year 2012, Prepared for Metropolitan Water District of Southern California, May 16.

Tetra Tech Inc. 2012. DASM-T: Delta ANN Simulation Model for Turbidity, Phase 1 Results, Prepared for Metropolitan Water District of Southern California, August 8.

The Bay Institute . 1998. From the Sierra to the Sea, The Ecological History of the San Francisco Bay-Delta Watershed. , Sec. IV.B.1 and IV.B.2.

Thompson, K.. 1960. Historic Flooding in the Sacramento Valley, Pacific Historical Review, v. 29, no. 4, pp. 352-353.

Thompson, K. 1961. Riparian Forests of the Sacramento Valley, California, Annals of the Association of American Geographers, v. 51, p. 297 and 299.

Thompson, K. 1957. The Settlement Geography of the Sacramento-San Joaquin Delta, California, Ph.D. Dissertation, Stanford University, Chapters 1-2, pp.135-136.

Thomson, J.R., W.J. Kimmerer, L.R. Brown, K.B Newman, R. Mac Nally, W.A. Bennett, F. Feyrer and E. Fleishman. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications. 20(5):1431-1448.

Troxell, H.C. 1933. Ground Water Supply and Natural Losses in the Valley of Santa Ana River Between Riverside Narrows and the Orange County Line, In: Water Losses Under Natural Conditions from Wet Areas in Southern California, Part 1, Bulletin No. 44, California Department of Public Works, pp. 147-172.

USFWS 1999

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online]1(2):1. Available at: http://www.consecol.org/vol1/iss2/art1/

Walters, C. J., and C.S. Holling. 1990. Large-Scale Management Experiments and Learning by Doing. Ecology 71: 2060-2068.

Walters, C.J. 2007. Is adaptive management helping to solve fisheries problems? AMBIO: A Journal of the Human Environment 36(4):304–307.

Warner, R.E and K.M. Hendrix. 1985. Riparian Resources of the Central Valley and California Desert, Final Draft, Department of Fish & Game, pp. 5.10-5.11, 5.15 - 5.16 and 5.18.

Williams, B.K. and E.D. Brown. 2012. Adaptive Management: The U.S. Department of the Interior Applications Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C.

Williams, B.K., R.C. Szaro, and C.D. Shapiro. 2009. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C.

Williams, J.G. 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science, 4(3).

Williamson, A.K, D.E. Prudic, and L.A. Swain. 1989. Ground-Water Flow in the Central Valley, California, U.S. Geological Survey Professional Paper 1401-D, p. D40 and 33.

Williamson, R.S. 1853. Report of Exploration in California for Railroad Routes to Connect with the Routes Near the 35th and 32d Parallels of North Latitude. In: Explorations and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean. U.S. War Department, V., p. 12. Available at: http://quod.lib.umich.edu/cgi/t/text/text-idx?c=moa&idno=AFK4383.0005.001.

Wissmar, R.C. and P.A. Bisson. 2003. Editors. Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems. Bethesda, MD: American Fisheries Society.

Young, A.A. and H.F. Blaney. 1942. Use of Water by Native Vegetation, California Department of Public Works Bulletin 50.

Zeug, S.C.. P.S. Bergman, B.J. Cavallo, and K.S. Jones. 2011. Application of a Life Cycle Simulation Model to Evaluate Impacts of Water Management and Conservation Actions on an Endangered Population of Chinook Salmon. Environmental Modeling & Assessment.

