Development of an environmental indicator system for watershed-based decision-making and tracking the outcomes of beneficial use restoration in the San Joaquin River basin

by

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Preface: San Joaquin Watershed Indicators

This Report was funded through a grant from the U.S. Environmental Protection Agency (U.S. EPA) to the San Francisco Estuary Institute (SFEI) to develop indicators of water quality condition and management in the San Joaquin River watershed. The Institute has substantial experience in monitoring and indicators and is probably best known for work in the San Francisco Bay area. There, SFEI directs the contaminant *Regional Monitoring Program* and each year issues *The Pulse of the Estuary,* an assessment directed toward managers and the public.[1] SFEI's partner in the San Joaquin project, The Bay Institute, contributed experience in developing indicators and combining sets of indicators into environmental indices such as the *Ecological Scorecard: San Francisco Bay.*[2]

The purpose of this San Joaquin project went beyond indicators or indices of environmental (in this case, water quality) conditions and trends: The U.S. EPA was interested in testing a method for measuring conditions, linking potential causes to observed conditions considered undesirable, and tracking results of management practices designed to improve water quality. Indicators of this kind could be used to report on project results and relate the government's program expenditures to basic objectives such as clean water. The ideal indicator framework would be useful for targeting problems at the watershed or sub-watershed scale and also transferable across watersheds, allowing comparison and aggregation of information.

This project tested a "pressure-state-response" (PSR) methodology, which is explained in detail in Section 2. Basically, the PSR model relates various causal factors (Pressure) to resultant water quality conditions (State); in turn, corrective management (Response) acts to change impaired conditions. Typically, the PSR framework posits cause-effect relationships (for example, between pressures and conditions) based on prior supporting information from research, field studies, and other evidence. This project was not designed to review existing information regarding causal linkages, but it does test for statistical evidence of relationships between factors (for instance, between flow management and water quality).

The test area, the San Joaquin River Basin, has the advantage of extensive monitoring and management data for certain water quality parameters, which accounts in part for selection of salinity (basin-wide) and selenium (the Grasslands sub-watershed) as test cases. On the other hand, the Basin generally is notable for its sheer size (it is the second largest basin in California) and complexity. Highly modified and managed, the San Joaquin defies standard conceptual models of a hydrologic system. It was quickly evident that there would be no

1 See: http://www.sfei.org/rmp/.

2 See, The Bay Institute, "Ecological Scorecard: San Francisco Bay Index 2005." At http://www.bay.org/news.htm. The potential for developing San Joaquin indices is discussed in this Report, at the conclusion of the Grasslands watershed case study.
Other examples of indices come from:
-- California EPA. Office of Environmental Health and Hazard Assessment, "Environmental Protection Indicators for California," 2004 and addendum 2005. See http://oehha.ca.gov/multimedia/epic/index.html.
-- The Great Valley Center, "Assessing the Region via Indicators The Environment 2000-2005," November 2005; "Assessing the Region via Indicators: Community Well-Being," (Second Edition). See: http://www.greatvalley.org/.

substitute for local knowledge and experience in identifying appropriate PSR parameters and their interrelationships.

To help define and interpret key PSR parameters for the San Joaquin, SFEI and The Bay Institute convened a "Steering Committee" comprising individuals selected for their familiarity with particular aspects of the San Joaquin watershed and water management practices there. *Appendix A* reports the meetings of this Committee. Guided by the Committee's advice, it was decided early on to focus on two water quality parameters (selenium and salinity) represented at different geographic scales (sub-watershed and basin level, respectively). Both case studies have proved instructive with respect to questions such as: can information about large-scale management (R) be linked to either reduction of pressure variables (P) or improvement in water quality condition variables (S), and at what scales; whether existing monitoring is directed to what we need to know (i.e., responds to management questions); what data gaps need to be filled to develop a line of evidence for identifying human-caused stressors (P) acting on a watershed; and whether we have adequately accounted for key external variables affecting water quality in the watershed, and have identified impacts 'exported' from the watershed. As case study this Report offers lessons in indicator design and application. However, it is important to keep in mind that the test cases do <u>not</u> constitute a complete profile of San Joaquin water quality conditions.

A second level of review occurred near the completion of project when the draft final report was sent out to individuals with expertise in indicators and/or interpretation of water quality conditions and related causes. The reviewers were invited to comment on the draft report in the context of a short list of questions. Their varied evaluations of the PSR framework reflected differing perspectives regarding the purposes of indicators and how they should be interpreted. The following points summarize these issues and various considerations for future use of the PSR framework.

1. **Use of the PSR indicators.**

a. <u>Measures of single pressure-state-response factors (such as selenium loads, or reduction in applied water per acre) versus measuring relationships between factors:</u>
PSR indicators such as those tested in this project are most readily used for reporting on single, discrete factors or combinations of these factors. In contrast, detecting posited cause-effect relationships between factors can be problematic for a number of reasons, including limited understanding of the watershed-specific basis for linkages; lack of available data to test relationships; and disproportionate scales—e.g., a sub-watershed response signal is 'drowned out' at larger scales.

b. <u>Status and trends applications</u>: In line with the preceding observations, assessment of status and trends for key water quality parameters is easier than relating observed conditions to particular stressors or to management activities.

c. <u>Indices</u>: Several reviewers remarked that the PSR indicator framework would work well for development of indices, and were quite supportive of this application. Developing suites of indicators to represent a composite assessment was judged appropriate and meaningful. In fact, an index which combines water quality indicators with other measures of environmental and/or social condition can provide a good survey of the state of a watershed and its communities. (A caveat is applicability to complex, interactive systems. See discussion under # 4).

2. **Limited data on watershed-specific 'best practices' and need to match monitoring with management questions**.
Often the report made use of data from monitoring designed for purposes other than the 'management objectives' posited in the test cases. Moreover, data on the results of particular management practices, as implemented in the San Joaquin, were not readily available—a point lamented by several reviewers, as well as members of the Steering Committee. This situation could be remedied: The PSR model could be used proactively to posit effects of management, help design appropriate monitoring to develop lines of evidence, and then assess the results.

3. **Geographic scales**.
a. Varying scales for factors acting within a watershed (sub-watershed): For any PSR application to the real world, the 'scales' of PSR factors relevant to the watershed of interest may differ. For example, an important water quality pressure (P) acting within a sub-watershed may be controlled by sources outside that watershed. In such situations, we might not expect local management responses (R) to be effective. Moreover, in focusing on a defined watershed, the PSR model may miss important effects on the broader scale (e.g., downstream). These effects could 'feed back' to further alter conditions within the watershed of interest. Several reviewers felt that the report overlooked the importance to the San Joaquin of controlling variables outside that geographic area, as well as effects of San Joaquin inflows to the Delta.

b. Difficulties in "scaling up": Water quality *conditions* (S) may be measured and compared at various scales more easily than the effects of many management activities on these conditions (R). As one would expect, local management activities may be verifiably effective at a small scale, but the 'signal' is lost at larger scales, unless the scale of management activities corresponds to the scale at which a signal might be differentiated from the "noise" Intuitively, the number of factors affecting water quality increases with up-scaling, but documenting this complexity is difficult. The generalization regarding difficulties in detecting effects of management activities, particularly on a larger scale, depends on the extent and magnitude of management actions: Actions such as large-scale flow manipulation can have basin-wide impact.

Setting aside issues of up-scaling and reporting of program results, some members of the Steering Committee emphasized the need to take a closer look at how to select appropriate practices and document localized results—that is, to use a PSR framework to help in refine local use of 'best management practices.'

4. **Need for basin-specific expertise**: The PSR framework is basically a way of classifying conditions, and factors influencing these conditions (P and R). Its practical value for selecting factors related by cause-effect depends on adequate knowledge of the particular watershed, of management practice effectiveness, of important exogenous influences, etc. In the case of the San Joaquin, developing conceptual models from the generic 'PSR' framework required basin-specific insights as to water sources and routing, irrigation

methods, return flow routing, drainage management, etc. Several reviewers noted the difficulty of using the framework in such a "complex, highly managed" environment.

5. **Caveats with complex and interactive systems**:
Some reviewers noted that the PSR model doesn't readily incorporate "functional relationships," interactions and feedback loops. Additionally, the PSR framework is not designed for complex processes where the outcomes can vary, depending on the values of the factors. Examples of these situations would be mercury cycling processes, and synergistic effects in a mix of chemicals. As a result, even an index measuring "system condition" using the PSR framework is unlikely to capture all important processes and functions. Given these considerations and recognizing the value of retaining a PSR framework of practical use to managers,[3] some reviewers suggested adding narrative which explains limitations of the assessments.

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U.S. EPA Region IX Water Division

[3] The conceptual models being developed through CALFED's Delta Regional Ecosystem Restoration Implementation Program (DRERIP) emphasize scientifically-based detail with respect to effects mechanisms and processes. Depending on complexities and uncertainties of a project, and its information needs for adaptive management, these models possibly are more useful in tailoring specific actions—but are less readily accessible to the lay public and managers than the PSR application demonstrated in this Report.

Indicator - Definition

A value that presents scientifically based information on the status of, and trends in, relevant metrics or parameters. An indicator conveys complex information in a concise, easily understood format, and has a significance extending beyond that directly associated with the metrics or parameters from which it is derived. Indicators are physical, chemical, biological, or socio-economic metrics (parameters) that represent the key elements of a complex system. Indicators simplify metrics, or data, into readily usable information that can be used to show trends or changes in a particular environmental or social condition. *Water Boards Glossary of Terms* (September 2005)

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Executive Summary

This project applied the Pressure-State-Response (PSR) model as a conceptual framework to develop example indicators for water quality in the San Joaquin River basin and tested whether these indicators are useful for linking management activities to changes in water quality. The proposed indicator system described here provides a potential watershed management tool to track progress of water quality improvement strategies, evaluate environmental outcomes in terms of water quality and beneficial use conditions, and communicate monitoring and assessment results in an accessible way.

The project focused on two water quality issues that are a major concern in the San Joaquin Basin, salinity and selenium. Indicators were developed on two different geographic scales - basinwide for salinity and in the Grassland sub-basin for selenium.

By focusing on two water quality issues that are a major concern in the San Joaquin Basin and have a large database associated with them, the project served to highlight the following findings:

The PSR framework offers a method for selecting indicators and identifying data requirements.

Monitoring efforts can more easily be adjusted and optimized on an ongoing basis as lines of evidence emerge that document which types of management actions can or cannot be associated with improvement of undesirable water quality conditions.

With additional targeted data collection and aggregation efforts, particularly for management response indicators, such as flow management and reductions in irrigation water applications (water conservation), lines of evidence can be created that would allow managers to evaluate which actions are likely leading to the greatest improvements in water quality indicators. However, it was beyond the scope of this project to consider all downstream impacts of management practices. Thus, only indicators with immediate relevance to water quality conditions and actions inside the lower San Joaquin Basin are discussed.

Key findings are as follows:

Salinity - San Joaquin River Basin

Salinity indicators with enough data and sensitivity to detect changes in the basin include monthly salt loads (pressure indicator), annual and monthly flows at Vernalis (pressure indicator), and surface water salinity (state indicator).

Other potential salinity indicators representing important basinwide variables were not calculated because data are sparse or don't exist, contain known errors that would compromise the results, or are insufficiently developed and dispersed among multiple entities in the basin. These include salt imports to the basin (pressure indicator), salt application/disposal of salt-containing dry or liquid waste materials to open fields (pressure

indicator), groundwater salinity (state indicator), and the total amount of salt in the basin (state indicator).

The project did not yield any strong indicators for salinity management on a basinwide scale. Management response indicators under consideration included water conservation, water quality at the CVP inlets in the Delta (in this context, in terms of source water management for the basin; although this indicator has broader implications for basinwide water management, i.e. regional water recycling), drainage reduction, and flow management:

- Water conservation was not calculated because not all needed data are available. Some of the data necessary to calculate this indicator exist (e.g., discharge volume, delivery volume) but other needed data are not available or insufficiently developed (e.g., groundwater pumping volumes).
- Source water quality management shows improvement in export water quality since the mid-1990s but does not provide information on specific management actions that may have been implemented or driving the observed improvement in export water quality.
- Agricultural drainage reduction does not have the sensitivity to detect changes in the system, even though there is a quantitative relationship relating salt load pressure to drainage volume.
- The flow management indicator fails to detect effects of periodic flow increases on the Stanislaus River that were initiated to meet the TMDL objectives for San Joaquin River water at the enforcement point at Vernalis.

The salinity example demonstrates the difficulty of developing indicators on the basin scale in a system in which both the types and magnitudes of pressures (and, as follows, relevant management responses) vary geographically.

Selenium – Grassland Sub-basin

The Grassland subbasin includes a Drainage Project Area (DPA) which has been subject to management for compliance with a TMDL for Selenium since 1989. The case is of interest because of the relevance of the contamination problem, the availability of more then 20 years of water quality data from a compliance monitoring program, and the documentation of various management activities that were undertaken to address the issue.

Selenium loads in subsurface tile drainage discharge were calculated as an example for a pressure indicator for selenium. The indicator is responsive (i.e. able to detect differences within an appropriate time frame to the decisions it is intended to inform), and data for the calculation are available and sufficiently developed.

Selenium concentrations in water and bioaccumulation were representative and responsive state indicators for selenium. Toxicity testing, on the other hand, is by design not a contaminant-specific indicator and cannot be readily used to assess impairments related to selenium. Data for selenium concentrations in water, bioaccumulation, and toxicity testing were available and sufficiently developed. Bioassessment/biomarker data were not available.

Calculated management response indicators for selenium in the Grassland subbasin with sufficient data to demonstrate visible trends and/or improvements include source water quality management, water conservation, water reuse, and flow management. Calculated trends for these management response indicators are consistent with predicted changes based on our conceptual understanding. Data were also available for land retirement and cropping, but these management responses were found of limited value as indicators.

The presented analysis is a first step toward linking management activities to changes in water quality condition. Moreover, statistically significant linkages were demonstrated between some of the calculated management and water quality condition indicators. Specifically, such relationships could be demonstrated for the Grassland management indicators source water quality management, water conservation, and flow management. However, the indicator method does not yet allow an evaluation of how effective certain management responses are or what the most effective practices are to improve water quality condition, as these are often the result of cumulative impacts of all activities combined[4]. This is even more challenging given the current scarcity of data on management activities or the limited utility of existing data for doing these kind of analyses. Targeted data collection efforts combined with the application of landscape modeling may help to improve our ability to make more specific connections between individual activities and environmental outcomes in the future.

In addition to the proposed and rejected water quality indicators, the project also provided examples for using the PSR model as a tool in adaptive management, to identify data gaps, evaluate monitoring design issues, or help focusing management-decisions.

Example 1: The failure to detect effects of periodic flow increases on the Stanislaus River with the flow management indicator, which is the documented Stanislaus River flow expressed as the percentage of the total SJR flow measured at Vernalis, suggests that (1) data may not be collected at the appropriate frequency to detect these changes; or (2) increasing flows from the Stanislaus River do not have a measurable effect on the Vernalis design flow.

Example 2: Although not a new insight, the PSR approach illustrates that toxicity results are of limited value for assessing water quality impairments on a constituent-by-constituent basis. Adaptive management based on PSR would suggest to decision-makers to either invest resources in identifying causes of toxicity and management actions that would eliminate the associated beneficial use impairments or, if no immediate actions are desired, discontinue or reduce the frequency of toxicity testing.

Recommended next steps include:

- Adaptation of the presented approach and material for the CALFED indicator development process; and
- the development of pilot projects for testing the Framework that involve a more systematic tracking of investments in management responses versus

[4] An exemption is the flow management indicator: a drastic change in condition occurring in 1996 (Mud Slough below SLD worsens, Salt Slough improves) can be very clearly associated with the construction of the Grassland bypass.

environmental outcomes. Testing on the pilot scale should involve the careful development of hypotheses regarding effect of management actions. Due to the difficulties of developing meaningful indicators on the basin scale, an aggregation method should be developed and tested that would allow "upscaling" of watershed scale indicator/indexes for basinwide assessments.

Section 1. Introduction

A. Project Rationale

Numerous state and federal agencies (US EPA, Resources Agency, CalEPA) have identified the need for concise ways to evaluate and explain environmental status and trends. The importance of indicators as tools for improved management and decision-making and as a means to communicate to the public and policy-makers regarding cumulative benefits of their investments and regulatory programs is now broadly recognized. The main rationale behind this project was the fact that a lack of appropriate performance indicators has been an impediment to tracking and reporting progress and systematically evaluating management actions. By having a common set of indicators available, it will become easier to evaluate environmental performance of permitting and incentive programs at a watershed scale across different programs and organizations. Management responses to undesirable environmental conditions, such as exceedances of water quality objectives, could benefit by tools in place to link investments with environmental outcomes.

The San Joaquin River and several of its tributaries are listed under CWA Section 303(d) as water quality limited segments due to pesticides, salinity, several trace elements, and unknown toxicity. Water quality data (as well as data for other relevant parameters, e.g., river flows) are available for many areas and for sufficiently long time periods in the watershed. This project made use of the relative data "richness" in the San Joaquin River watershed to suggest suitable water quality indicators and assess their utility for tracking and evaluating the status and progress of water quality management efforts.

B. Project Objectives

The current water quality management system involves a number of players: (1) those that regulate discharges under the Clean Water Act and the California Water Code; (2) natural resource trustee agencies (primarily the U.S. Fish and Wildlife Service and the California Department of Fish and Game); (3) municipal, industrial, and agricultural dischargers; and (4) those agencies managing the complex water storage, supply, and conveyance infrastructure that has substantial indirect influence over the attainment of aquatic life uses. The management activities by the latter three groups are in large part driven by the regulatory framework. All four entities have information needs in common, as well as specific needs to inform their individual management activities. Our project objectives were to:

- develop a common framework useful to all four groups to facilitate communication and adaptive management
- review conceptual models (simplified depictions of our current understanding and hypotheses of watershed functions, processes, land/water use, and management
- compile and analyze available data and means to aggregate them into indicators capable of showing the interaction between 303(d)-listed pollutants and other contributing factors impairing beneficial uses in the San Joaquin River basin; and development of specific assessment question upon which indicators can be based

- develop and test multiple water quality and management response indicators, and evaluate the feasibility of aggregating indicators into multi-metric water quality and management response indices.

C. Geographic Scope

Data-gathering was restricted to the San Joaquin River basin, defined to include the San Joaquin River's east-side watersheds from the terminal dams to the mainstem San Joaquin River, the watersheds of west-side tributaries to the mainstem San Joaquin River, and the mainstem San Joaquin River to the Sacramento-San Joaquin Delta (Delta) at Vernalis and/or the Stockton Deep Water Ship Channel (**Figure 1.1**). Evaluation of water quality conditions and management in the Tulare basin and in the Delta is not included in this project, except as it relates to water quality conditions at Vernalis and the Stockton Deep Water Ship Channel, Delta water export operations that deliver water and contaminants to some areas in the basin, and flood inflows from the Tulare basin that occur in some years.

D. Linkage to TMDLs and other Management Priorities

San Joaquin River basin waters are polluted with a wide range of contaminants including: trace elements; heavy metals; pesticides and herbicides; industrial chemicals; nutrients; pharmaceuticals and personal care products; and pathogens (CVRWQCB, 2006; Lee and Jones-Lee, 2006). Currently in the basin, TMDL implementation programs are underway for five contaminants: salinity (or total dissolved solids), boron, selenium, organophosphate pesticides, and dissolved oxygen (using oxygen-demanding substances as the contaminant).

The proposed indicator system described here provides a potential watershed management tool to track progress of water quality improvement strategies, evaluate environmental outcomes in terms of water quality and beneficial use conditions, and communicate monitoring and assessment results in an accessible way. To assure relevance of the conceptual framework to water management priorities in the San Joaquin River basin, there need to be evident linkages to the TMDL implementation process and related basin-wide approaches to beneficial use protection. These linkages are demonstrated in the testing of water quality and management response indicators described in Section 3.

E. Potential Applications

The project provides an example of how a systematic representation of pressures (P), states (S), and management responses (R) and the potential/hypothesized linkages between P-S-R can be applied for selecting indicators, assessing their utility, and identifying data requirements. There are a number of potential applications of the PSR system which vary with respect to user interest, need, and feasibility (e.g., data requirements). Regulated dischargers and water managers might use the PSR system to identify potential indicators and data requirements to evaluate which management practices might be most effective. Regulators might use PSR to design and adjust monitoring efforts geared toward assessing trends in pressures and states.

The PSR system can be used to identify representative and consistent indicators of pressures and state (condition). In addition, use of PSR has the potential of informing how to manipulate and reduce pressures .Lastly, it can help structure a broad, watershed-wide assessment of conditions that looks beyond water quality and includes, for example indicators of ecosystem integrity and socio-economic health. At a minimum, PSR is useful in identifying data requirements to produce a "weight-of-evidence," identify associations between reductions in pressures or improvements in water quality conditions and management actions taken, and select those with the most favorable ratio of management costs and environmental outcomes.