Electronic File Name	Title of Reference
allen_2005.pdf	The ASCE Standardized Reference Evapotranspiration Equation
allen_et_al_1998.pdf	Crop evapotranspiration Guidelines for computing crop water requirements
allen_et_al_2011.pdf	Evapotranspiration information reporting I. Factors governing meansurement acccuracy.
anderson_et_al_2003.pdf	Watershed restoration Adaptive decision making in the face of uncertainty
anderson_et_al_2008.pdf	Progress on incorporating climate change into management of California's water resources
anderson_et_al_2010.pdf	Report of the 2010 Independent Review Panel (IRP) on the Reaonsbale and Prudent A ternative (RPA) Actions Affecting the Operations Criteria and Plan (OCAP) for State/Federal Water Operations
baldocchi_et_al_2004.pdf	How Plant Functional-type, Weather, Seasonal Drought, and Soil Physical Properites A ter Water and Energy Fluxes of an Oak-Grass Savanna and an Annual Grassland
baptist_et_al_2007.pdf	On Inducing Equations for Vegetation Resistance
bartholow_2004.pdf	Modeling Chinook Salmon w th SALMOD on the Sacramento River California
bartholow_et_al_1997.pdf	SALMOD. A Population Model for Salmonids. User's Manual
bennett_2005.pdf	Critical assessmentof the de ta smelt population in the San Francisco Estuary Ca ifornia
bertoldi_et_al_1991.pdf	Ground Water in the Central Valley Cal fornia -- A Summary Report
blaney_1933.pdf	Consumptive Use of Water by Native Plants Growing in Moist Areas in Southern California
blaney_1957.pdf	Monthly Consumptive Use of Water by Irrigated Crops and Natural Vegetation
blaney_muckel_1955.pdf	Evaporation and Evapotranspiration Investigation in the San Francisco Bay Area
bolger_et_al_2011.pdf	Simulating the Pre-development Hydrologic Conditions in the San Joaquin Valley California
bryan_1915.pdf	Groundwater for Irrigation in the Sacramento Va ley, Ca ifornia
bucland_et_al_2007.pdf	Embedding population dynamics moels in inference
buckland_et_al_2004.pdf	State-space models for the dynamics of wild animal populations
cdpw_1931.pdf	Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay
chen_et_al_2001	Watershed Analysis Risk Management Framework Update One A Decision Support System for Watershed Anaysis and Total Mazimum Daily Load Calculation
cheng_2012.pdf	Email Re Pan Evap for the Central Va ley dated July 20, 2012
chico_state_university_2003.pdf	The Central Valley Historic Mapping Project
costanza_et_al_1998.pdf	Ecological modeling on mode ing ecological and economic systmes with Stella
davis_et_al_1959.pdf	Ground-Water Cond tions and Storage Capac ty in the San Joaquin Valley California
demuth_beale_2002.pdf	Neural Network Toolbox for Use with Metlab. User's Guide, Version 4
deriso_2010.pdf	Adult Smelt Salvage as a Function of Turbid ty and OMR Flows
dev tt_et_al_1994_pdf	Evaporation and Growth Response of Three Woody Ornamental Species Placed Under Varying Irrigation Regimes
dutzi_1978.pdf	Valley Oaks in the Sacramento Valley Past and Present Distribution
dwr_2001.pdf	Methodology for flow and salinity estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 22nd Annual Progress Report to the SWRCB in Accordance with Water Right Decisions 1485 and 1641, Chapter 7
dwr_2007.pdf	California Central Valley Unimpaired Flow Data Fourth Ed tion Draft May 2007
dwr_2011.pdf	Methodology for flow and salinity estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 32nd Annual Progress Report to the SWRCB in Accordance with Water Right Decisions 1485 and 1641 Chapter 7
dwr_2012.pdf	The State Water Project DRAFT Delivery Reliabil ty Report. January 2012.
enright_culberson_2010.pdf	Salinity trends, variability, and control in the northern reach of the San Francisco Estuary
ferreira_et_al_2005.pdf	Musing on a model CalSim II in California's water community
fox_1987.pdf	Freshwater Inflow to the San Francisco Bay Under Natural Conditions
gatewood_et_al_1950.pdf	Use of Water by Bottom-Land Vegetation in Lower Safford Valley, Arizona
good_et_al_2007.pdf	Recovery Planning for Endangered Species Act- listed Pacific Salmon Using Science to inform Goals and Strategies
gregory_et_al_2006.pdf	Deconstructing Adaptive Management Criteria for app ications to Environmental Management
grunsky_1929.pdf	The Relief Outlets and By-Passes of the Sacramento Valley Flood-Control Project
gunderson_2006.pdf	Ecological Resilience in Theory and Application
hall_1887.pdf	Topographical and Irrigation Map of the Great Central Valley of California Embracing the Sacramento, San Joaquin, Tulare and Kern Valleys and the Bordering foothi ls
healey_et_al_2004.pdf	Conceptual models and adaptive mangament in ecological restoration The CALFED Bay-Delta Environmental Restoration Program
herr_chen_2007.pdf	Forecasting Results Report, CALFED Project ERP-02D-P63, Moniroting and Investigation of the San Joaquin River tributaries Related to Dissolved Oxygen
herr_et_al_2001.pdf	User's Guide to WARMF Documentation of Graphical User Interface
hobbs_hilborn_2006.pdf	A ternatives to statistical hypothesis testing in ecology
jassby_et_1995.pdf	Isohaline Position As A Habitat Indicator For Estuarine Populations
kadir_2012.pdf	E-mail re Long Term Average Preciptition for Valley Floor
kat bah_1984.pdf	
keller_2000.pdf	Peer Review of the watershed analysis risk management famework (WARMF) an evaluation of WARMF for TMDL applicatiosn by independent experts using USEPA guidelines
kimmerer_2008.pdf	Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta