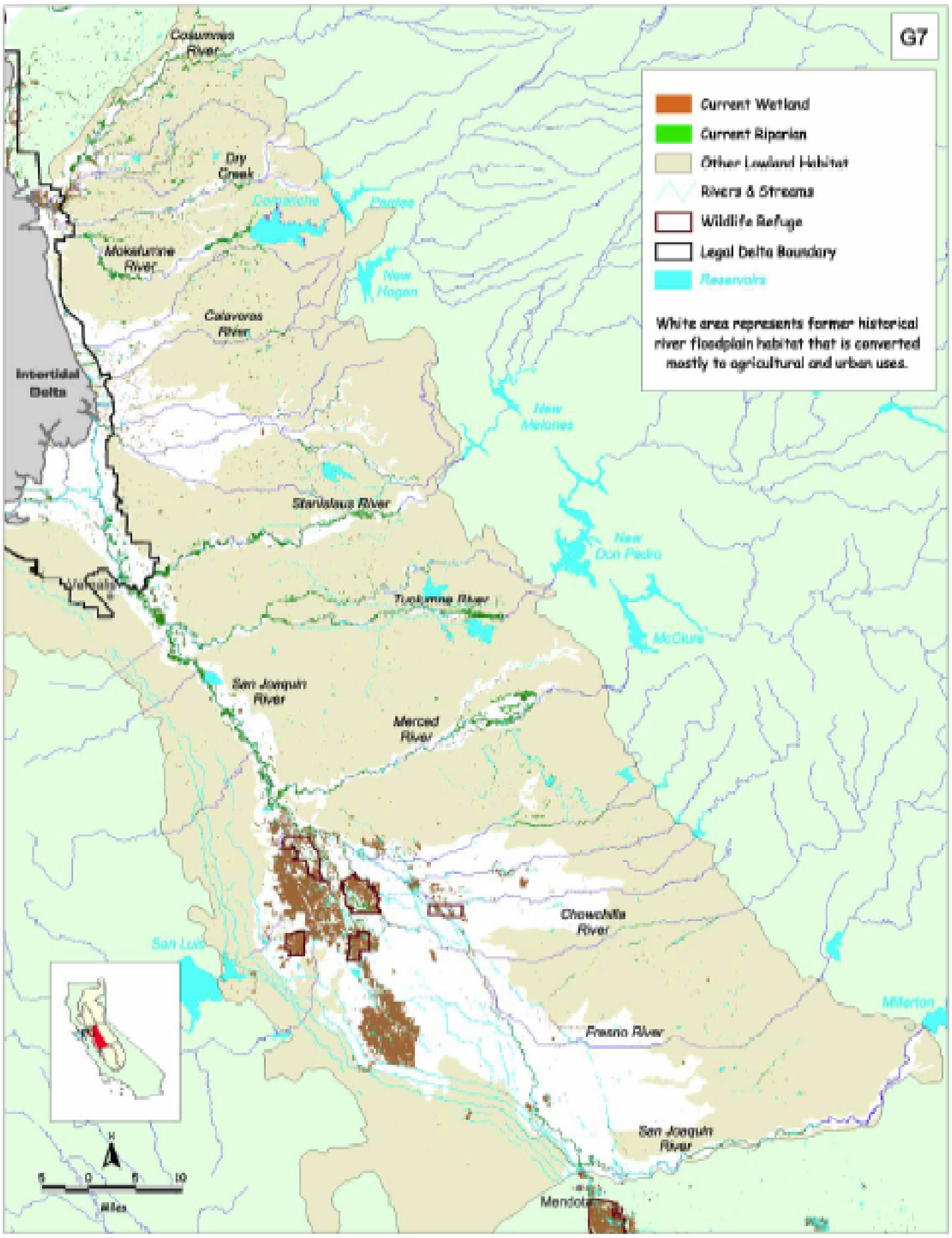

Figure 1.1. The geographic scope of this project is the San Joaquin River basin, including the east-side watersheds from the terminal dams to the mainstem San Joaquin River, the watersheds of west-side tributaries to the mainstem San Joaquin River, and the mainstem San Joaquin River to the Sacramento-San Joaquin Delta (map source: The Bay Institute, 1998).

References

CVRWQCB. 2006.Total Daily Maximum Loads (TMDLs) and Impaired Water Bodies 303(d) List. *http://www.waterboards.ca.gov/centralvalley/programs/tmdl/index.htm*.

Lee, G. F. and Jones-Lee, A. 2006. San Joaquin River Water Quality Issues: an Update. G. Fred Lee & Associates, El Macero, CA.

The Bay Institute. 1998. From the Sierra to the Sea: The Ecological History of the San Francisco Bay-Delta Watershed. The Bay Institute of San Francisco, Novato, CA.

Section 2. Approach and Work Steps

Step 1. PSR Model

The Pressure-State-Response (PSR) model was used as the conceptual framework for this project. In this model description, management responses address impairments of water quality and beneficial uses by reducing pressures on water quality (**Figure 2.1**). The system response to reduced pressure is measured as the resulting change in water quality condition (state)(see **Figure 2.1**). PSR provides a consistent approach to connect actions with system response.

The rationale for using PSR is as follows:

- Adaptive management can only happen if we can develop a line of evidence that links actions with environmental outcomes (are we collecting the right kinds of data to help answer the right kinds of questions?)
- Systematically organizing information according to an agreed-upon framework can help identify critical gaps as well as potential monitoring efficiencies that might currently not be realized.
- The framework can be used as a communication tool and road map with the various stakeholders to avoid "getting lost" in the complexity of issues.

The PSR model presents an intentionally simplified view of the complex connections between natural systems. It does not incorporate indicators of exogenous pressures such as climate or weather (reflected in hydrology). In the context of this project, the model was used to describe diffuse pollution source "pressures" from agricultural, urban, and industrial landscapes, their relationships with water quality condition (state), and management actions (response) that affect both pressure and condition (state).

The PSR model has several shortcomings that have been taken into consideration for this project. One of these shortcomings is that there is considerable overlap and interaction among the model components that frequently make it difficult to differentiate, for example, pressure and state components (see Section 3). Moreover, the PSR model does not account explicitly for natural variability (e.g. hydrology) or unintended water quality consequences of human actions. Berger and Hodge (1998) fault the model for not addressing natural change over time. The model has also been criticized by some for not recognizing the underlying forces (i.e. population growth, consumerism, income inequalities) that lead to environmental pressures, and not recognizing how ecosystem changes impact human health and well-being (Rapport, 2006).Some projects have used modified versions of the PSR model, such as the Driving force Pressure State Effects Action (DPSEA) model or the Driving force Pressure State Impact Response (DSPIR) model, to take these factors into account (Kjellstrom and Corvalan, 1995; Smeets and Weterings, 1999).

Although these shortcomings were taken into account, the PSR model was selected as the most suitable conceptual framework for this project. Selection of the PSR model was partly due to its simplicity, which allows developing clear messages about the linkages between environmental outcomes and actions. It was also based on previous examples, where it has been applied successfully in facilitating the evaluation of environmental concerns in relation to the forming and monitoring of environmental policy and management activities (Barker, 2001). We further attempted to reduce the PSR model's shortcomings by linking it to the EPA Framework for Assessing and Reporting on Ecological Condition (Young and Sanzone, 2002), which describes environmental condition attributes (equivalent to state), anthropogenic and natural stressors (equivalent to pressures), and implementation actions designed to reduce or mitigate the effects of stressors (equivalent to response).

Step 2. Review of Contaminant Processes in the San Joaquin River Basin

(See **Table 2.4.** for a timeline of major hydrological and regulatory events.)

A total of 28 general conceptual models for contaminant and hydrologic processes in the San Joaquin basin were reviewed. (**Appendix B**). These models describe one or more of the three PSR components in the basin (or, in some cases, the Delta) for specific contaminants (e.g., selenium, including loading sources, locations, and/or magnitudes); physical and biological cycling of contaminants between land and water bodies within the basin; and impacts of the contaminants on biota and water quality).

The conceptual hydrologic/water management model that was used as the main reference for this project identifies eight areas from which contaminants enter and/or can impair water quality in the tributaries and mainstem of the San Joaquin River (**Figure 2.2**) (CMARP 1998). These areas are:

- the east-side tributary rivers (Cosumnes, Mokelumne, Stanislaus, Tuolumne, and Merced);
- the upper San Joaquin area (San Joaquin River upstream of Merced confluence and Bear Creek);
- the Grasslands area managed wetlands drained by Salt and Mud Sloughs;
- the Drainage Problem area, which drains into the river via Mud Slough;
- the west-side tributary rivers (e.g., Orestimba Creek);
- the mainstem San Joaquin River;
- groundwater; and
- the Delta-Mendota Canal (DMC).

Step 3. Application of PSR to the San Joaquin River System

Based on the review of contaminant and hydrologic processes (Step 2), PSR was adapted for describing the San Joaquin River system as presented in **Figure 2. 3.** The modified PSR schema developed for this project brakes the generic PSR triangle (**Figure 2.1**.) into systematically indexed categories of water quality pressures, state variables, and management responses (**Figure 2.3**) that are potentially linked through varying cause/effect relationships:

Water quality pressure categories P1-5:

P1. Soil & land use
P2. Water
P3. Air
P4. Discharge
P5. Application
P6. Hydro-regime modification

Water quality state categories WQ1-4:

WQ1.	Water and sediment quality
WQ2.	Toxicity
WQ3.	Sublethal effects
WQ4.	Bioaccumulation

Management response categories MR1-5:

MR1.	Direct application practices
MR2.	Land management
MR3.	Water use management
MR4.	Treatment
MR5.	Flow management

Figures 2.4 – 2.6 provide some examples for using the resulting PSR framework to identify potential linkages between management responses and pressures. In theory, these potential linkages can be empirically tested using statistical methods to detect existing relationships. Indicators can then be selected and tested based on the conceptual understanding of the specific system (e.g., San Joaquin hydrologic system and conceptual model for contaminant in question) or based on a hypothesis about possible cause/effect relationships.

Discussion 1: EPA's Framework for Assessing and Reporting on Ecological Condition (Young and Sanzone, 2002)

EPA's Framework for Assessing and Reporting on Ecological Condition (Young and Sanzone, 2002) provided the basis for developing the categories and subcategories of the PSR framework depicted in **Figure 2.3** The EPA ecological assessment framework is based on a comprehensive list of reporting categories and ecological attributes to describe the whole array of ecological and characteristics in both aquatic and terrestrial ecosystems and the full range of environmental media, including water, air, soil, and sediment. The framework is derived from the principles of ecology and ecological risk assessment (represented by conceptual models) and provides a scientifically defendable basis for the selection of metrics and indicators to describe the resource characteristics that are essential for understanding and managing an ecosystem. In this project, the EPA framework was adapted to identify categories (and subcategories) and attributes that are specific to water quality issues. The purpose was to aggregate and organize generic information about water quality conditions and the processes affecting it in a system that that is consistent across a variety of scales and allows displaying the relationships between various monitoring data or indicators.

Step 4. Assessment Questions and Initial List of Indicators

The PSR model for water quality in the San Joaquin River (**Figure 2.3**.) was used to draft a list of proposed assessment questions and initial indicators (**Appendix A, Table 1**). This initial list was finalized to include revisions suggested by the project steering committee (**Tables 4 1 – 4.3)**. In accordance with PSR (**Figure 2.3**), potential indicators were selected to represent three broad categories of attributes:

- Water quality attributes,
- Attributes representing human-induced water quality pressures, and
- Attributes representing management activities

Based on a recommendation by the steering committee, indicator development, testing, and aggregation were then focused on two priority pollutants for which large amounts of data are available: salt and selenium. Also based on a recommendation by the steering committee, the indicator development proceeded on two different geographic scales: the San Joaquin Basin for salt, and the Grassland region for selenium.

The following Steps 5 and 6 describe in generic terms the approach followed in this project for indicator development, testing, and aggregation. Section 3 describes more specifically, how example indicators for salinity in the San Joaquin basin and selenium in the Grassland region were developed, tested, and aggregated by following Steps 5 and 6.

Step 5. Indicator Development and Testing

Development

The process of selecting indicators followed the approach taken by the EPIC Project and involved the following steps (not necessarily in a linear sequence): (a) identification of environmental issues (or elements of the system) to be characterized, and organization into a structure reflecting relationships among these; (b) identification of candidate indicators for these issues or system elements; (c) evaluation of the candidate indicators based on selection criteria; (d) characterization of the availability of data for the selected indicators; and (e) presentation of indicator information, including figures depicting status or trends, and a discussion of the significance of the indicator, factors that influence the indicator, and a characterization of the strengths and limitations of the data.

For data evaluation, indicator selection criteria were adapted and modified from the EPIC Process (**Figure 2.7**; Cal/EPA and OEHHA, 2002). The following criteria were applied:

- **Data Quality:** the data yield measures that are scientifically acceptable and support sound conclusions about the state of the system being studied. This requires sound data collection methods, management systems, and quality assurance procedures (i.e. data have been assessed for statistical variability, precision, and accuracy).
- **Reproducibility:** the indicator is transparent and reproducible.

- **Scalability:** the indicator is valid across different spatial and temporal scales.
- **Representativeness:** the indicator is designed to reflect the environmental issue it is selected to characterize and can be linked to other variables for describing the system.
- **Sensitivity:** the indicator should be able to distinguish meaningful differences in environmental conditions with an acceptable degree of resolution.
- **Responsiveness:** the indicator should be able to detect differences in environmental conditions within a time frame appropriate to the types of decisions it is intended to inform.
- **Decision Support:** the indicator should provide information appropriate for making decisions.

In addition, the indicators were evaluated for their potential to contribute information as part of a suite of indicators to address multiple assessment questions and for potential uses at multiple geographic scales (Step 6).

Testing

In essence, testing assured that the indicators, once developed and calculated, were still meeting the indicator selection criteria described above[5]. The indicators were, more or less extensively, tested for all the criteria mentioned above. However, focus of the discussion of example indicators in Section 3 is on conceptual relevance, in accordance with the scope of this project[6]:

1. **Representativeness: Is the indicator relevant to a particular water quality issue, attribute, or management practice? ()**
   The PSR framework (**Figure 2.3**) was applied to evaluate whether the proposed indicators are conceptually linked to a water quality issue, attribute, or management practice of concern.
2. **Responsiveness: Is the indicator responsive to an identified assessment question?**
   The PSR framework for San Joaquin water quality served as a reference to determine whether the selected indicator clearly pertained to one or more identified assessment questions (**Table 2.1**). Testing for responsiveness, includes for example, to evaluate whether an indicator is able to detect an expected change in conditions or relationship based on our conceptual understanding of the system (**Figure 2.3**) and a corresponding data review (**Appendix C**)

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[5] The indicator selection criteria of the EPIC Process (Cal/EPA and OEHHA, 2002) are consistent with the USEPA Evaluation Guidelines for Ecological Indicators (Jackson et al, 2000).

[6] A technically detailed, step-by step description of the indicator selection and testing methodologies and procedures is beyond the objective and funding scope of the project.

Step 6. Aggregating and Scoring

Aggregating

(Aggregation: refers here to the grouping of two or more variables into one index)

Discussion 2: Why Aggregate?

Traditionally, water quality trends are reported as variable-by-variable, water-body by water-body statistical summaries. This type of reporting is of value to experts and managers dealing with certain aspects of water quality, but it is often not to the point and insufficient to assess overall progress toward beneficial use protection. An assessment of beneficial use conditions in a watershed, for example, is based on a multi-dimensional water quality concept and can rarely be conducted based on studies of temporal trends in individual parameters only. Conflicting trends among parameters and across locations make it difficult to draw conclusions from comparing studies of individual parameters. The assessment is further complicated by the use-dependency of perceptions regarding water quality. Aggregated indices can provide meaningful summaries of overall water quality and trends that can be compared across watershed, regions, or river basins. They also simplify the communication process by which major trends and policy results are shared and discussed by experts, decisions-makers, regulated interests, and the general public (Canadian Council of Ministers of the Environment, 2001; Schultz, 2001; Goldberg, 2002).

The demonstrated examples of indicator aggregation followed the Aggregation Criteria for Environmental Indices proposed by the Organization for Economic Co-operation and Development (Goldberg, 2002):

- **Transparency of calculations:** every step of the aggregation process should be traceable. Calculations, assumptions, choices in terms of weighting, input of missing data, etc. need to be documented.
- **Independency of variables:** combined measures should be independent, i.e. not show a cause-effect relationship.
- **Amenability to change:** all components to be aggregated should be descriptive of the identified problem and amenable to change in response to human intervention.
- **Transformation and weighting rules:** the conversion (transformation) of indicators prior to their aggregation and their weighting should follow certain explicit and logical rules.
- **Consistency of data sets:** the time period and geographic scales of all components to be aggregated should be consistent.

Scoring

Scoring of indicators is a necessary step in developing an index-type indicator system because it allows the expression of multiple variables with different measurement units in a common metric and enables the valuation of indicator results; i.e. the comparison of scores with a predetermined classification of what constitutes good or poor values. Considerations in developing a scoring system included:

1. The scoring method should be logical and transparent to facilitate reporting
2. Measured values should be compared to reference conditions based on historical conditions, restoration goals, biological objectives, or other targets.
3. Results for individual variables need to be transformed into a consistent scale.

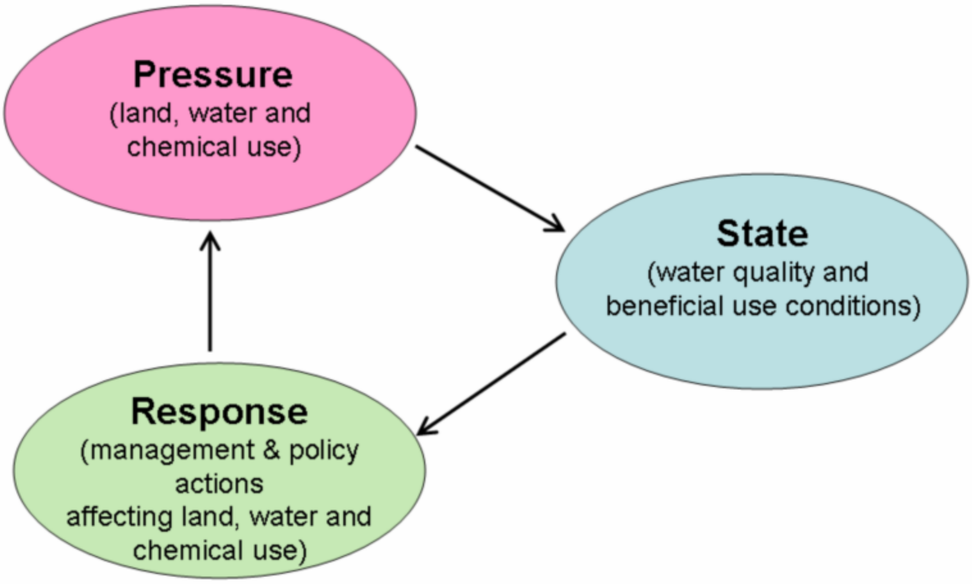

Figure 2.1. The PSR model. See **Figure 2.3** for a graphical schema of how the PSR model was used as the conceptual framework for developing water quality indicators for the San Joaquin River basin.

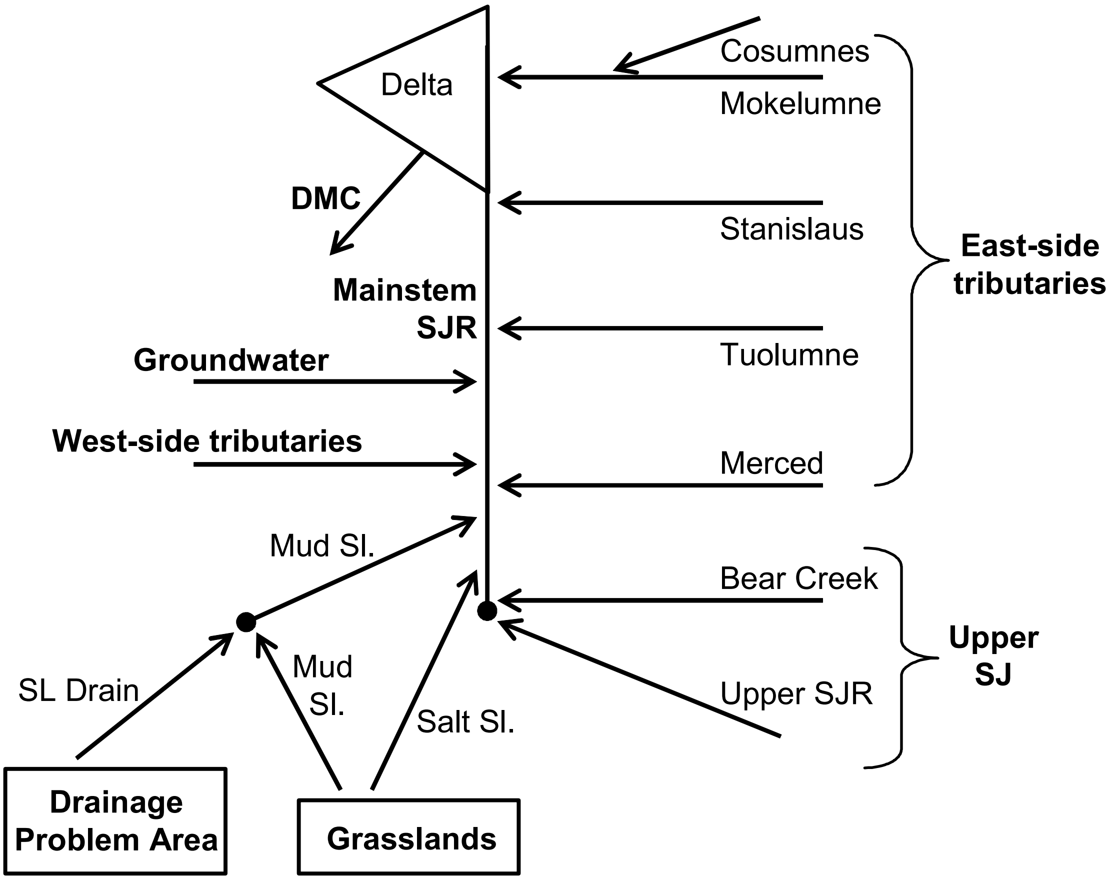

Figure 2.2. Conceptual model of the hydrologic and water management connections in the San Joaquin River basin (based on CMARP 1998). In the basin, eight areas (or subregions, shown in bold text) are identified from which contaminants enter and/or can impair water quality in the tributaries and mainstem of the San Joaquin River.