kooser_et_al_1861.pdf	Notes of Trips of the San Joaquin Va ley Agricultural Society's Visiting Comm ttee on Orchards and Vineyards
lee_1912.pdf	An Intensive Study of the Water Resources of a Part of Owens Valley, Ca ifornia
levin_1992.pdf	Orchestrating Environmental Research and Assessment
lewis_1968.pdf	Annual Hydrologic Response to Watershed Conversion from Oak Woodland to Annual Grassland
macnally_et_al_2010.pdf	Analysis of pelagic species dec ine in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR)
maier_dandy_2000.pdf	Neural networks for the prediction and forecasting of water resources variables a review of mode ing issues and applications
maier_et_al_2010.pdf	Methods used for the development of neural networks for the prediction of water resource variables in river systems
manly_2010.pdf	Summary of Reports on the Estimation of Delta Sme t Salvage Numbers and the proportion of Delta Smelt in the Southeast Delta Produced Before December 2010
maunder_deriso_2011.pdf	A state-space multistage life cycle model to evaluate population impacts in the presence of density dependence i lustrated with application to delta smelt (*Hyposemesus transpacificus*)
michel_2010.pdf	River and Estuarine Survival and Migration of Yearling Sacramento River Chinook Salmon (*Oncorhynchus Tshawytscha*) Smolts and the Influence of Environment. Thesis submitted University of California, Santa Cruz.
miller_et_al_2012.pdf	Investigation of Factors Affecting the Decline of Delta Smelt (Hypomesus transpacificus) in the Sacramento-San Joaquin Estuary.
muckel_1966.pdf	Phreatophytes-Water Use and Potential Savings
newman_1998.pdf	State-space modeling of animal movement and mortal ty with app ication to salmon
newman_brandes_2010.pdf	Hierarchical modeling of juvenile Chinook salmon survival as a function of Sacramento-San Joaquin Delta water exports
newman_lindley_2006.pdf	Accounting for demographic and environmental stochasticity, observation error, and parameter uncertainty in fish population dynamics models
nichols_williams_2006.pdf	Monitoring for conservation
nrc_2004.pdf	Adaptive Management for Water Resources Project Planning Panel on Adaptive Management for Resource Stewardship
nrc_2011.pdf	A Review of the Use of Science and Adaptive Mangement in California's Draft Bay Delta Conservatino Plan
olmstead_davis_1961.pdf	Geologic Features and Ground-Water Storage Capac ty of the Sacramento Valley California
rains_et_al_2006.pdf	The Role of Perched Aqu fers in Hydrological Connectivity and Biogeochemical Processes in Vernal Pool Landscapes
rich_1951.pdf	Consumptive Use of Water by Forest and Range Vegetation
ricker_1975.pdf	Recruitment and stock-recruitment relationships
rma_2010.pdf	Turbidity and Adult Delta Smelt Modeling w th the RMA-2D Models December 2009-May 2010
rma_2012a.pdf	Turbidity and Adult Delta Smelt Modeling w th the RMA-2D Models November 2011-February 2012
rma_2012b.pdf	RMA/Systech Collaboration to Improve WARMF Model Turbidity Estimates
robinson_1952.pdf	Phreatophytes and their Relation to Water in Western United States
rosenfeld_2010.pdf	Life history conceptual model and sub-models for longfin smelt, San Francisco Estuary population
ruckelshaus_2002.pdf	The Pac fic Salmon Wars What Science Brings to the Challenge of Recovering Species
ryu_et_al_2008.pdf	Interannual Variability of Evapotranspiration and Energy Exchange Over an Annual Grassland in California
she ton_1987.pdf	Irrigation Induced Change in Vegetation and Evapotranspiration in the Central Valley of Ca ifornia
swrcb_2010.pdf	2010 Flow Criteria Report
systech_2011a.pdf	Task 3 Technical memorandum Analytical Modelng of the Sacramento River
systech_2011b.pdf	Analytical Modeling of the Delta East Side Tr butaries
systech_2011c.pdf	Task 2 Technical memorandum Analytical Modeling of the San Joaquin River
systech_2011d.pdf	WARMF Forecasting, Automation, and Technical Support
systech_2012.pdf	WARMF Forecasting Water Year 2012
tbi_1998.pdf	From the Sierra to the Sea The Ecological History of the San Francisco Bay-Delta Watershed
tetra_tech_2012.pdf	DASM-T Delta ANN Simulation Model for Turbidity
thompson_1957.pdf	The Settlement Geography of the Sacramento-San Joaquin Delta, California
thompson_1960.pdf	Historic Flooding in the Sacramento Valley
thompson_1961.pdf	Riparian Forests of the Sacramento Valley California
thomson_et_al_2010.pdf	Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary
troxell_1933.pdf	Ground Water Suppy and Natural Losses in the Valley of Santa Ana River Between Riverside Narrows and Orange County Line
walters_1997.pdf	Cha lenges in adaptive mangement of riparian and coastal ecosystems
walters_2007.pdf	Is adaptive mangement helping to solve fisheries problems
walters_holling_1990.pdf	Large-Scale Management Experimetns and Learning by Doing
warner_hendrix_1985.pdf	Riparian resources of the Central Valley and California Desert
wi liams_2006.pdf	Central Valley Salmon A Perspective on Chinook and Stee head in the Central Va ley of California
wi liams_brown_2012.pdf	Adaptive Mangement The U.S. Department of the Interior Applications Guide
wi liamson_et_al_1989.pdf	Ground-Water Flow in the Central Valley California
wi liams_et_al_2009.pdf	Adaptive Management The U.S. Department of the Interior Technical Guide
young_blaney_1942.pdf	Use of Water by Native Vegetation
zeug_et_al_2010.pdf	Application of a Life Cycle Simulation Model to Evaluate Impacts of Water Management and Conservation Actions on an Endangered Population of Chinook Salmon