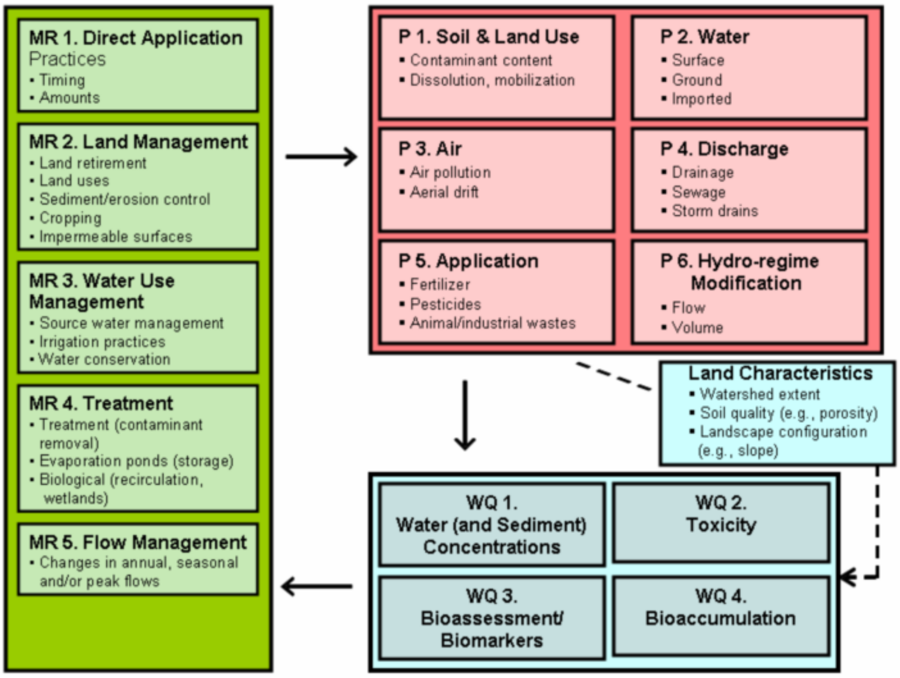

Figure 2.3. PSR model of contaminant sources, water quality conditions, and management practices in the San Joaquin River basin[7]. The model broadly categorizes water quality pressures, state, and management responses as follows: pressures (P1-P6, pink boxes) are direct and indirect sources of contaminants as well as other "controllable" factors that affect the amounts of a contaminant delivered to surface waters and the concentration of contaminant in the water. State is the condition of water quality and beneficial uses and is characterized by water quality (concentrations of constituents), toxicity, sublethal effects, and bioaccumulation (tissue levels of constituents) in the water (WQ1-WQ5, blue boxes). Management responses are practices that control the reduction of contaminant loads to waters and/or affect their concentrations in basin waters (MR1-MR5, green boxes). Uncontrollable factors such as ambient temperature or hydrology are omitted from this

[7] The project scope was limited to data evaluation in the lower San Joaquin River basin downstream of the dams and upstream of Vernalis. Therefore, it was not possible to evaluate conceptual PSR linkages across watershed boundaries, such as effects of selenium on downstream components of the ecosystems such as the Delta or San Francisco Bay (see Appendix D, Comment 1). In theory, however, the conceptual model presented here can be readily transferred to describe conceptual linkages in the larger watershed or across watershed boundaries.

representation. Land characteristics are shown as a state component (blue) that mediates the link between the pressure and water quality state. While land characteristics affect water quality, indicators for this component are outside the scope of this project.

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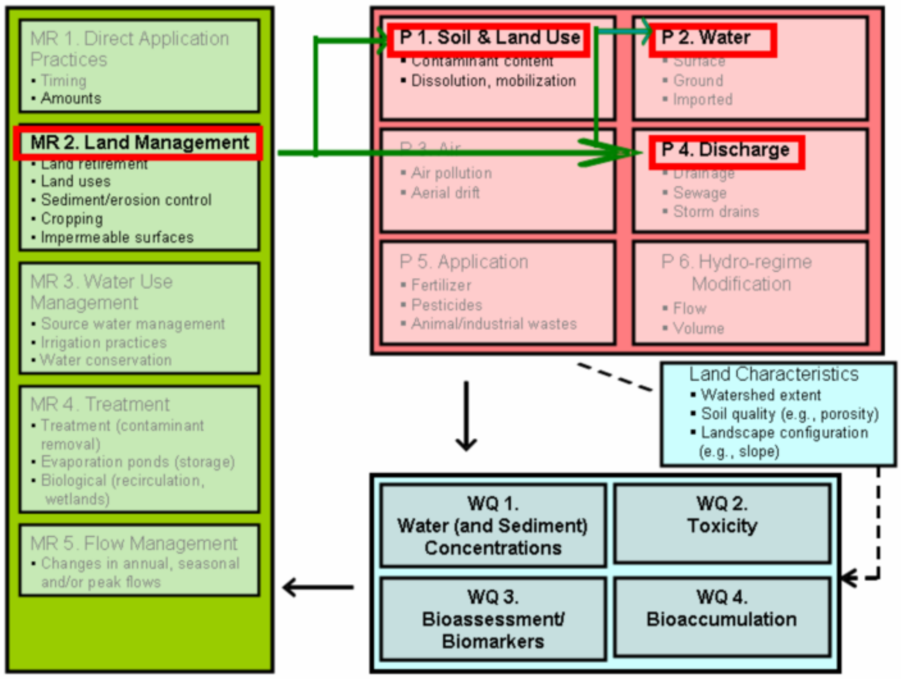

Figure 2.4. Land management practices (MR2), for example land retirement, land uses, erosion control, or cropping, affect pressures on water quality condition from soil (P1), water (P2), and discharge (P4). Examples are the reduction of selenium and salinity loads in return waters from irrigated fields.

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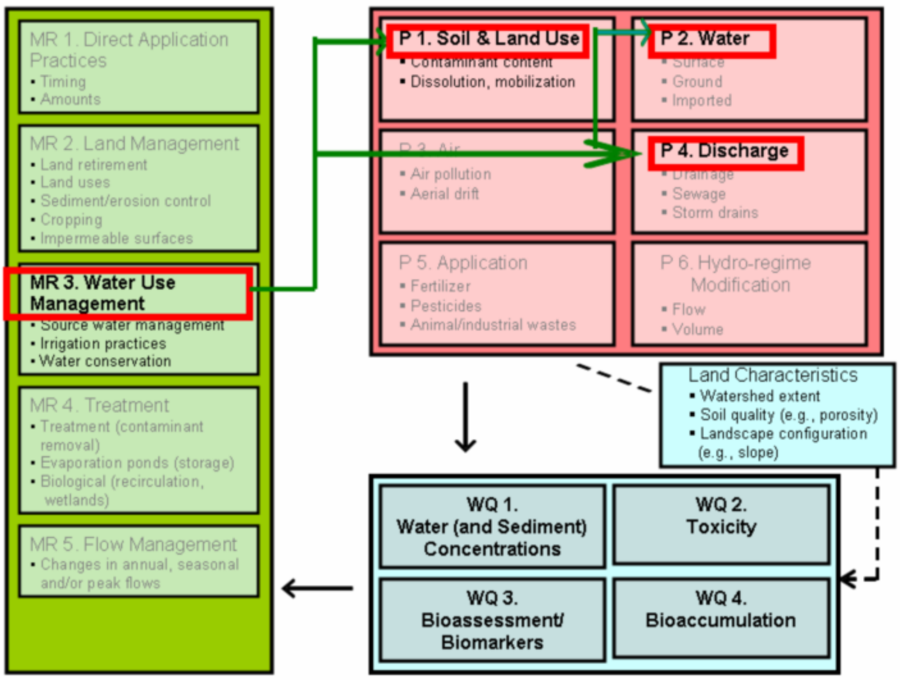

Figure 2.5. Water use management (MR3), for example source water management, irrigation practices or water conservation, affect pressures on water quality condition from soil (P1), water (P2), and discharge (P4). Examples are the reduction of selenium and salinity loads in return waters from irrigated fields through drainwater reduction activities, such as recycling, drip irrigation, or reuse on salt-tolerant crops.

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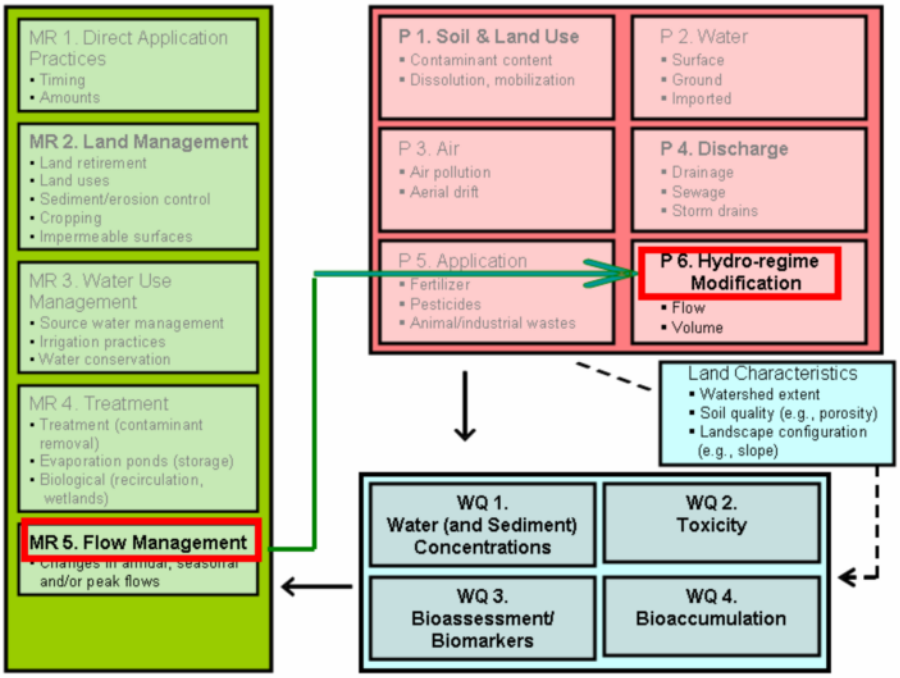


Figure 2.6. Flow management affects pressures on water quality condition (e.g., contaminant concentration) related to hydro-regime modification (P5). An example is the release of water from tributary reservoirs (for example New Melones Reservoir) to increase flow and reduce downstream pollutant concentrations (e.g., salinity at Vernalis).

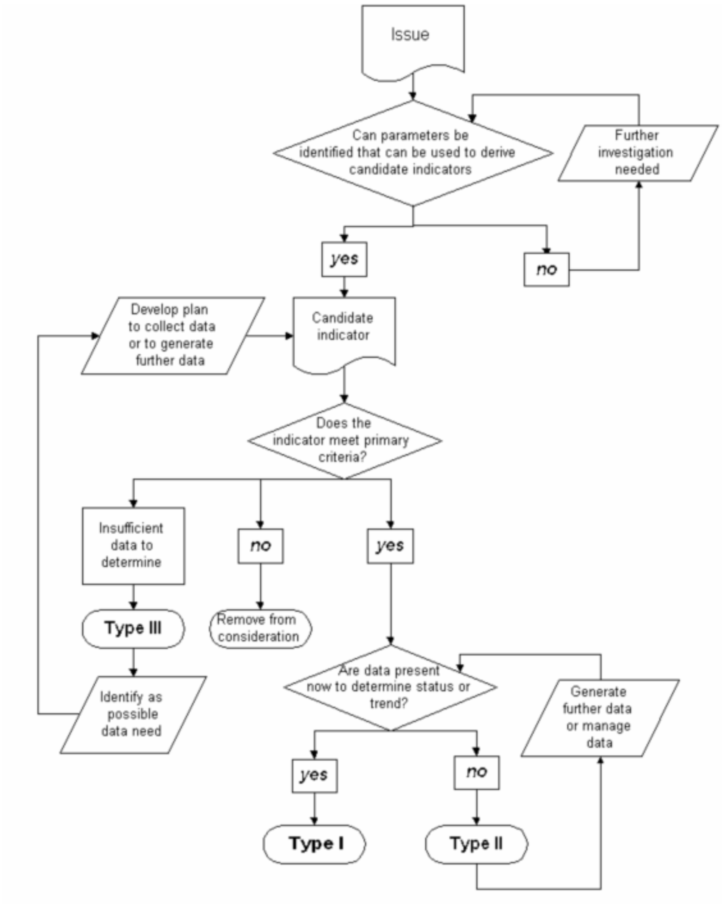


Figure 2.7. EPIC indicator identification & selection process (Cal/EPA and OEHHA, 2002).

Table 2.1. Generic assessment questions and potential indicators for evaluating and tracking the pressures that affect water quality and beneficial use conditions in the San Joaquin River basin.

PRESSURE: Human activities that affect contaminant concentrations and loads	
Assessment Question	**Potential Indicators**
P1. Contaminant Application (i.e., fertilizers, pesticides, animal wastes)	
What types of contaminants are applied (e.g., short-lived vs. persistent contaminants)?	Numbers and types of contaminants
How much contaminant is applied directly to the land or water?	Pounds of pesticides used Pounds of fertilizer applied Pounds (or volume) of animal or food processing waste applied to land
What is the area of land where contaminants are being applied?	Area (and geographic extent) of land where contaminants are applied?
What is the area of land used to spread/dispose of animal and food processing wastes?	Area (and geographic extent) of land used for disposal
P 2. Land Uses (causing impairment)	
What are the land uses that impair the landscape, leading to impaired water quality?	Numbers and types of land uses
What is the area (extent) of these land uses?	Area (and geographic extent) and percent of landscape utilized. i.e., area of crops that exacerbate impairment, grazing, erosion-causing practices, area of impermeable surfaces
Occurrence of impervious surfaces within 300 ft of waterway is associated with impaired uses.	What is the extent of impervious cover within riparian buffer?
P3. Air Pollution	
How much of the contaminant is imported from the air?	Volume, quality (e.g., total dissolved solids), and/or pounds of contaminants contained in the air.
P 4. Water Use (causing impairment)	
Contaminants from source water	
How much of the contaminant is imported from the Delta?	Volume, quality (e.g., total dissolved solids), and/or pounds of contaminants contained in imported water
How much of the contaminant is imported from groundwater?	Volume, quality (e.g., total dissolved solids), and/or pounds of contaminants contained in pumped groundwater
Water Use	
How much irrigation water is applied to contaminant-impaired (or drainage-impaired) land?	Volume of water applied to contaminated lands *Volume of water applied in relation to predicted evapotranspiration volume*
P5. Discharge	
What types of discharge sources occur in the	Number and types of point and non-point source

watershed?	discharges
How much water drains from contaminant-impaired land directly into surface waters?	Volume of drainage water (absolute or per acre of land irrigated)
How much of the contaminant is in the drainage water discharged into surface waters?	Concentration of contaminant (total and/or dissolved) Amount of contaminant delivered to surface waters (concentration x volume)
P 6. Receiving Water Flow Regime ***(note: this could be a state variable as well)***	
Flow volume	
How much have flows been reduced or changed relative to historical conditions and particularly as they relate their ability to dilute contaminants?	Reduction in flow volume (annual, seasonal, daily) Timing of flow volume
Export of Contaminants?	
How much of the contaminant is removed from the basin in outflowing surface waters?	*Concentration of the contaminant at Vernalis* *Amount of contaminant contained in water at Vernalis in relation to amount applied and discharged*

Table 2.2. Generic assessment questions and potential indicators for evaluating and tracking water quality and beneficial use conditions in the San Joaquin River basin including other waters impinging on watershed water quality (i.e., source water, tributary waters and drainage water quality)

STATE: Water Quality and Beneficial Uses	
Assessment Question	**Potential Indicators**
WQ 1. Concentration (water and benthic sediments; source water, land, and air)	
What is the concentration of the contaminant relative to regulatory or biological objectives?	Concentration of contaminant (total and/or dissolved)
Over what geographic range does the contaminant exceed regulatory or biological objectives (geographic scope)?	Number of sampling sites with exceedances relative to total sites or area sampled
How frequently do contaminant concentrations exceed regulatory or biological objectives (frequency)?	Percentage of samples that exceed objectives[8]
By how much does the contaminant concentration exceed regulatory or biological objectives (magnitude[9])?	Ratio of concentration of contaminant to regulatory or biological objective
How many contaminants exceed regulatory or biological objectives (contamination scope)?	Number and/or percentage of tested contaminants that exceed regulatory or biological objectives per sample, site, or region
WQ 2. Toxicity (restricted to water)	
Is the water toxic to aquatic plants and/or animals?	Bioassay results, number and/or percentage of samples that show reduced survival or growth of selected test organisms
Over what geographic range is the water toxic to plants and/or animals?	Bioassay results, number and/or percentage of sites or geographic areas that show reduced survival or growth of selected test organisms
WQ 3. Sublethal Effects on Indicator Organisms (biomarkers)	
Does exposure to the water have sublethal effects on aquatic plants and/or animals?	Number and/or percentage of plants and/or animals exhibiting biomarkers indicative of exposure to one or more contaminants
Over what geographic range does exposure to the water have sublethal effects on aquatic plants and/or animals?	Number and/or percentage sites or geographic areas from which plants and/or animals exhibit biomarkers indicative of exposure to one or more contaminants
WQ 4. Bioaccumulation (animal tissue)	
What is the concentration of the contaminant in invertebrate, fish and/or bird tissues, relative to regulatory or biological objectives of screening levels?	Concentration of contaminant in animal tissues
How many bioaccumulative contaminants have been identified in the tissues of invertebrates, fishes, and/or birds (scope)?	Number of contaminants present in animal tissues at levels greater than regulatory or biological objectives of screening levels

[8] Regulatory or biological reference conditions were selected for demonstration purposes only. This project was not intended to provide recommendations on reference conditions or baseline conditions.

[9] See Demonstration of Possible Methods for Aggregating Indicators into Multi-Metric Indices (p. 79) for use of frequency and magnitude as independent measures of variance for an indicator.

WQ 5. Landscape Conditions	
Is there a riparian buffer that might reduce impacts of contaminants on waterways?	Size of the riparian buffer around waterways with ag land use? Size of the riparian buffer around waterways with urban land use? What is the % canopy cover or other vegetation greater than 6 ft high within the buffer?

Table 2.3. Generic assessment questions and potential indicators for evaluating the management responses designed to change the levels of the pressures and improve water quality.

RESPONSE: Management Responses including BMPs, to reduce contaminant levels[10]	
Assessment Question	**Potential Indicators**
MR 1. Application Practices	
What methods are used to apply the contaminants (e.g., aerial spray)?	Types of methods
How long is the contaminant held on the land before discharged as drainage or runoff?	Number of days Number of days relative to contaminant break-down
MR 2. Land Management Practices	
Land Retirement: What percent of (contaminant laden) land is retired from irrigation?	Area of land retired from irrigation
Cropping methods: What alternate cropping techniques have been employed to reduce contaminants?	Practices or area affected by alternative cropping techniques designed to improve water quality.
Runoff Management, Sediment and Erosion Control: What types of sediment and erosion control practices have been implemented (structural, grazing practices, vegetated buffers, cover crops, wetland restoration)?	Numbers and types of sediment and erosion control practices Area (and geographic extent) of land with runoff and erosion control measures
Grazing Management:	Changes in area, duration and frequency of grazing
MR 3. Water Use Management	
Source Water Quality Management	
Implementation of techniques to reduce contaminants in the source water	
Water Use, Conservation and Recycling	
What types of irrigation practices (e.g., drip, spray, flood) are used in the watershed?	Area of land irrigated with "Efficient irrigation systems"
How much irrigation water is applied to contaminant-impaired (or drainage-impaired) land?	Volume of water applied to land Volume of water applied in relation to predicted evapotranspiration volume
Tiered pricing for water	**Number of districts with tiered pricing practices**
Drainage	
How much irrigation drainage is recirculated or reused? **(Tailwater return?)**	Volume of recirculated water (absolute or per acre of land irrigated) Volume of water discharged after recirculation (absolute or per acre of land irrigated)
Are discharges of drainage timed in relation to stream flows?	Volume of drainage discharged in relation to stream flow
MR 4. Treatment	
Discharge treatment:	
How many and what types of water treatment practices are used in the watershed?	Number and types of water treatment facilities. Numbers of districts with water treatment facilities

[10] All categories of management measures should be linked to indirect measures (MR6)

How much water is treated to remove contaminants before discharge into surface waters?	Volume of water treated (total, and/or as % of total drainage and/or stormwater runoff volume)
In-basin storage	
How much drainage water is diverted into evaporation ponds (i.e., in-basin storage of contaminants)?	Volume of water diverted to evaporation pond Amount of contaminant diverted into evaporation pond
MR 5. Flow Management	
Flow volume	
What are the annual and seasonal flows in drainage-receiving streams and rivers?	Flow volume (annual, seasonal, daily)
How variable is the flow within and between years?	Range of flow volumes, within and between years
MR 6. Indirect Management Measures (These can be applied to specific MRs and associated pressures)	
Education and Outreach	
What educational measures have been implemented to inform contaminant users and/or land and water managers of practices to reduce contaminant use and/or pollution prevention?	Number (and/or geographic extent) of workshops conducted Number (and/or geographic extent) of participants receiving education materials Number (and/or geographic extent) of educational signage programs Number (and/or geographic extent) of participants indicating change in behavior due to educational materials
Policy and Regulation	
What public policy measures have been implemented to reduce water pollution from urban, industrial and agricultural sources and practices?	Number (and/or geographic extent) of public policy measures (e.g., formation of watershed associations)
What “best management practices” have been identified?	Number of “best management practices” identified
What regulatory measures have been adopted to reduce water pollution from urban, industrial and agricultural sources and practices? (Stringent regulatory standards)	Number (and/or geographic extent) of regulatory measures adopted.
Economic Incentives	
What economic incentives have been adopted to promote water pollution reduction from urban, industrial and agricultural sources and practices??	Number (and/or geographic extent) of economic incentives adopted Dollars expended (by pollution reduction program type, geographic area)
Monitoring	
How many sites are sampled regularly for water quality condition (geographic scope)?	Number (and/or geographic extent) of water quality sampling sites
How many contaminants are measured at each site (“contaminant scope”)	Number of contaminants tested
How frequently are water quality measurements made (frequency)?	Number of times per years site sampled

Table 2.4. .Timeline of major hydrologic and regulatory events in the San Joaquin basin.

	Events	Regulatory/Policy	Management
1850s	Human development began in San Joaquin Valley along with diversions of the river		
1912	Southern Edison begins building reservoirs, dams, & powerhouses on upper San Joaquin River		
1933		California voters approve State Water Plan	
1942			Friant Dam completed
1951			DMC imports water to the west side of the San Joaquin Valley, including the San Joaquin River Water Authority Exchange Contractors
1982		CVRWQCB grants conditional waivers to irrigated lands, exempting the agricultural discharges using the waste discharge requirements process.	
Early 1990s			Agencies begin to make progress in efforts to set aside and restore acreage for wetland habitat.
1995		SWRCB adopts Sacramento – San Joaquin Bay Delta Water Quality Control Plan with significant water quality and flow standards for the lower SJR	
1998			Contra Costa Water District completes Los Vaqueros Reservoir

	Events	Regulatory/Policy	Management
2000			– Vernalis Adaptive Management Plan (VAMP) starts as a 10-year test program designed to study methods to improve salmon smolt survival in the lower San Joaquin River – CALFED Record of Decision (ROD) of 2000: "250 to 700 [thousand acre-feet] of additional storage in the upper San Joaquin watershed … would be designed to contribute to restoration of and improve water quality for the San Joaquin River, and facilitate conjunctive water management and water exchanges that improve the quality of water deliveries to urban communities. Additional storage could come from enlargement of Millerton Lake at Friant Dam or a functionally equivalent storage program in the region." – Westside Integrated Water Resources Plan initiated
2003		– January 1: Passage of SB 390 ends the previously used conditional waivers for waste discharge requirements for 23 types of waste discharges, including irrigated agriculture and logging. – July: CVRWQCB adopts two types of conditional waivers for such discharges into surface water, one for "coalition groups" and the other for individuals.	
2004		USBR ruled in violation of California law for not letting enough water flow to maintain the historic salmon population	

References: DWR (2005), Wikipedia (2007).

References

Barker, T. 2001. Representing the Integrated Assessment of Climate Change, Adaptation and Mitigation. Tyndall Centre Working Paper No. 11.

Berger, A. R. and Hodge, R. A. 1998. Natural change in the environment: A challenge to the pressure-state-response concept. Social Indicators Research 44: 255-265.

Cal/EPA and OEHHA. 2002. Environmental Protection Indicators for California (EPIC). Sacramento, CA.

Canadian Council of Ministers of the Environment. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0. In Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB, 13.

CVRWQCB. 2006.Total Daily Maximum Loads (TMDLs) and Impaired Water Bodies 303(d) List. *http://www.waterboards.ca.gov/centralvalley/programs/tmdl/index.htm*.

Goldberg, E. 2002. Aggregated Environmental Indices: Review of Aggregation Methodologies in Use. ENV/EPOC/SE(2001)2/FINAL. Organisation for Economic Co-operation and Development, Environment Directorate, Environment Policy Committee, Working Group on Environmental Information and Outlooks, Paris, France.

Jackson, L. E., Kurtz, J. C. and Fisher, W. S., Eds. 2000. Evaluation Guidelines for Ecological Indicators. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Kjellstrom, T. and Corvalan, C. 1995. Framework for the development of environmental health indicators. World Health Statistics Quarterly 48(2): 144-54.

Lee, G. F. and Jones-Lee, A. 2006. San Joaquin River Water Quality Issues: an Update. G. Fred Lee & Associates, El Macero, CA.

Rapport, D. J., and Singh, A.. 2006. An eco-health based framework for State of the Environment Reporting. Ecological Indicators 6: 409-428.

Schultz, M. T. 2001. A critique of EPA's index of watershed indicators. Journal of Environmental Management 62: 429-442.

Smeets, E. and Weterings, R. 1999. Environmental Indicators: Typology and Review. European Environment Agency Technical Report 25. European Environment Agency, Copenhagen, DK.

Young, T. and Sanzone, S. (eds.). 2002. A Framework for Assessing and Reporting on Ecological Condition. EPA-SAB-EPEC-02-009. U.S. Environmental Protection Agency, EPA Science Advisory Board, Washington, DC.

Section 3. PSR Indicators for Water Quality in the San Joaquin Basin

Based on recommendations by the steering committee, the application of the PSR model for indicator development, testing, and aggregation was demonstrated for two priority pollutants for which large amounts of data are available, salt and selenium, on two different geographic scales. Hence, salinity indicators were developed for the San Joaquin basin and selenium indicators for the Grassland subbasin..

Example 1. Salinity in the San Joaquin Basin

A. Background

The lower San Joaquin River, from Mendota Pool to Vernalis, is listed under the Federal Clean Water Act's section 303(d) as "impaired" for salinity (and boron)[11]. This designation required the development of TMDLs to provide a basis to regulate discharges of salt into the river. In 2004, the CVRWQCB adopted TMDLs for salt (and boron) and amendments to the Water Quality Control Plan (Basin Plan) for the San Joaquin River (CVRWQCB, 2004a). Our analysis for the development of pressure, state, and management response indicators for salt in the San Joaquin basin relied extensively on the approach used and analyses conducted by the CVRWQCB for development of the Vernalis Salt TMDL.

Geographic Scope

The geographic scope of this analysis encompassed the entire San Joaquin River drainage, defined to include the San Joaquin River's eastside watersheds from the terminal dams to the mainstem San Joaquin River, the watersheds of west-side tributaries to the mainstem San Joaquin River, and the mainstem San Joaquin River to the Sacramento-San Joaquin Delta (Delta) at Vernalis. For the purpose of our analysis, we also adopted the seven sub-regions identified by the CVRWQCB in their development of the Vernalis Salt TMDL (**Figure 3.1.1**).

Data Sources

In addition to the technical reports prepared by the CVRWQCB for the development of the Vernalis Salt TMDL (CVRWQCB, 2004a), we used information and data from DWR, including online resources (DWR, 2006; IEP, 2006; DWR, 2007) and Unimpaired Flow

[11] Beneficial use impairments of agricultural and municipal water supplies downstream of Vernalis affected are among the major concerns behind the development of the salt and boron TDML for the lower SJR. However, the project scope was limited to data evaluation in the lower San Joaquin River basin from Vernalis upstream to Friant Dam. Therefore, it was not possible to evaluate data and potential indicators for water quality impairments, pressures, and management responses downstream of the Vernalis enforcement point (see Appendix D, Comment 3).

datasets for the 1921-1994 period[12]; the U.S. Bureau of Reclamation San Luis Drainage Feature Re-evaluation Final EIS (USBR, 2006); SFEI (SFEI, 2006a), the USBR Grasslands Bypass Project (USBR, 2005); and the San Joaquin River Water Quality Management Group Summary Recommendations Report (SJRWQMG, 2005).

The CVRWQCB used specific flow and water quality monitoring sites in their development of the Vernalis Salt TMDL, but their analysis included data only for the 1977-1997 period (CVRWQCB, 2004b). For our analyses, we used the data reported by the CVRWQCB for that period (CVRWQCB, 2004b) and also acquired more recent data from DWR (DWR, 2006, 2007) and SFEI Grasslands Bypass Project data files (SFEI, 2006a) for the same sampling sites. Salt loads (tons) were calculated from measured electrical conductivity (EC) values, measured flow values, and the same regionally specific EC:total dissolved solids conversion factors used by the CVRWQCB (CVRWQCB, 2004b). For two of the seven sub-regions (East Valley Floor and Northwest side, see **Figure 3.1.1**) direct data on flows and salt concentrations were not available. Therefore, for the 1998-2005 period for the East Valley Floor, we extrapolated data for annual salt loads from the 1977-1997 period calculated by the CVRWQCB using a regression relating East Valley Floor salt load and Vernalis flow:

East Valley Floor salt load (tons x 1000)
= 24.39+7.73(Vernalis flow, MAF)-0.19(Vernalis Flow, MAF)^2.

We calculated annual salt loads from the Northwest side using the same methods as the CVRQWCB in their analyses (i.e., by subtraction for total salt load at Vernalis):

Northwest side salt load
= Vernalis salt load-[sum salt loads from the other six sub-regions].

Effects of Hydrology

The amounts and timing of flows in the tributary and mainstem rivers in the San Joaquin basin vary substantially within and between years (**Figure 3.1.2**). Because flow (and precipitation-related runoff from lands adjacent to the rivers) affect salt loads and salt concentrations in the San Joaquin River, it was necessary to consider uncontrolled variations in flow in development, testing and evaluation of the indicators. For these first indicator analyses reported here, we accounted for inter-annual variations in flow by categorizing each year by water year type, using the San Joaquin Valley Index (CDEC, "Water Supply"; DWR, 2006).

B. Methodology and Results

Step 1. Application of PSR to Salt in the San Joaquin Basin

The PSR framework was adjusted to more specifically describe the sources, practices, water quality consequences, and potential management responses in the region that relate to

[12]Unimpaired Flow datasets for the 1921-1994 period where directly provided by DWR to The Bay Institute (TBI).

salinity. For example, among the six broad categories of pressures identified in the Framework (see **Figure 2.3**), contamination from air pollution and/or aerial drift ("Air", P3) was not relevant to salt in the region. Only one of the state categories, Water Concentrations (WQ1), was relevant (for both surface and groundwater). However, salt is a persistent contaminant that can accumulate in or be physically exported from the system. Therefore, an additional category of the state component of the model, Change in Basin Salt Content, was added to the conceptual framework.

Next, we reviewed information on salt contamination in the basin, including geographic and hydrologic conditions and factors, and identified quantitative linkages between the pressure and state conditions and qualitative linkages between specific management responses and specific pressures. Results of this review yielded several important conclusions relevant to developing indicators, including:

- The majority of the salt discharged into the San Joaquin River comes from the Northwest side and Grasslands sub-regions, the result of saline soils and irrigation with saline water imported from the Delta (**Figure 2.4**).

- Multiple pressures, including soil and land (P1, e.g., irrigation of saline soils), use of saline imported water or groundwater for irrigation (P2), and direct application of salt to land within the drainage areas (P5) interact and combine to affect the amount of salt discharged into the river (P4), which is most easily measured as load, or tons of salt per unit time (**Figure 2.5**).

- In the basin, most flow derives from the eastside tributaries (**Figure 2.6**) and reduction of flows in eastside tributaries is the most relevant aspect of hydro-regime modification (see **Figure 2.3**).

- Salt concentration in surface waters, the most easily measured state variable, is quantitatively and directly related to salt load (pressure) and (in most areas of the basin) inversely related to flow (pressure) (**Figure 2.7**).

- Specific potential management responses can be expected to affect single or multiple categories of pressures in one or more sub-regions of the basin. For example, a management response that improves the quality (i.e., reduces salt concentration) of water imported to the basin from the Delta could potentially affect the salt loading pressures from soil, water and drainage in the Northwest side and Grasslands sub-regions but is unlikely to affect salt loading from the other sub-regions or hydro-regime modification.

Step 2. Selection of Indicators and Reference Conditions

Ideally, an indicator is a physical, chemical or biological measurement that best represents one or more key elements of a complex system. An effective indicator describes status and trends and can be made to apply over a variety of spatial and temporal scales. For evaluation, the measured value of an indicator is quantitatively compared to some reference condition, a level of the parameter that reflects a desired goal or target, historic conditions and/or pristine conditions, as supported by available science. For selecting and developing the example indicators described in the following sections, we also considered the general indicator selection criteria described in Section 2.

However, because of limited data availability (e.g., groundwater salt concentration) and/or the insufficient development of some datasets for some parameters (e.g., land use practices), only a small subset of the potential indicators were calculated and evaluated. In addition, for this preliminary analysis, the indicators below are explicitly presented as examples, intended to test our approach, the conceptual framework, and the utility of the available data for developing quantitative measures capable of detecting change in the system. They are not intended to be nor should they be interpreted as "recommended" indicators for tracking and evaluating aspects of salt contamination in the San Joaquin basin.

Step 3. Development, Calculation, and Testing of Example Indicators for Salinity: Methodology and Results

Pressure indicators were developed to evaluate salt loading in the basin, hydro-regime modification, salt import to the basin, and salt application in the basin. State, or water quality, indicators were developed to evaluate surface and groundwater salt concentrations, and to assess changes in the overall San Joaquin basin salt content. For salt load, hydro-regime modification and surface water salt concentration, several different versions of the indicators were developed to demonstrate alternative approaches for quantitatively assessing pressure and state conditions. Example management response indicators were developed for source water quality management, drainage reduction, water conservation, and flow management.

All of the example indicators that were calculated using data from long-term datasets (e.g., 1977-2005) and present results using either an annual or monthly time step. For each indicator, the measured value (e.g., annual salt load in tons) was compared to a reference condition based on existing or proposed regulatory objectives and/or historical conditions. All reference conditions based on historical conditions were normalized to account for inter-annual variations in flow using water year type as categorized by the San Joaquin Valley Index (DWR, 2006). In addition to comparison of measured indicator values with a reference condition, indicators can be scored to identify broad categories of condition or response, such "high", "medium", or "low". In this context, we provide an example of a scoring approach for one indicator, Annual Salt Load.

Pressure Indicators

P2. Water – Annual Salt Load

This indicator was designed to answer two broad assessment questions:

- How much salt is delivered into San Joaquin basin surface waters each year?

Salt load to the San Joaquin River was calculated as the sum of the annual salt loads from each of the seven sub-regions in the basin (see **Figure 3.1.3**). The unit of measure for the indicator is tons of salt (x 1000) per year. The reference condition was based on historic salt loads, using the water year type-specific average annual salt loads calculated from the 1977-1994 period, i.e. the same data that were included by the CVRWQCB in their analysis for the the Vernalis Salt TMDL. **Figure 3.1.7** shows the indicator and reference condition. In the top panel, both the indicator and reference condition are shown as the measured values for each year (tons x 1000s of salt per year). For the bottom panel, the measured value of the indicator was subtracted from the reference condition value and presented as the difference from the reference condition (which is shown as a horizontal line at "zero"). For interpretation of the bottom panel graph, for years in which the indicator is negative, the annual salt load to the San Joaquin River was less than the average salt load for that type of water year during the historic reference period. Positive values indicate that the annual salt load was greater than in the past.

This indicator was used to develop an example of a scoring approach for indicator evaluation (**Figure 3.1.8**). For this example, the reference condition was set as the intermediate level, or "medium" pressure, with a range of ± 250,000 tons of salt. Indicator values that were at least 250,000 tons of salt lower than the reference condition were scored as "low" pressure, while indicator values that were at least 250,000 tons of salt higher than the reference value were scored as "high" pressure.

Preliminary evaluation of indicator results: Results of this indicator suggest that there has been no marked decline in the annual salt load to the San Joaquin River since 1995. However, annual values for most of the post-1994 years were below the water year type-specific average for the 1977-1994 reference period and the 1996, 2003 and 2005 values were scored in the "low" pressure category. Large variations in salt loads during the 1977-1994 reference period, even after accounting for variations in water year type, suggest that the ability of this indicator to detect change in the system and/or the resolution of the reference condition may be low.

P2a. Water – Monthly Salt Load

This indicator was designed to answer three broad assessment questions:

- How much salt is delivered into San Joaquin basin surface waters each month?
- Has the salt load changed over time?
- How does the salt load compare to total maximum monthly loads established by in the Vernalis Salt TMDL?

Salt load to the San Joaquin River was calculated as the sum of the monthly salt loads from each of the seven sub-regions in the basin. The unit of measure for the indicator is tons of salt (x 1000) per month. The reference condition was set as the Total Maximum Monthly Loads (TMMLs) established by the CVRWQCB in the Vernalis Salt TMDL (CVRWQCB, 2004b). The Vernalis TMML varies with water year type (as defined by the San Joaquin Valley Index) and, for each water year type, is specified in the Basin Plan for the Salt and Boron TMDL, Appendix 1, Table 4-8, Base Load Allocations (CVRWQCB, 2004b) for each month from January through December. However, the water year calendar is from October-September, and water year type cannot be determined until several months into the water year. Therefore, for assigning the monthly TMML as the monthly reference condition for each year, we used TMMLs for the specified water year type starting in January of the water year and continuing through the first three months of the following water year (i.e., October-December; see **Table 3.1.1**, for example).

Figure 3.1.9 shows the indicator presented as directly measured monthly values (top panel) and as the difference between the measured value and the monthly reference condition (bottom panel). For interpretation of the bottom panel graph, for months in which the indicator is negative, the monthly salt load to the San Joaquin River was less than the TMML and for months in which the indicator is positive, the monthly TMML was exceeded.

Preliminary evaluation of indicator results: Results of this indicator suggests that monthly salt load to the San Joaquin River is highly variable but that there has been no long-term change in salt loading since the late 1970s or since 1997 (effectively the end of the historic reference period used by the CVRWQCB for establishing the TMMLs). However, the indicator suggests that the magnitude of TMML exceedances may be lower during the past five years than during most of the earlier period. This version of a salt load indicator appears to offer greater resolution and, because TMML values are based on historic conditions (1977-1997) and vary with water year type, the indicator should be capable of detecting change over time. The indicator is also potentially useful for evaluating progress towards meeting TMML discharge objectives.

<u>P2b. Water – Imported Salt</u>
This indicator was designed to answer the question:

- How much salt is imported into the San Joaquin Basin with water exported from the Delta?

This indicator was developed but not calculated. The indicators would be calculated as the amount of salt (tons) imported into the Grasslands and Northwest side sub-regions of the San Joaquin basin drainage from the Sacramento-San Joaquin Delta via the Central Valley Project (CVP) and State Water Project (SWP). Imported salt load would be calculated from the salt concentration (measured EC) and volume of water distributed to irrigation districts in the basin at three locations: directly from the Delta-Mendota Canal (DMC) and Checks 13 and 21 further down the DMC and in Mendota Pool. Possible reference conditions would include recent historical imported salt loads, recent historic salt loads corrected for water year type-related variations in volumes and/or salinity of water imported, and/or design loads for imported salt identified by the CVRWQCB (2004b).

Status of indicator development: The data necessary to calculate this indicator exist however, for some years, EC and volume measurements for irrigation water delivered via Mendota Pool contained errors.

<u>P5. Salt Application</u>
This indicator was designed to answer two broad assessment questions:

- How much salt is applied to San Joaquin Basin lands?

This indicator was developed but not calculated. This indicator would be calculated as the amount of salt (tons) applied to lands within each of the San Joaquin basin sub-regions. Applied salts include salt contained in fertilizers, food processing wastes, sewage treatment facilities (e.g., wastewater treatment ponds), and other materials that contain salt that are applied to lands within the drainage areas. Possible reference conditions would include recent historical salt application amounts or a target salt application amount.

Status of indicator development: The data necessary to calculate this indicator are insufficiently developed and, where they exist, dispersed among multiple entities within the San Joaquin basin.

P6. Hydro-regime Modification (1)

This indicator was designed to answer two broad assessment questions:

- How much have San Joaquin River flows been modified?

Hydro-regime modification was calculated as flow (acre-feet [AF] per month) at Vernalis expressed as the percent of estimated unimpaired outflow from the San Joaquin basin. Unimpaired outflow was calculated from DWR's unimpaired flow dataset (available for the 1921-1994 period, see Footnote 1) and full-natural flow (FNF) data available from CDEC for the 1995-2005 period (DWR, 2006). The DWR total SJ Basin outflow dataset incorporates accretions from minor San Joaquin River tributaries, precipitation, and land-use based flow depletion upstream of Vernalis. The CDEC FNF flow summed for the four main San Joaquin River tributaries (Stanislaus, Tuolumne, Merced, and San Joaquin Rivers) does not and therefore underestimates total unimpaired outflow from the San Joaquin Basin in wet years and overestimates it in dry years. To correct the summed unimpaired flows from the four rivers for the 1995-2005 period, the following equation was used to convert the summed four rivers unimpaired data to total San Joaquin Basin unimpaired outflow:

Total SJ Basin Unimpaired Outflow (AF/month)
= -4755 + (1.124 x [4 river unimpaired, AF/month])[13].

Percent of unimpaired flow was calculated for each month as:

% of unimpaired flow
= (Vernalis flow, AF/Total SJ Basin Unimpaired Outflow, AF) x 100[14].

[13] To calculate total unimpaired San Joaquin basin outflow for the 1995-2005 period (the Central Valley unimpaired streamflow dataset had not been updated past 1994 at that time), a regression equation was developed to predict total SJ basin outflow from the sum of the unimpaired annual flows from the San Joaquin basin major tributaries (Stanislaus River, Tuolumne River, Merced River, and San Joaquin River at Friant) using full natural flow data available on CDEC (http://cdec.water.ca.gov/cgi-progs/previous/FNFSUM).

[14] The 4-river estimate in the previous equation overestimates total unimpaired San Joaquin River basin outflow in dry years and underestimates it in wetter years. For estimating the percent of the unimpaired flow that actually flowed down the river, the second equation was used, which divides actual flow (as total annual flow measured at Vernalis - from dayflow) by the total unimpaired flow value (from the estimate described above).

Average percent of unimpaired flow for each year was calculated as the average of the monthly percent of unimpaired flows. The reference condition was based on historic hydro-regime modification, using water year type-specific average percent of unimpaired flows calculated for the 1950-1994 period.

Figure 3.1.10 shows the indicator and reference condition. In the top panel, both the indicator and reference condition are shown as the measured values for each year. The bottom panel shows the indicator as the difference from the reference condition value. For interpretation of the bottom panel graph, for years in which the indicator is negative, the modification of the hydro-regime was greater than the average modification for that water year type during the historic reference period. In these years, San Joaquin River flow at Vernalis was lower than the reference condition. Positive values indicate that Vernalis flows were less altered and, as the percent of estimated unimpaired flows, higher than the reference condition.

Preliminary evaluation of indicator results: Results of this indicator suggests that the degree to which the annual hydro-regime in the San Joaquin basin is modified by in-basin diversions is highly variable but that, since 1994, it is not markedly different than in early years. However, in seven of the11 years since 1994, hydro-regime modification has been greater than in the past (i.e., negative indicator value). Despite the annual time-step, this indicator does appear to be a reasonable approach for quantifying the hydro-regime modification "pressure" in the basin and capable of detecting change in the system: several multi-year trends associated with multi-year droughts (e.g., the 1987-1992 drought) and wet periods (e.g., the late 1990s) are clearly evident in the indicator results.

P6. Hydro-regime Modification (2)

This indicator was designed to answer three broad assessment questions:

- How much have San Joaquin River flows been modified?
- Has the magnitude of flow alteration changed over time?
- How do San Joaquin River flows compare to design flows identified in the Vernalis Salt TMDL?

For this alternative indicator of hydro-regime modification, the indicator was calculated as monthly flows in the San Joaquin River at Vernalis (thousand acre-feet, TAF) and compared to a reference condition based on the monthly "design flows" identified by the CVRWQCB in the Vernalis Salt TMDL (**Figure 3.1.11**). For the reference condition, monthly design flows for each water year type were assigned using the same methods as for the salt TMMLs (see Monthly Salt Load Indicator, above) For interpretation of the bottom panel graph, for months in which the indicator is negative, the flow at Vernalis was less than the design flow and the objective was not met. Positive values indicate months in which the Vernalis flow was greater than the design flow.

Preliminary evaluation of indicator results: Results of this indicator show that Vernalis flows were almost always greater than the design flows identified by the CVRWQC and have been so for most of the indicator's 38-year record. This version of a hydro-regime modification indicator offers greater resolution by use of the monthly time step but may provide less information on actual flows and, by use of the design flow reference condition, the degree to which those flows have been altered. However, the indicator should be capable of detecting change over time and be potentially useful for evaluating progress towards meeting Vernalis Salt TMDL design flow objectives.

State Indicators

WQ 1a. Water Salt Concentrations – Surface Water
This indicator was designed to answer three broad assessment questions:

- What is the salt concentration in the San Joaquin River?

Surface water salt concentration was calculated as average monthly EC (us/cm) measured at Vernalis. The reference condition was set at the seasonal Vernalis EC objectives established by the SWRCB (1995), 700 us/cm during the April-August period and 1000 us/cm during the September-March period. **Figure 3.1.12** shows the indicator and reference condition. In the top panel, both the indicator and reference condition are shown as the measured values for each year. In the bottom panel, the measured value of the indicator is presented as the difference from the reference condition. For interpretation of the bottom panel graph, for months in which the indicator is negative, measured monthly EC was less than the Vernalis EC objective. Positive values indicate that surface water salt concentration levels exceeded the Vernalis EC objective.

Preliminary evaluation of indicator results: Results of this indicator show several multi-year trends in EC that correspond to basin-wide hydrological conditions (e.g., the 1987-1992 drought, the wet period during the 1990s). The indicator also shows that, since 1995, the Vernalis EC objective has not been exceeded in any month. This indicator appears to offer sufficient resolution to monitor compliance and track changes in average monthly EC on annual and multi-year bases.

WQ 1b. Water Salt Concentrations – Groundwater
This indicator was designed to answer two broad assessment questions:

- What is the salt concentration in San Joaquin Basin groundwater?
- Has the salt concentration changed over time?

This indicator was preliminarily developed but not calculated. For this indicator, groundwater salt concentration from wells distributed throughout the San Joaquin basin would be measured as EC. However, locations of sample wells and the frequency of testing necessary to provide sufficient data to reliably assess overall groundwater salt concentrations and track changes over time are not known. Possible reference conditions would include recent historical groundwater salt concentrations or target EC levels based on agricultural or drinking water quality objectives.

Status of indicator development: The data necessary to calculate this indicator are insufficiently developed and, where they exist, dispersed among multiple entities within the San Joaquin basin. We recommend that a useful first step would be to compile data and calculate the indicator for a single sub-region.

WQ 5. Change in San Joaquin Basin Salt Content
This indicator was designed to answer two broad assessment questions:

- Has the overall San Joaquin Basin salt content increased or decreased?
- Have trends in changes in Basin salt content changed over time?

This indicator was developed but not calculated. The indicator would be calculated as:

Change in Basin Salt Content
= [Salt Import (tons) + Salt Application (tons)
+ Net change in Groundwater salt content (tons)
+ Evapo-concentration of salt from in-basin diversions]
– Salt Export (tons)

Salt Import and Salt Application would be calculated as the indicators described above. Groundwater salt content would be calculated from groundwater salt concentration and estimated groundwater volume. Evapo-concentration of salt from in-basin diversions would be calculated from the EC and volume of waters diverted from in-basin tributaries for local irrigation. Salt export would be calculated from flow (volume) and EC at Vernalis.

Status of indicator development: The data necessary to calculate this indicator and its multiple components are incomplete and insufficiently developed. We recommend that a useful first step would be to correct errors in the data necessary to calculate salt import levels, calculate salt export, and to preliminarily calculate the difference between the two.

An indicator of basin salt content would be essential for management, since there is concern that the current approach to regulating salinity may result in reduced irrigation return water return flows and increased migration of salt to groundwater, thus increasing the overall salt basin content over time[15] (Lee and Jones-Lee, 2007)

Response Indicators

MR3.1: Water Use Management – Source Water Quality Management
This indicator was designed to answer two broad assessment questions

- What is the salt concentration of water imported to the San Joaquin Basin from the Delta?

Source water quality was calculated as average salt concentration (EC) of water exported for the Sacramento-San Joaquin Delta by the CVP measured at the headworks of the Delta-Mendota Canal during the June-September period of each year. The reference condition was based on historic salt concentrations, using the water year type-specific average salt

[15] See Appendix D, Comment 3

concentrations calculated from the 1978-1994 period (1977, an extremely dry year in which the salt concentration of exported water was very high, was excluded from the reference period for this indicator). **Figure 3.1.13** shows the indicator and reference condition. In the top panel, both the indicator and reference condition are shown as the measured values for each year (average June-September EC). The bottom panel shows the indicator as the difference between the measured EC value and the reference condition EC value. For interpretation of the bottom panel graph, for years in which the indicator is negative, the average salt concentration of exported water was lower (i.e., better water quality) than the average levels measured in that water year type during the reference period. Positive values indicate that the salt concentration was higher than in the past.

Preliminary evaluation of indicator results: Results of this indicator suggests that the quality of water exported from the Delta by the CVP has improved since the mid-1990s[16]. In every year since 1995, salt concentrations of exported water were lower than water-year type-corrected average levels measured in the past and, during the last three years, were the lowest for the entire 38-year record for the indicator. The indicator appears to provide sufficient resolution and be capable of detecting change in the system. However, by itself, the indicator does not provide information on the specific management actions (e.g., reduced salt concentrations in the south Delta, reduced salt concentration of San Joaquin River inflows to the Delta, operations of in-Delta agricultural barriers, etc.) that may have been implemented and/or may be driving the observed improvement in export water quality.

MR3.2: Water Use Management – Drainage Reduction

This indicator was designed to answer two broad assessment questions

- What is volume of agricultural drainage water discharged into the San Joaquin River?
- Has the volume of agricultural drainage water changed over time?

Drainage reduction was measured only for the Grasslands sub-region as volume of water (flow, TAF) discharged into Mud and Salt Sloughs during the June-September period of each year. The June-September period was selected because it is the peak irrigation (and drainage) season and to reduce the effects of non-agricultural drainage flows from precipitation-related runoff. The reference condition was based on historic drainage volumes, using the water year type-specific average volumes calculated from the 1978-1994 period (1977, an extremely dry year with very little irrigation and therefore very low drainage discharges, was excluded from the reference period for this indicator). **Figure 5.1.14** shows the indicator and reference condition. In the top panel, both the indicator and reference condition are shown as the measured values for each year (average June-September flow, TAF). The bottom panel shows the indicator as the difference between the measured flows and the reference condition. For interpretation of the bottom panel graph, for years in which the indicator is negative, the average drainage volume was lower than the average levels measured in that water year type during the reference period. Positive values indicate that the drainage volumes were higher than in the past.

[16] Based on the data presented here, no inferences can be made regarding the impacts of long-term variability in hydrology (flow) or climate on water quality at the CVP (see Appendix D, Comment 1). Possible effects of long-term fluctuations in climate and flow will need to be considered when evaluating the implications of this indicator for source water management, such as increasing recycling of water within the basin.

Preliminary evaluation of indicator results: Results of this indicator suggests that flows in Mud and Slat Slough have been highly variable and there has been no marked decline in the drainage discharge volumes since 1995 (although volumes in the most recent five year have been lower than the reference condition). The large variations in discharge volumes during the 1978-1994 reference period, even after accounting for variations in water year type, suggest that the ability of this indicator to detect change in the system and/or the resolution of the reference condition may be low. By itself, the indicator does not provide information on the specific management actions (e.g., drainage re-use and recycling) nor does it explicitly relate drainage volume to salt load (i.e., the "pressure"). However, for Mud and Salt Sloughs, there is a clear quantitative linkage between flow and salt load (**Figure 5.1.15**), supporting the validity of drainage reduction as a potentially effective management response for reducing the salt load pressure.

MR3.3. Water Use Management – Water Conservation

This indicator was designed to answer two broad assessment questions

- How efficiently is agricultural irrigation water used?
- Has water use efficiency changed over time?

This indicator was developed but not calculated. The indicator would be calculated for the Grasslands sub-region as the difference between volume (TAF) of water used by irrigators in the sub-region and the volume of water discharged into Mud and Salt Sloughs (TAF) for the June-September period of each year, expressed as the percent of volume used. Total volume of water used by irrigators would be calculated as the sum of water delivered by the CVP and SWP (using the same data and methods as for the Salt Import indicator, see P2b. Water – Imported Salt) and the volume of water pumped from groundwater wells. Volume of water discharged into Mud and Salt Sloughs has already been calculated as the Drainage Reduction indicator (above). The reference condition would be based on historic drainage volumes as percent of water used, using the water year type-specific averages calculated from the 1978-1994 period, as for the Drainage Reduction indicator above.

Status of indicator development: Some of the data necessary to calculate this indicator exist (e.g., discharge volume, delivery volume) but other needed data are not available or insufficiently developed (e.g., groundwater pumping volumes). We recommend that a useful first step would be to intially calculate this indicator using CVP delivery volumes and Mud + Salt slough discharge volumes (i.e., excluding consideration of groundwater volumes used to irrigate lands in the sub-region).

MR5. Flow Management

This indicator was designed to answer two broad assessment questions

- How much have tributary contributions to total San Joaquin River flows been increased?
- Have tributary contributions to San Joaquin River flow changed over time?

In this example, flow management was calculated as Stanislaus River flow (acre-feet [AF] per month) expressed as the percent of total San Joaquin River flow measured at Vernalis and calculated as the average for the June-August period. The reference condition was based on historic Stanislaus River flows (as percent of total San Joaquin River flow), using the water year type-specific averages calculated from the 1981-1994 period. The 1981 start date for the reference period was based on the completion of the New Melones Dam on the Stanislaus River. **Figure 5.1.16** shows the indicator and reference condition. In the top panel, both the indicator and reference condition are shown as the measured values for each year (percent of total San Joaquin River flow). The bottom panel shows the indicator as the difference between the measured flow contribution and the reference condition. For interpretation of the bottom panel graph, for years in which the indicator is negative, the percent contribution of the Stanislaus River to total San Joaquin River flow was lower than the average level measured in that water year type during the reference period. Positive values indicate that the Stanislaus River flows as percent of Vernalis flows were higher than in the past.

Preliminary evaluation of indicator results: Results of this indicator suggest that the relative contribution of the Stanislaus River to total San Joaquin River flows has been variable and that there are no detectable trends associated with either time or hydrology. Since 1995, flows on the Stanislaus River have been managed to assist with compliance with salinity objectives for San Joaquin River water at Vernalis established by the State Water Resources Control Board (SWRCB, 1995). This indicator of flow management, which uses a multi-month period and an annual time step, does not appear to be able to detect effects of those actions, probably because the specific management actions were small and short duration and/or because other changes in flow operations in the San Joaquin basin were occurring at other times of the year.

Step 4. Multi-metric Approach for Assessing Salinity Pressure and State Indicators

This section describes an alternative approach for assessing salt load and hydro-regime modification (or flow) pressures and the resultant water quality state using a multi-metric indicator. The indicator's component metrics were designed to answer three broad assessment questions:

- How frequently are regulatory objectives for Load, Flow, and Salt Concentration exceeded?
- For each, what is the magnitude of the exceedance?
- Have the frequencies and magnitudes of exceedances changed over time?

For each component parameter (load, flow, salt concentration) in each year, the indicator measures the number of months per year that the objectives for that parameter were exceeded (i.e., frequency) and, for those months in which the objective was exceeded, the average amount by which it was exceeded (i.e., magnitude of exceedance). Measurements were made at Vernalis. For load, the monthly objectives were the Vernalis TMMLs. Monthly flows were compared to the Vernalis Salt TMDL design flows. Monthly average salt concentrations were compared to the Vernalis EC objectives. **Figure 3.1.17** shows the paired graphs for each of the three component parameters. For all three parameters, positive values on the frequency graph panels indicate the number of months per year that the objectives were exceeded. For the salt load magnitude graph, positive values indicate the average amount (tons) by which the TMML objective was exceeded. For the flow magnitude graph, negative values indicate the average amount (TAF) by which Vernalis flows were below the design flow objective. For the EC magnitude graph, positive values indicate the average amount by which EC exceeded the Vernalis EC objectives.

Preliminary evaluation of indicator results: This indicator was evaluated by comparing the 1987-1994 period to the 1995-2005 period. Prior to 1995, salt load, flow levels and Vernalis EC regularly exceeded the regulatory objective-based reference conditions. In contrast, beginning in 1995, salt load and design flow objectives were still periodically exceeded but Vernalis EC objectives were consistently met. This multi-metric indicator, by integrating results from key pressure and state variables, capitalizes on the demonstrated quantitative linkage between salt load, flow, and resultant surface water salt concentration. It is capable of detecting and demonstrating a change in the system. In addition, for the purposes of identifying and testing potential management response indicators, this multi-metric indicator offers insights into which management response avenues to explore (e.g., management actions that affect salt loading v flow management actions) as well as likely time frames during which changes in management might be detected. Also, it was the preliminary evaluation of these multi-metric indicator results that was the basis for setting the historic reference period used in many of the other indicators as the pre-1995 period.

C. Conclusions

The indicators developed for salt in the San Joaquin basin varied in their sensitivity and resolution. For example, some management responses known to have been at least partially implemented were not detected by the example indicators developed to assess the action. In addition, use of the basin scale in a system in which both the types and magnitudes of pressures (and, as follows, relevant management response") vary geographically added complexity and made assembling basin-wide data difficult. However, even these coarse and preliminary results appear to demonstrate the applicability of the PSR framework we developed for identifying, selecting and developing relevant indicators that relate contaminant pressures, water quality conditions, and management responses.

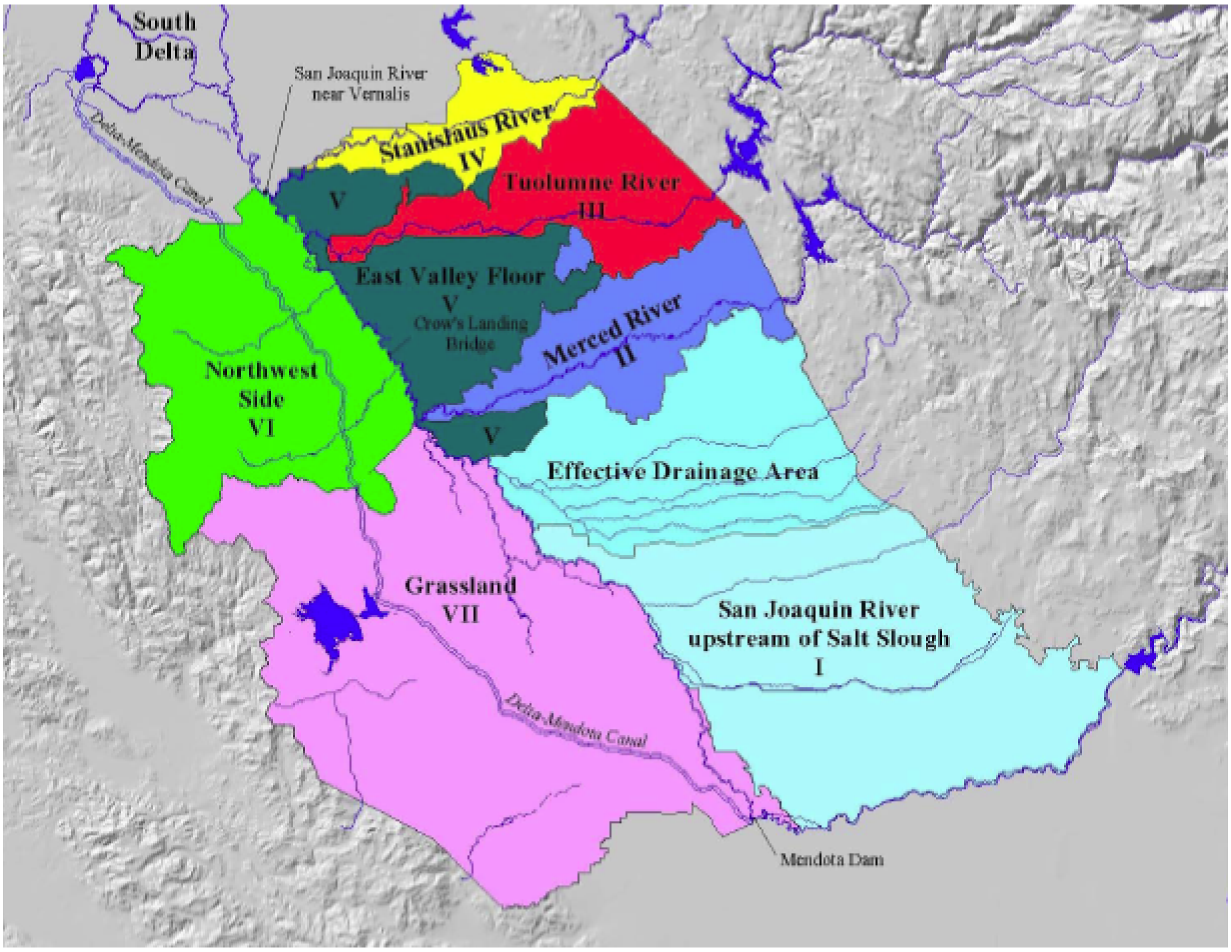


Figure 3.1.1. The seven sub-regions identified by the CVRWQCB in their development of the Vernalis Salt TMDL (from (CVRWQCB, 2004b; Figure 3-4).

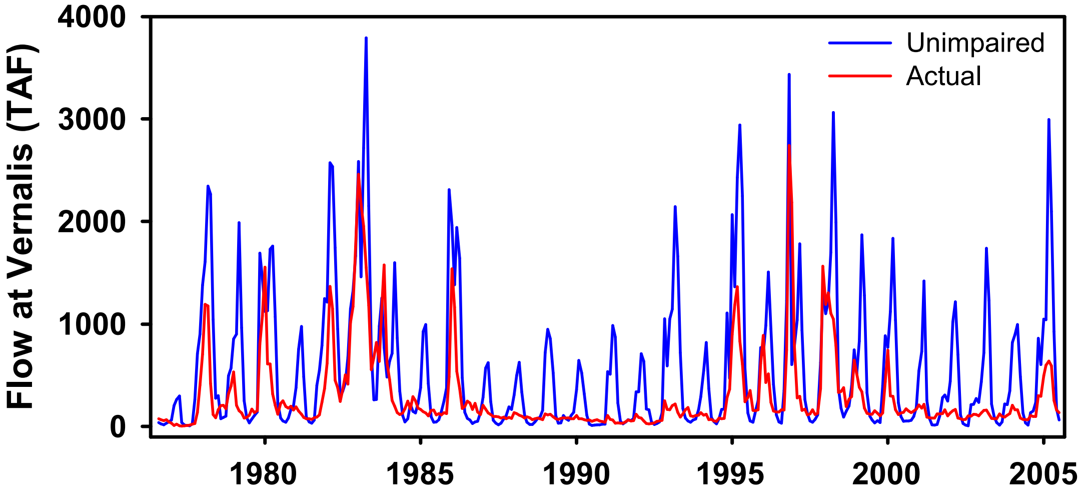


Figure 3.1.2. Comparison of actual flow in the San Joaquin River at Vernalis to estimated unimpaired outflow from the San Joaquin basin. The amounts and timing of flows in the tributary and mainstem rivers in the San Joaquin basin vary substantially within and between years. Data source: DWR (CDEC, Dayflow, and unimpaired flow datasets)(DWR, 2006; IEP, 2006; DWR, 2007).

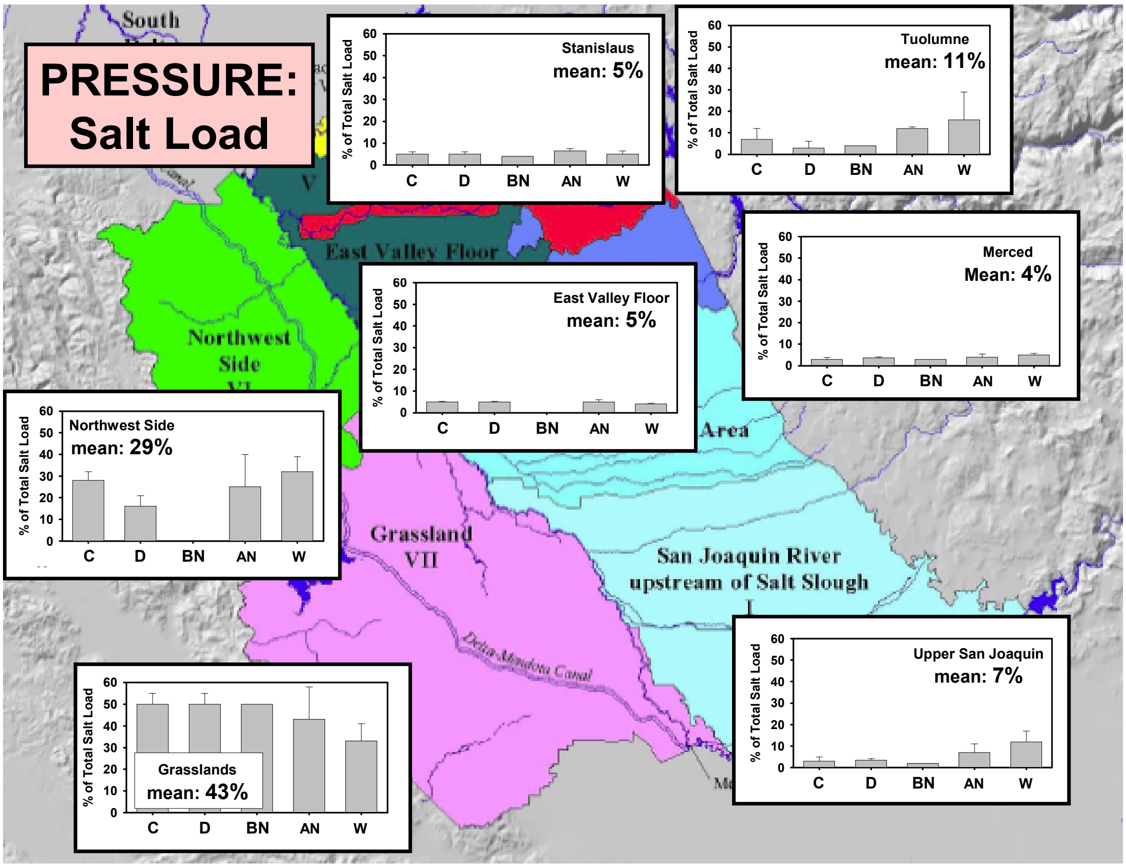


Figure 3.1.3. Average percent contribution to the total salt load from each of the seven San Joaquin basin sub-regions for each water year type: C = critical, D = dry, BN = below normal, AN = above normal, w = wet. The majority of the salt discharged into the San Joaquin River comes from the Northwest side and Grasslands sub-regions, the result of saline soils and irrigation with saline water imported from the Delta .

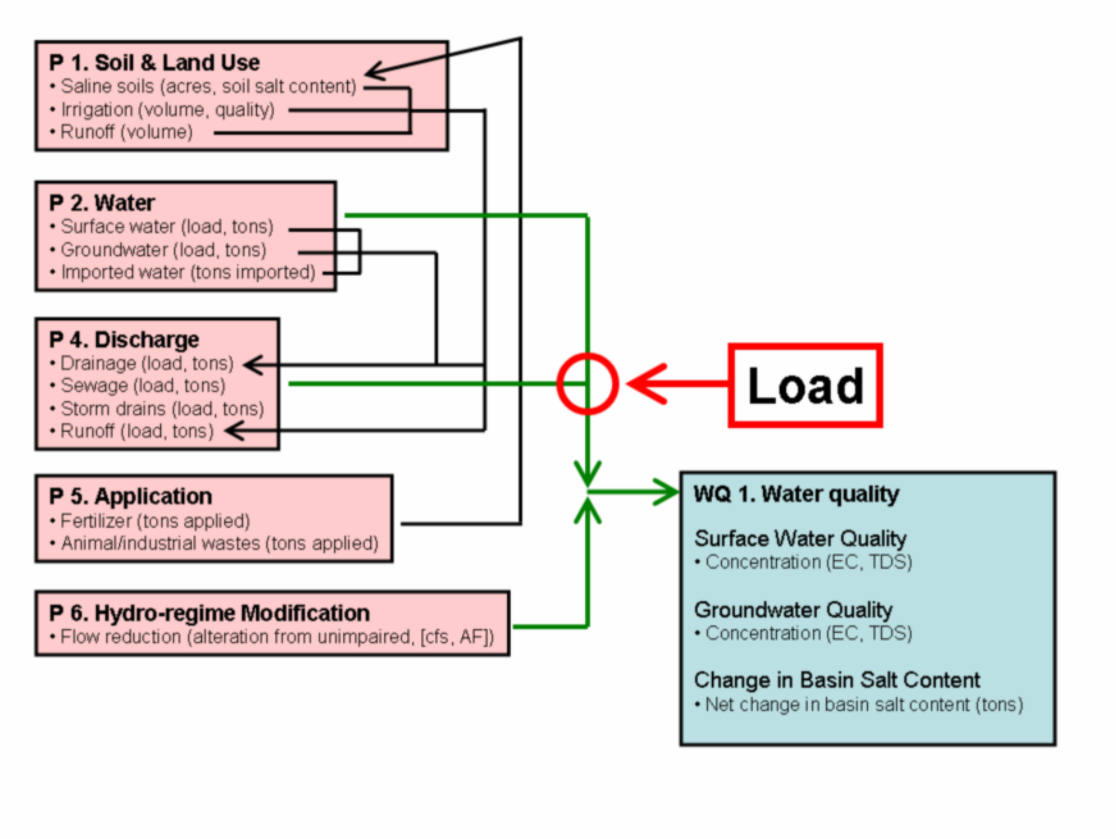


Figure 3.1.4. Expanded conceptual model to describe the relationships among and between of salt contamination pressures and water quality state. The model shows that multiple pressures, including soil and land (P1, e.g., irrigation of saline soils), use of saline imported water or groundwater for irrigation (P2), and direct application of salt to land within the drainage areas (P5) interact and combine to affect the amount of salt discharged into the river (P4), which is most easily measured as load.

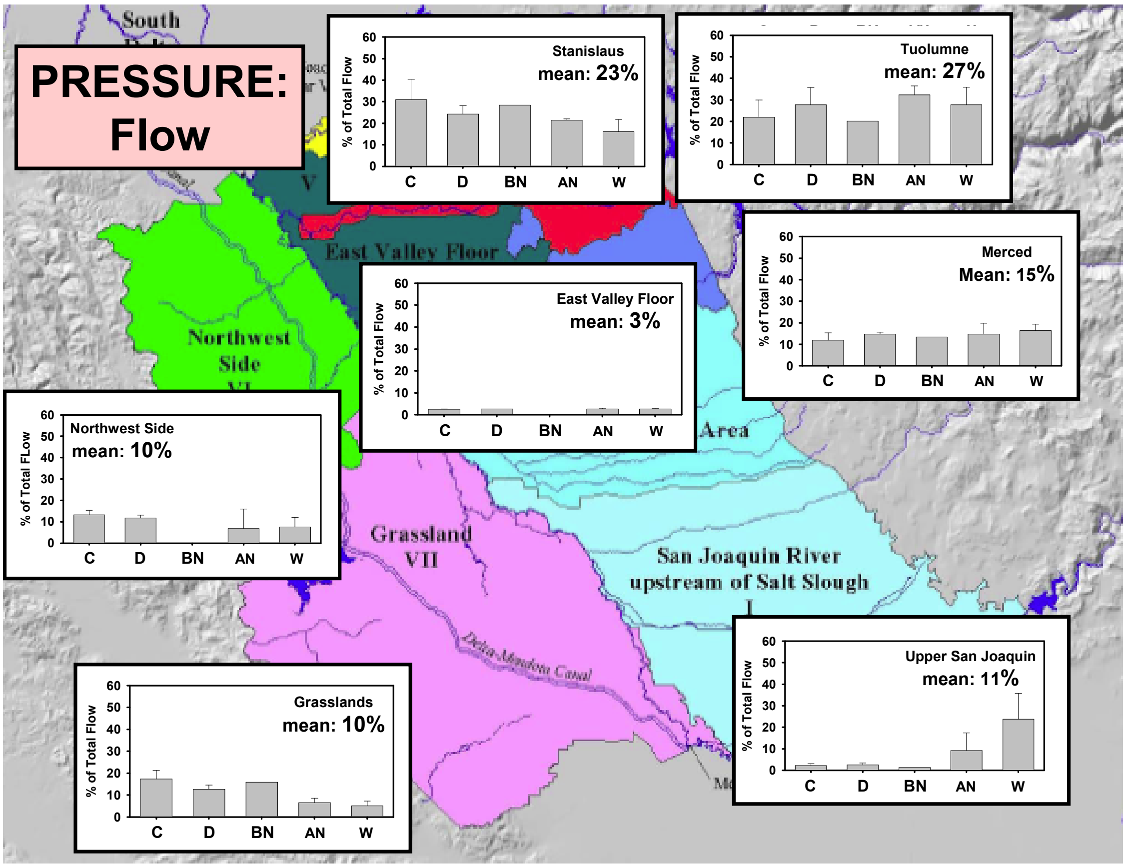


Figure 3.1.5. Average percent contribution to the total flow of the San Joaquin River (at Vernalis) from each of the seven San Joaquin basin sub-regions for each water year type. Most flow in the basin derives from the eastside tributaries.

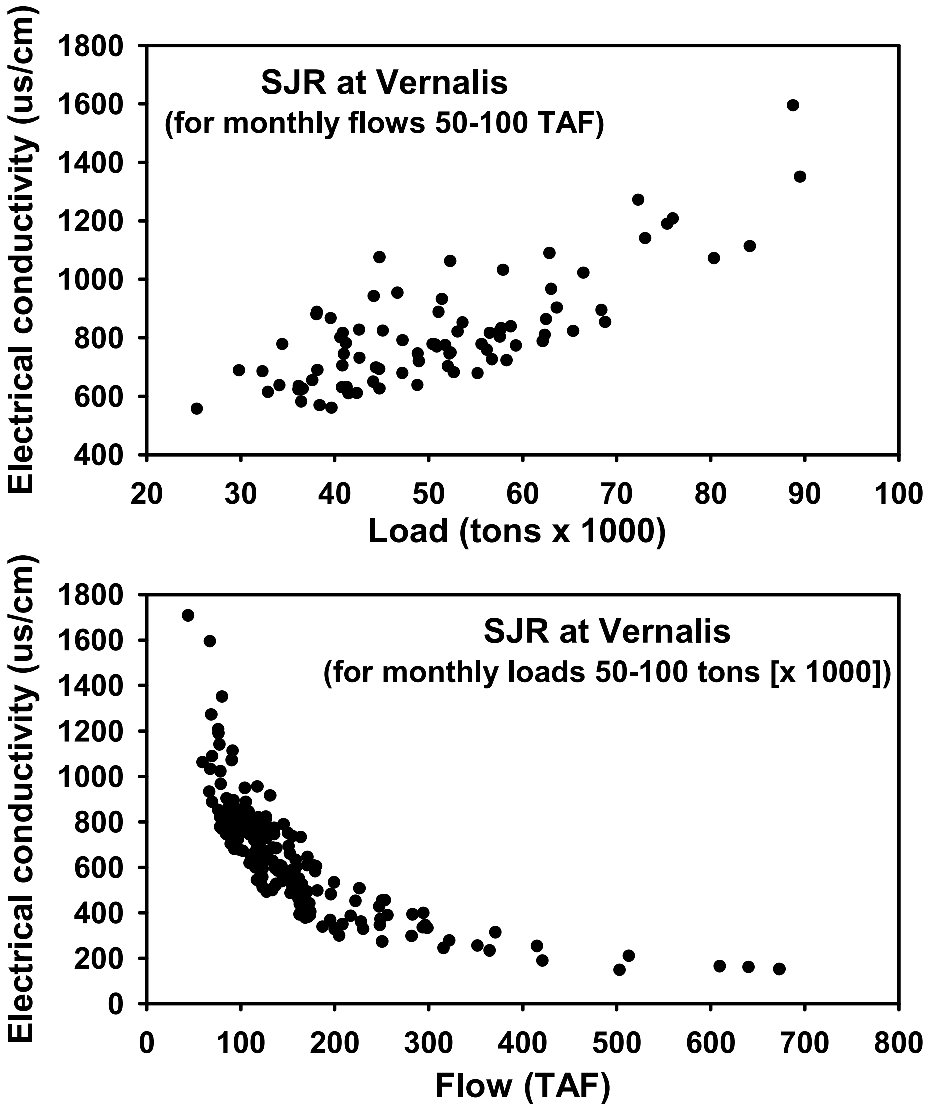


Figure 3.1.6. Relationship between salt concentration (EC) and salt load (tons) (top panel) and between salt concentration and flow (TAF) (bottom panel) at Vernalis. At relatively constant flows, EC increase with increases in salt load. At relatively constant loads, EC decreases with increases in flow.

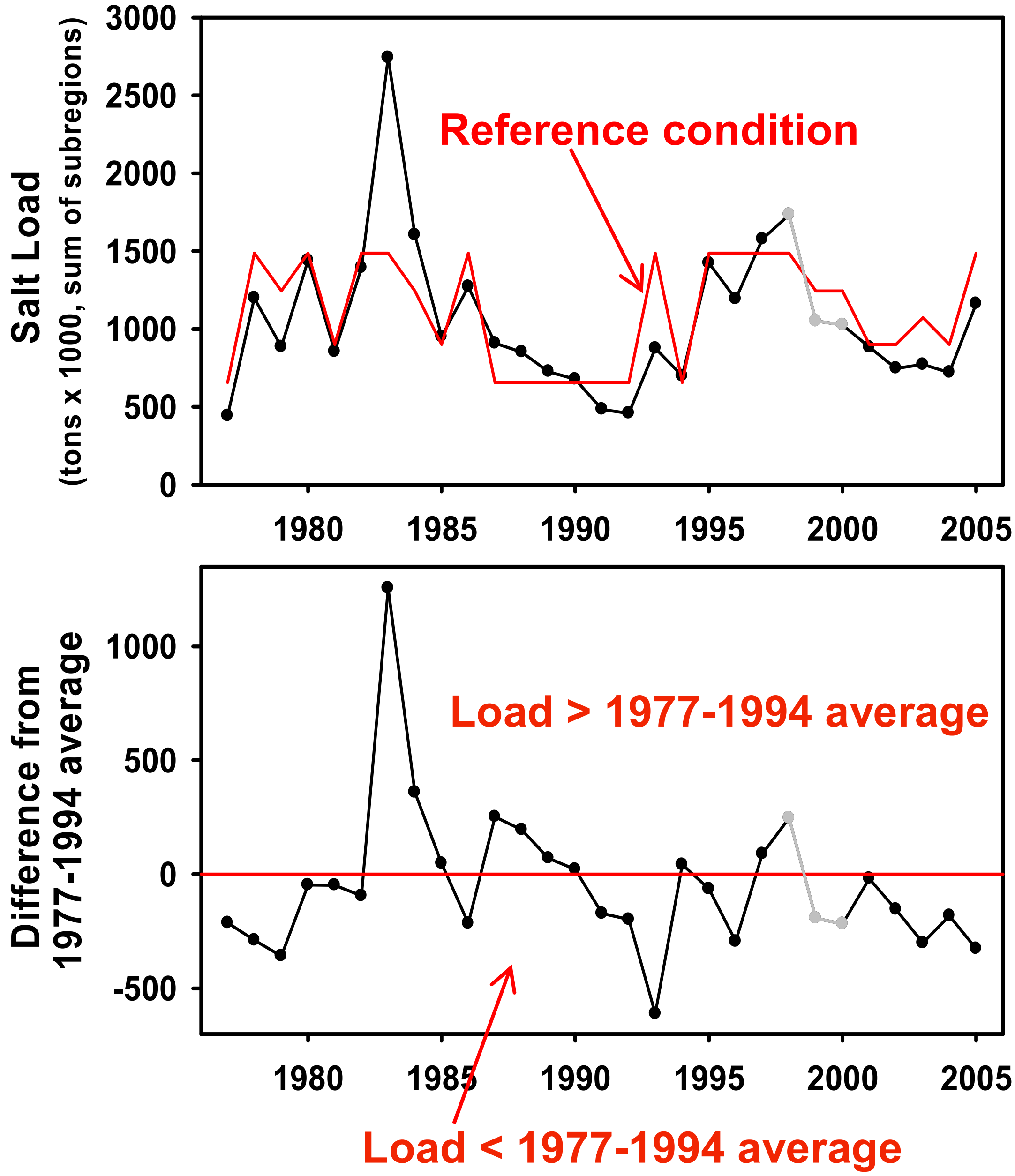


Figure 3.1.7. Annual salt load indicator. Top panel shows the measured values for annual salt load at Vernalis (-●-) and the reference condition (—). Bottom panel shows the salt load expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.

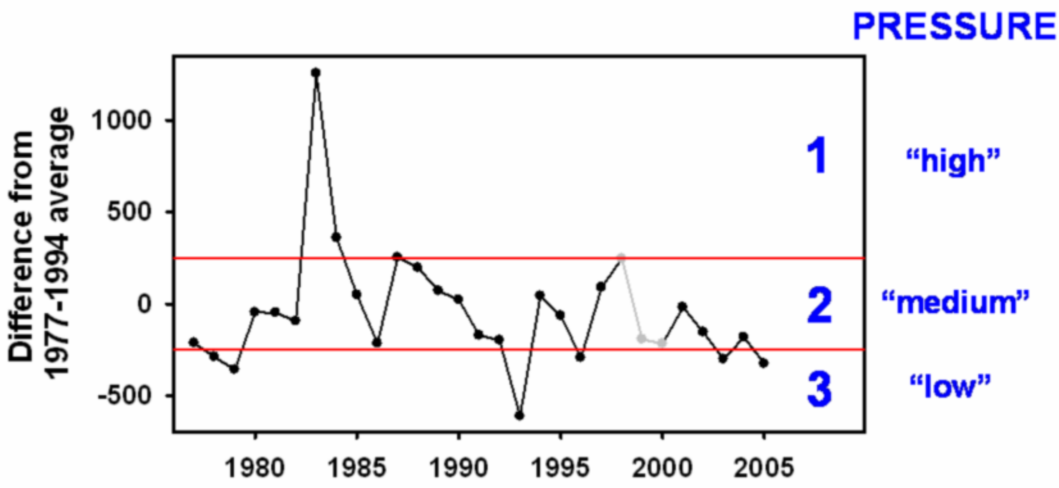


Figure 3.1.8. Annual salt load indicator (as shown in **Figure 5a.7**, bottom panel) evaluated using a three-point scoring system. See text for further explanation.

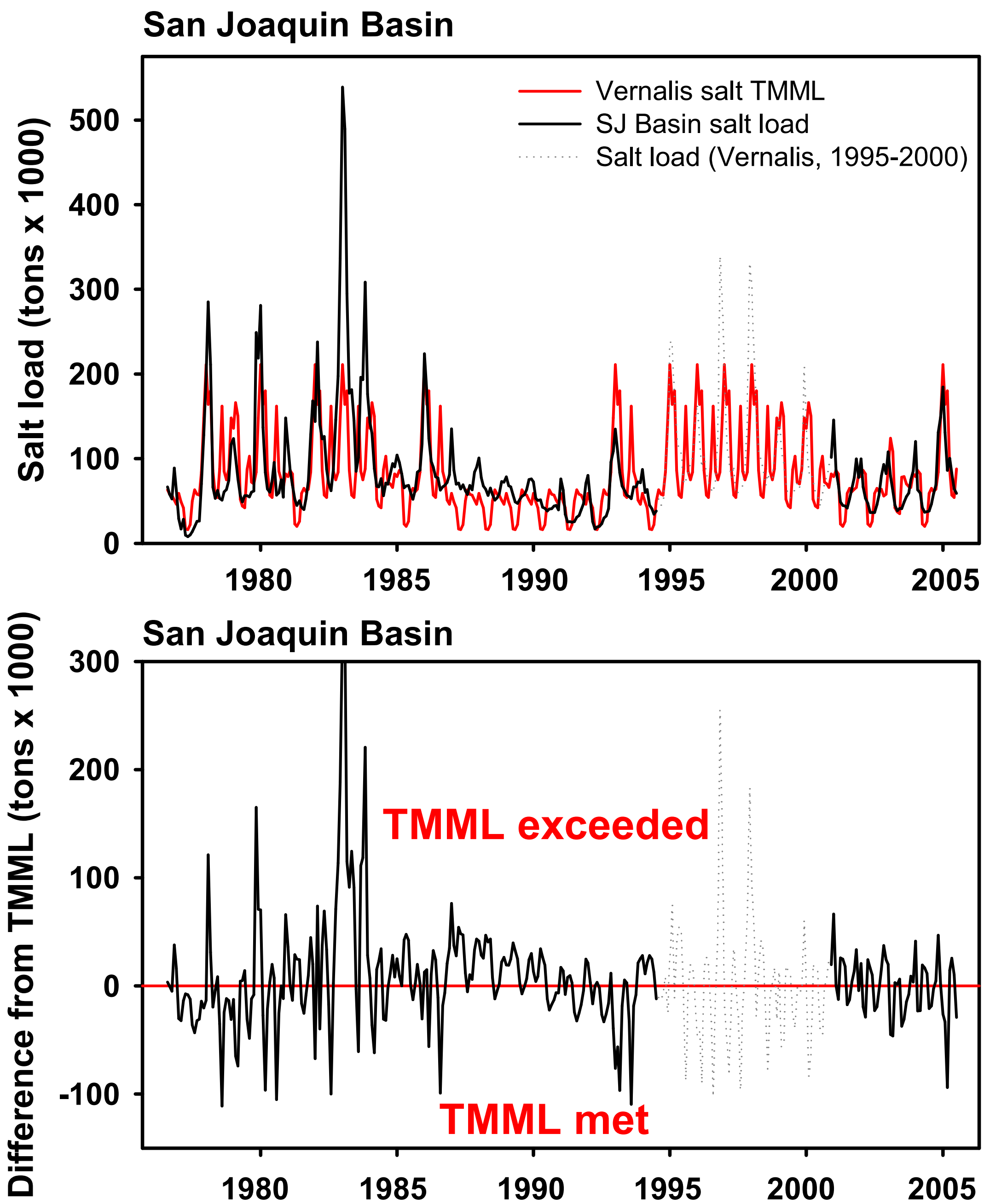


Figure 3.1.9. Monthly salt load indicator. Top panel shows the measured values for monthly salt load at Vernalis (-●-) and the reference condition (—). Bottom panel shows the salt load expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.

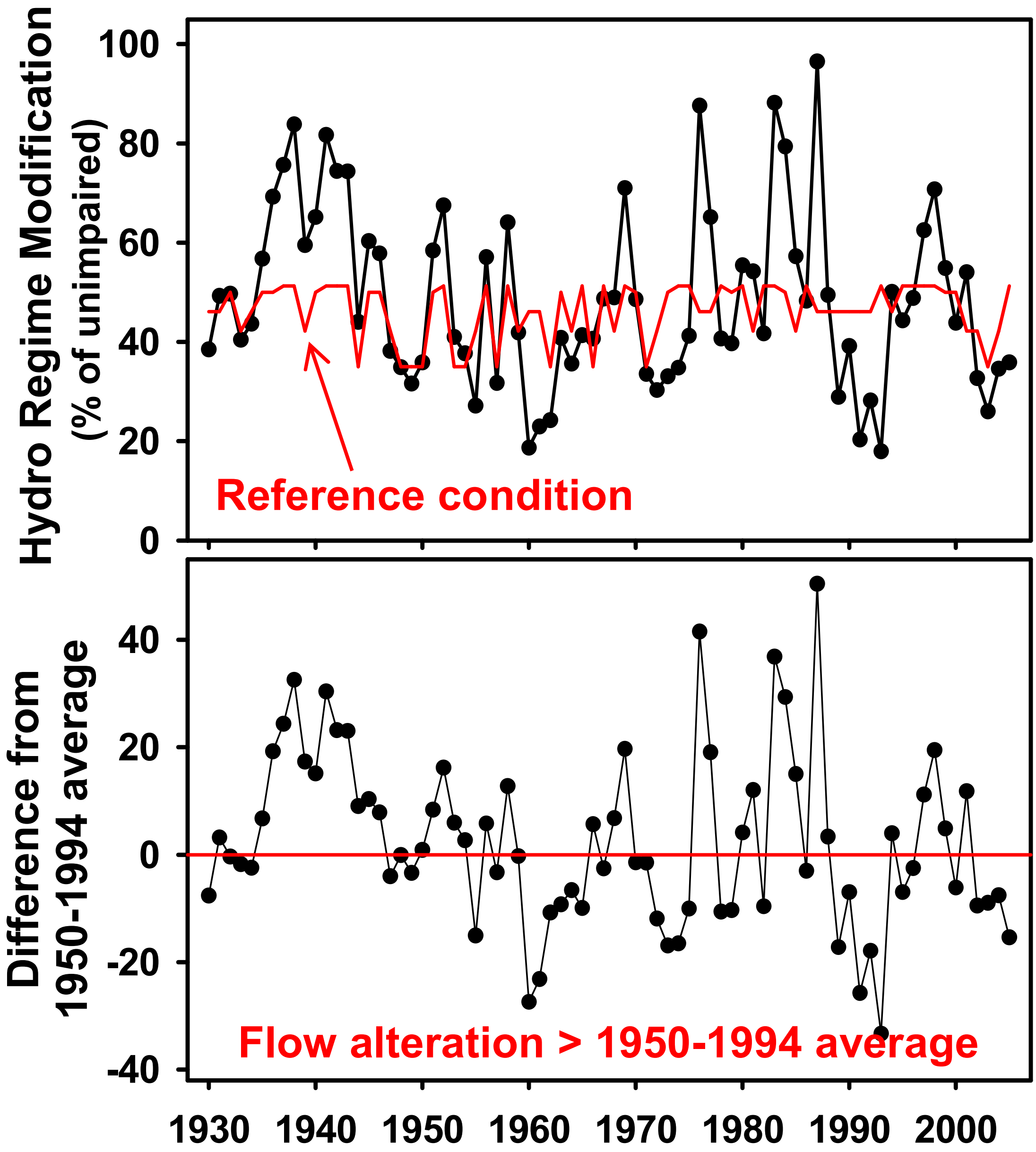


Figure 3.1.10. Hydro-regime Modification Indicator (1). Top panel shows the measured values for total annual flow at Vernalis expressed as the percent of estimated unimpaired total San Joaquin basin outflow (-●-) and the reference condition (—). Bottom panel shows the percent of estimated unimpaired flows expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.

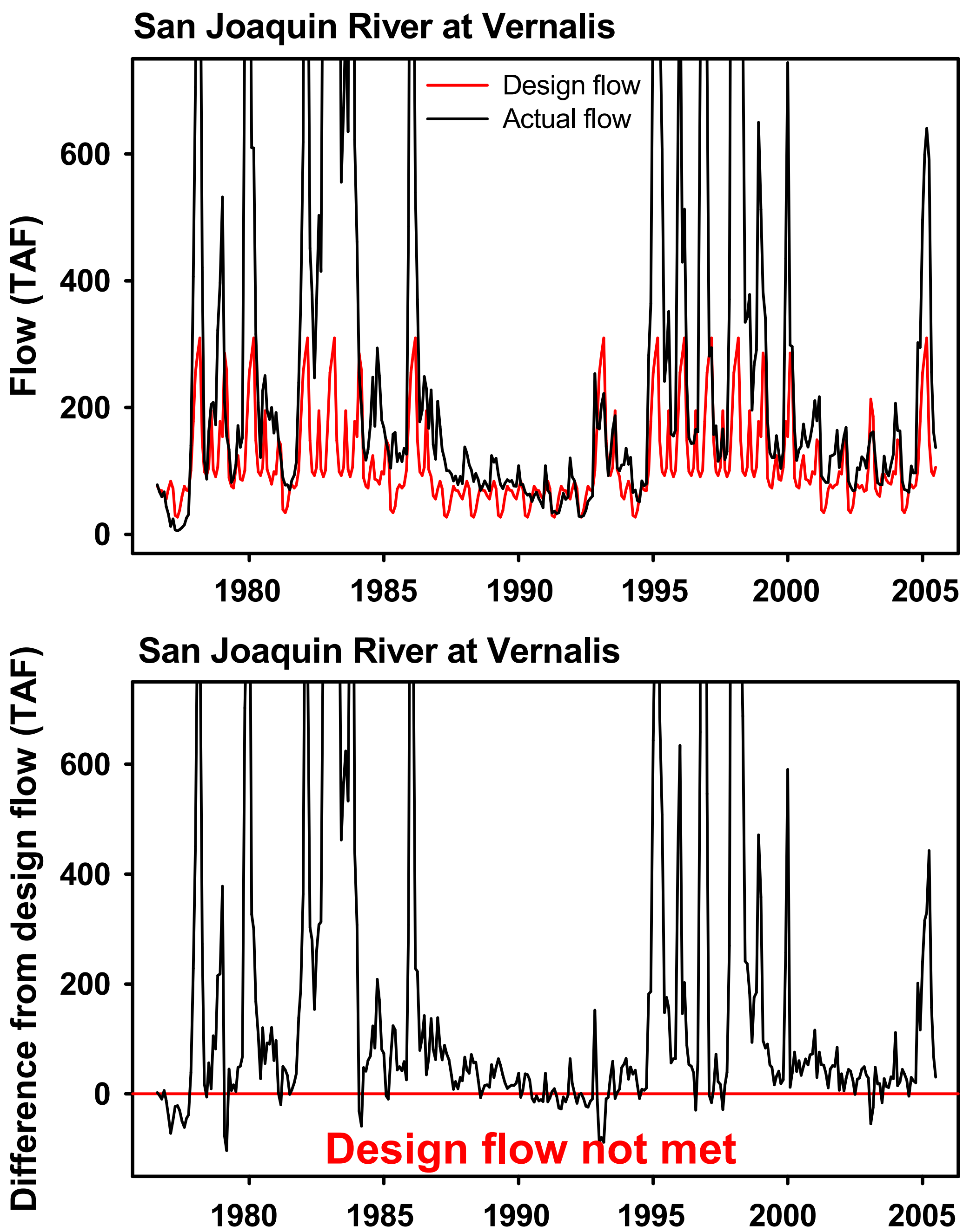


Figure 3.1.11. Hydro-regime Modification Indicator (2). Top panel shows the measured values for monthly flow at Vernalis (-●-) and the reference condition (—). Bottom panel shows the monthly flow expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.

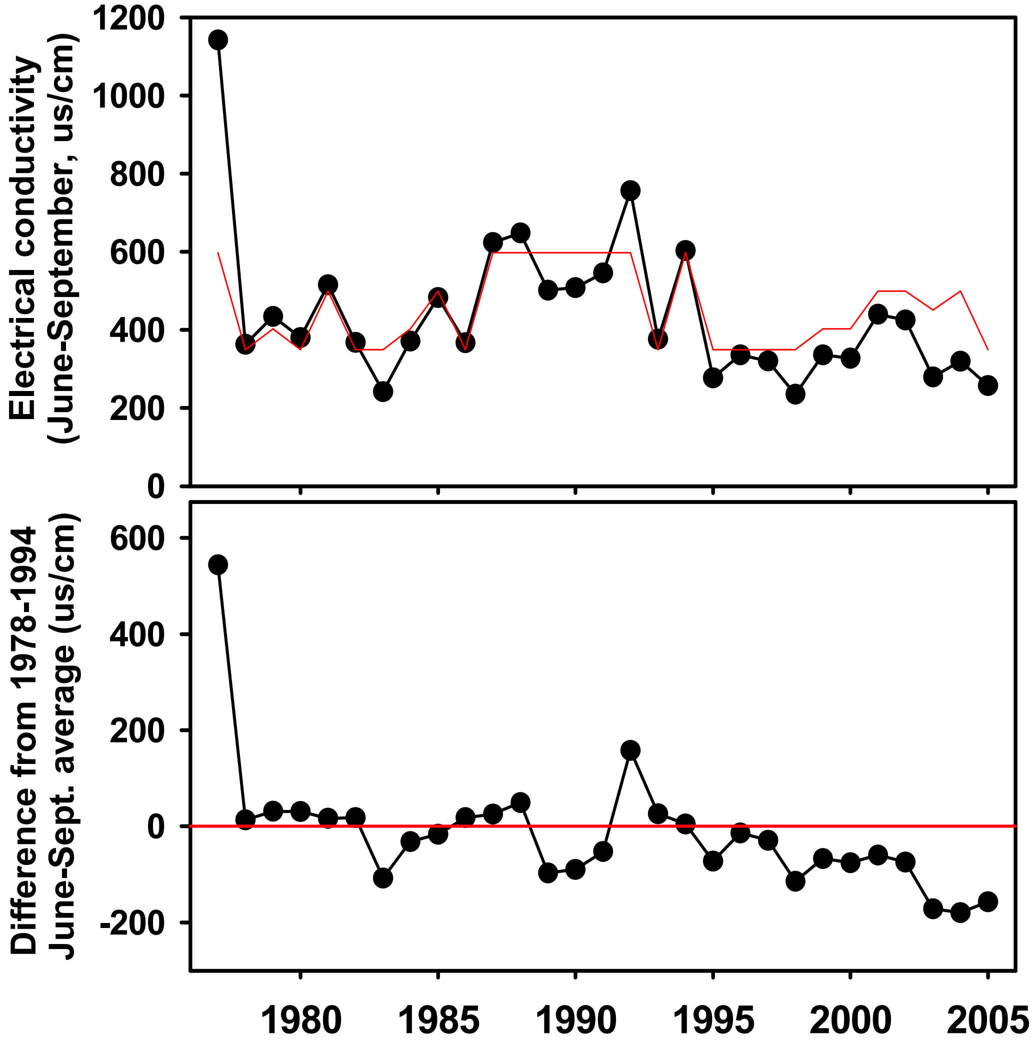


Figure 3.1.13. Source Water Quality Management Indicator. Top panel shows the measured values for average June-September EC at the Delta Mendota Canal headworks (-●-) and the reference condition (—). Bottom panel shows the average EC expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.

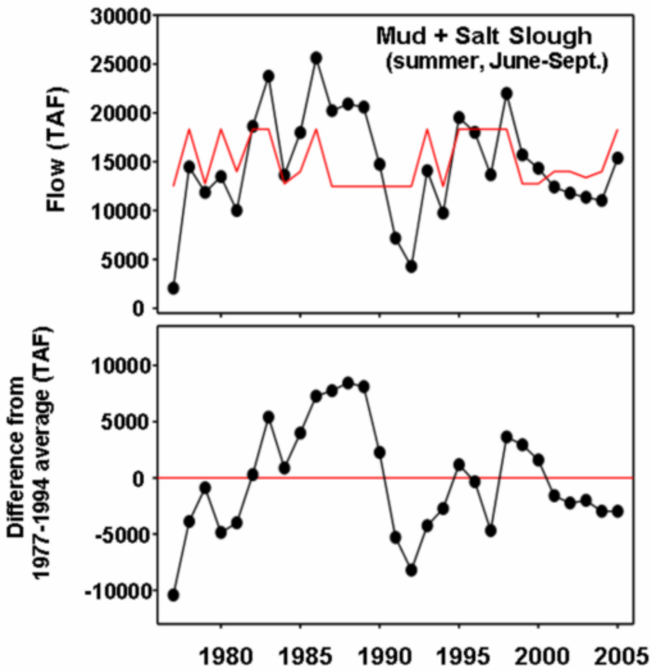
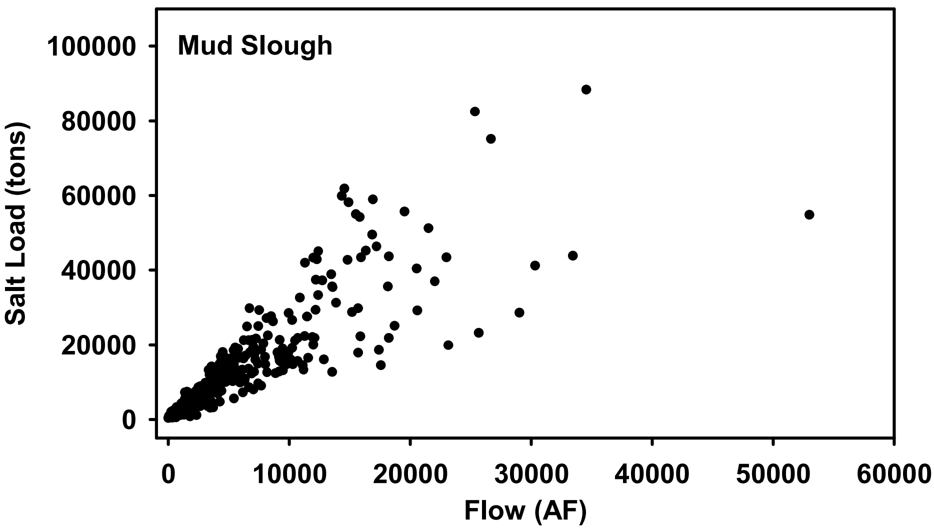


Figure 3.1.14. Drainage Reduction Indicator. Top panel shows the measured values for June-September flows (TAF) in Mud and Salt sloughs (-●-) and the reference condition (—). Bottom panel shows the Mud and Salt slough flows expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.



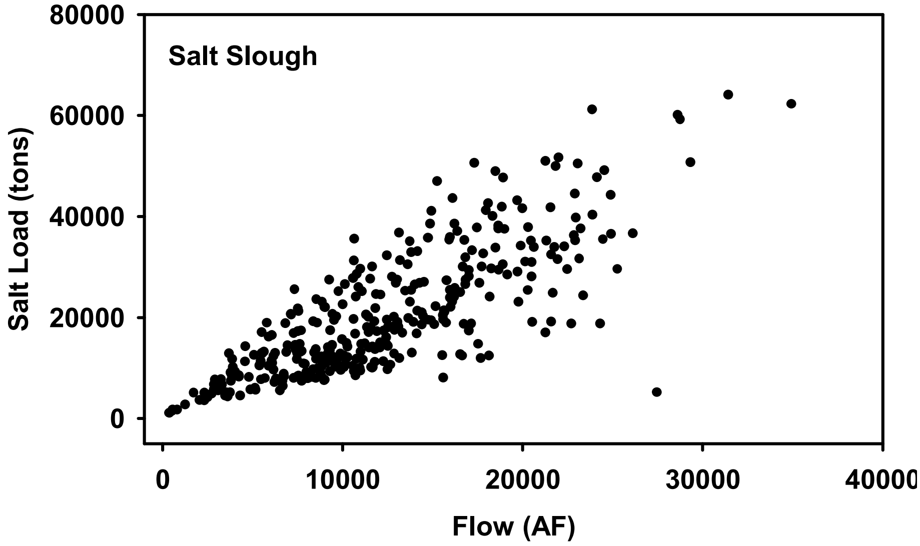


Figure 3.1.15. Relationship between salt load (tons) and flow (AF) for Mud Slough (top panel) and Salt Slough (bottom panel) at Vernalis.

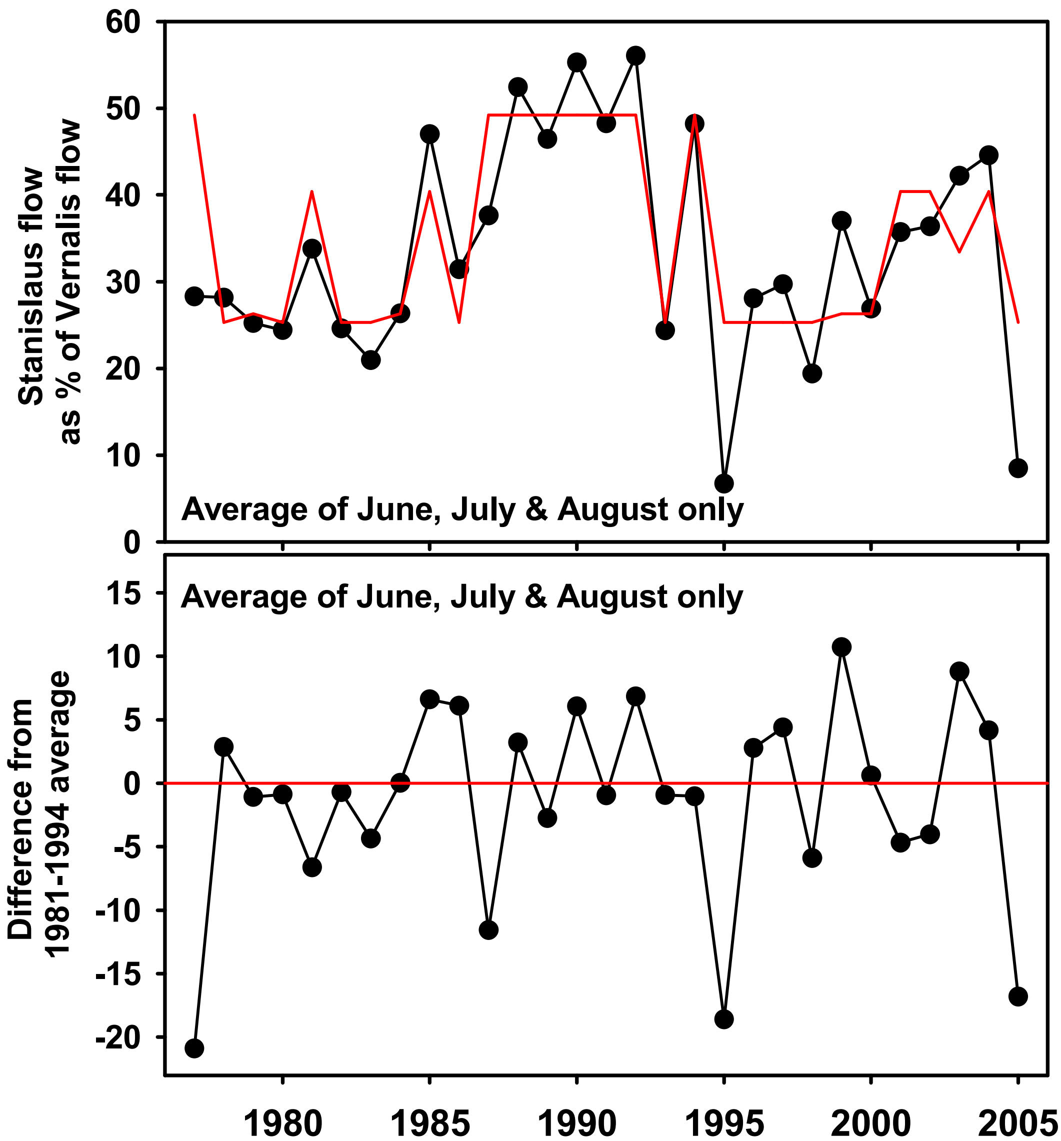
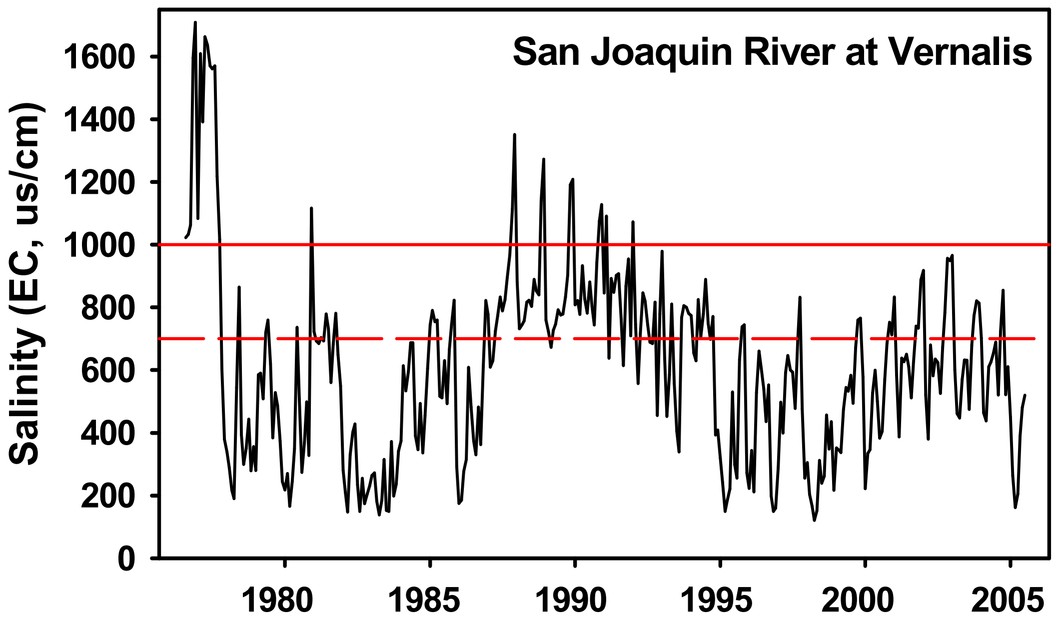


Figure 3.1.16. Flow Management Indicator. Top panel shows the measured values for Stanislaus River flows expressed as percent of total San Joaquin River flows at Vernalis (-●-) and the reference condition (—). Bottom panel shows the Stanislaus River flow contributions expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.



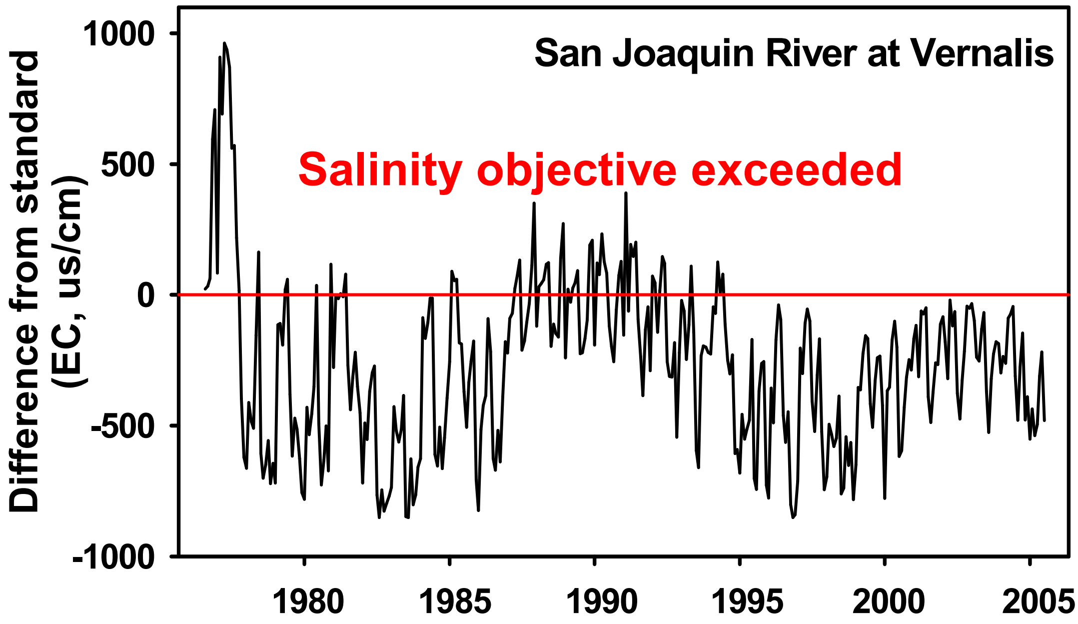


Figure 3.1.17. Surface Water Salt Concentration Indicator. Top panel shows the measured values for monthly EC at Vernalis (-●-) and the reference condition (—). Bottom panel shows the monthly EC expressed as the difference between its measured value and the reference condition (-●-). See text for further explanation.

Table 3.1.1. .Monthly Salt Loads – Examples for how the appropriate Water Year TMML reference condition was determined for each calendar month of the period of record included in the indicator calculations (see text).

Water Year Type	Water Year	Month	TMML used as reference condition
Above Normal	1979	September	87 (Table 4-8 for AN years)
Wet	1980	October	103 (Table 4-8 for AN years)
Wet	1980	November	72 (Table 4-8 for AN years)
Wet	1980	December	70 (Table 4-8 for AN years)
Wet	1980	January	84 (Table 4-8 for W years)
Wet	1980	February	148 (Table 4-8 for W years)
Wet	1980	March	211 (Table 4-8 for W years)
Wet	1980	April	164 (Table 4-8 for W years)
Wet	1980	May	180 (Table 4-8 for W years)
Wet	1980	June	86 (Table 4-8 for W years)
Wet	1980	July	57 (Table 4-8 for W years)
Wet	1980	August	54 (Table 4-8 for W years)
Wet	1980	September	88 (Table 4-8 for W years)
Dry	1981	October	162 (Table 4-8 for W years)
Dry	1981	November	85 (Table 4-8 for W years)
Dry	1981	December	75 (Table 4-8 for W years)
Dry	1981	January	66 (Table 4-8 for D years)

Example 2. Selenium in the Grasslands

A. Background

(See **Table 3.2.1.** for a timeline of the regulatory and management context.)

The Grassland watershed is a valley floor sub-basin of the San Joaquin River Basin, covering approximately 1360 square miles (**Figure 3.2.1**). This basin is located west of the San Joaquin River and bounded on the north by the alluvial fan of Orestimba Creek and to the south by the Tulare Lake Basin. The watershed contains managed wetlands, irrigated agriculture, and a 97,000-acre drainage project area (DPA), which is the primary source of selenium to the San Joaquin River and encompasses seven irrigation/drainage districts. Mud Slough and Salt Slough are tributaries to the river and serve as the only drainage outlets for the Grasslands (CVRWQCB, 2006).

Soils on the westside of the San Joaquin River basin are derived from marine sedimentary rocks on the Diablo Range and contain naturally high concentrations of salts and trace elements, including boron and selenium. With irrigation, salts and trace elements of the surface soils were getting mobilized and leached into the shallow groundwater or collected in tile drains and discharged offsite into wetlands or the river. Irrigation drainage water from the DPA was formerly being reused to supply the wetland habitats in the Grasslands Water District (GWD)[17], which are important to migratory birds. However, the discovery in 1983 that selenium-contaminated drainage left a trail of dead and deformed birds in the Kesterson section of the San Luis National Wildlife Refuge caused the CVRWQCB to issue selenium TMDLs for the Grasslands and the Lower San Joaquin River and induced a change in disposal practices by the farmers, in order to meet the regulatory requirements and address the problem (CVRWQCB, 2000; Environmental Defense, 2000; Tanji et al, 2002; CVRWQCB, 2006; USBR, 2006).

Grassland area farmers requested in 1995 permission from the U.S. Bureau of Reclamation to use the San Luis Drain (SLD, a federal canal) to convey selenium-laden agricultural drainage around the wetlands and directly into Mud Slough. By 1996, a bypass was constructed that would provide for the rerouting of the drainage to the SLD (Figure 3.2.2). The San Luis Drain discharges into Mud Slough (north) nine miles upstream of its confluence with the San Joaquin River. The effect of this Grassland Bypass Project was removal of most of the selenium load from wetland supply channels and therefore the wetlands themselves. The region's farmers also began implementing additional activities aimed at reducing discharge of subsurface drainage water to the San Joaquin River. Actions to reduce drainage have involved retirement of irrigated lands from production, the construction of drainage collection systems, recycling of drainage and tailwater, concentration of drainage on lands acquired for this purpose, and the planting of salt tolerant crops (Environmental Defense, 2000; USBR, 2006).

[17] GWD encompasses both federal and privately owned wetlands (duck hunting clubs etc.)

Previous to the construction of the bypass, agricultural subsurface (tile) drainage water from irrigated lands entered GWD from the south, where it was mixed with variable quantities of surface return flows (tailwater) from the Central California Irrigation District (CCID) and other riparian diverters. In 1985, wetlands ceased to use water with selenium concentrations greater than 2ppb, and wetland managers began to use a complicated "flip-flop" system to alternately transport agricultural drainage and wetland supply water through the Grasslands conveyance system (Figure 3.2.2). The commingled water flowed northward through the GWD in ditches and canals leading to Mud and Salt Sloughs and eventually to the San Joaquin River. This system required a high level of coordinated water management, including that channels be flushed of selenium contaminated drainage water before being returned to conveying wetland supply water. The results were inefficient water use, and the potential for contaminating wetland water supplies with drainage water during this "flip-flop" operation. In addition, scheduling restrictions inherent in this system restricted, and sometimes prevented, wetland managers from utilizing otherwise available water supplies to optimize habitat and wildlife benefit (SFEI, 2006a).

The Grassland Bypass Project was approved in 1995, when the USBR signed a Use Agreement with the San Luis and Delta-Mendota Water Authority (SLDMWA) allowing the northern 28-mile portion of the previously decommissioned San Luis Drain, a federal drain, to be reopened for a trial period to route agricultural drain water from the Grassland Drainage Area around the wildlife habitat areas in Mud and Salt Sloughs (Quinn et al, 2006). The bypass intercepts drainage water south of the GWD and conveys it through the SLD for discharge into Mud Slough (north). This system allows agricultural drainage flows to bypass the GWD altogether, thus removing agricultural drainwater contaminated with selenium from Salt Slough and from approximately 90 miles of wetland canals and ditches flowing through the interior of the Grasslands. Therefore, implementation of the GBP is believed to have benefited aquatic biota in GWD canals and ditches, their associated marsh ponds, Salt Slough, and the reach of Mud Slough lying upstream from the terminus of the SLD because these surface waters are no longer exposed to tile drainage contaminated with selenium. Instead, the discharges are now diverted into the lowermost 6 miles of Mud Slough and, eventually (then as now), into the San Joaquin River. Approval of the GBP was granted with the understanding that certain benefits and risks are associated with the Project. The anticipated benefits were as follows (SFEI, 2006a):

- Agricultural drainage water would be removed from the GWD water delivery channels, thus allowing refuge managers to receive and apply all of their fresh water allocations according to optimum habitat management schedules[18].
- Removal of agricultural drainage water from the GWD channels would reduce the selenium exposures to fish, wildlife, and humans in the wetland channels and Salt Slough. Concentrations of salinity and other constituents may also be reduced within the wetland channels and Salt Slough.
- Combining agricultural drainage flows within a single concrete-lined structure, the SLD, would allow better measurement, potentially leading to a more detailed evaluation and effective control of selenium and agricultural drainage.

[18] The Central Valley Project Improvement Act (CVPIA) of 1992 required an increased volume of fresh water be allocated to the wetlands in GWD.

- The establishment of an accountable drainage entity would provide the framework necessary for responsible watershed management in the Grassland Basin.
- These benefits were weighed against the potential risks:
- Combining agricultural drainage flows within the SLD would result in an increase in selenium and other constituents which are discharged into Mud Slough. These constituents would be above the levels historically discharged to Mud Slough. Such increases may have an adverse environmental effect on six miles of Mud Slough, since aquatic biota in Mud Slough downstream from the SLD could be exposed to higher concentrations of selenium and other constituents.

The GBP included the development of a compliance monitoring program that establishes monthly load limits for selenium. The plan for the monitoring program were developed with the coordination and cooperation of several State and Federal agencies including USBR, USFWS, USGS, USEPA, CVRWQCB, The California Department of Fish and Game (DFG), and the San Luis Delta-Mendota Water Authority (SLDMWA). Farmers from seven irrigation and drainage districts formed a drainage entity (Grassland Area Farmers) under the umbrella of SLDMWA, which is in charge of the use and operations of the SLD (SFEI, 2006a)..

In 2001, a new Use Agreement was drafted that requires continuing selenium load reductions to meet implementation dates for water quality objectives (the applicable selenium load limit for 2006, based on current applicable total maximum monthly load [TMML] is 3,087 pounds, compared to the existing load value under the 1995 Use Agreement, 5,661 pounds, for Water Year 2001). The new Use Agreement included an updated compliance monitoring plan, the revised selenium load limits, and a new Waste Discharge Requirement from the Regional Water Quality Control Board that includes:

1) addition of approximately 1,100 acres to the Grassland Drainage Area, i.e. 1,100 acres of unincorporated land immediately adjacent to the Grassland Drainage Area, south of the SLD and east of the Grassland Bypass Channel, would be included in the Grassland Drainage Area; and
2) In-Valley Treatment and Drainage Reuse: the In-Valley Treatment/Drainage Reuse element would be implemented on up to 6,200 acres of land within the Grassland Drainage Area in phases, and it is anticipated that each phase would significantly reduce the quantity of drain water discharged to the San Joaquin River.

Finally, the Draft San Joaquin Water Quality Management Plan, endorsed by the multi-stakeholder San Joaquin River Water Quality Management Group, calls for the elimination of all subsurface drainage discharge from agriculture in the Grassland Drainage Area to the San Joaquin River by 2009 and a program that includes source control measures, drainage water reuse on salt tolerant plants, and drainage treatment to cope with salt, selenium and boron contaminant loads. (SJRWQMG. 2005)

Data and Information Sources

Data and information sources included the technical reports prepared by the CVRWQCB for the development of the Grasslands and Lower San Joaquin River TMDLs (CVRWQCB, 2000, 2001), The Grassland Bypass Project (GBP) Annual Report 2003 (SFEI, 2006b), the GBP database, the GBP Ten Year Loads Report 1985 – 1995 (CVRWQCB, 1998a), the U.S. Bureau of Reclamation (USBR) GBP monthly data reports (USBR, 2005), (SFEI, 2006a), the San Luis Drainage Feature Re-evaluation Final Environmental Impact Statement (USBR, 2006), the Summary Recommendations of the San Joaquin River Water Quality Management Group for Meeting the Water Quality Objectives for Salinity Measured at Vernalis and Dissolved Oxygen in the Stockton Deep Water Ship Channel (SJRWQMG, 2005), the U.S. Geological Survey (USGS) Estimation of a Water Budget for 1972–2000 for the Grasslands Area (Brush et al, 2004), the report Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1997 – September 1998 (CVRWQCB, 1998b), and personal communications with Phil Crader, Matthew McCarthy, Rudy Schnagl (all CVRWQCB), Joe McGahan (Grassland Area Farmers), Nigel Quinn (Lawrence Berkeley National Laboratory), and others.

B. Methodology and Results

Steps 1 and 2. Application of PSR to Selenium in the Grasslands and Selection of Indicators and Reference Conditions

Specific assessment questions and candidate pressure, state, and response indicators for the selenium issue in the Grasslands were derived from a generic list of assessment questions and indicators (Tables 4.1 to 4.3).These generic assessment questions and indicators were derived from the PSR framework introduced in Section 2 (Figures 4.2 to 4.4). Selection of specific assessment questions and candidate indicators was based on our conceptual understanding of the San Joaquin hydrologic system (particularly the Grasslands subbasin), the processes affecting selenium transport therein, and known effects on beneficial uses. Toward the end of this section, the relationships of some example indicators within the PSR Framework are investigated. Reference conditions were gleaned from regulatory targets specified in the selenium TMDLs for the Grasslands (CVRWQCB, 2000) and the Lower San Joaquin River (CVRWQCB, 2001) or biological thresholds for the recommended ecological risk guidelines for selenium concentrations of the Grassland Bypass project (SFEI, 2006b).

Step 3. Development, Calculation, and Testing of Example Indicators for Selenium: Methodology and Results

Pressure Indicators

Pressure indicators were developed to address the basic assessment question

- Are pressures on the system declining spatially and temporally?

P1. Selenium in Soil

Approach/calculation: this indicator was not calculated. It does not meet the criteria of responsiveness to address the assessment question above.

P2. Selenium Load in Source Water

Approach/calculation. DMC water imported to wetlands x Se concentrations (lbs/yr, tons/yr).

Indicator status: The indicator was rejected. Various datasets containing information on water deliveries to the Grasslands were received but analyses were not completed. The only available Se concentrations for the DMC channel were those measured in conjunction with toxicity testing. These data did not meet criteria of data quality (potential contamination issues for 1999 data; also, many samples had concentrations below the method limit of detection), however, Se load contributions to the Grassland wetlands from source water deliveries are expected to be fairly minimal.

P3. Air pollution/aerial drift

Not relevant to Se issue in the Grassland region.

P4. Subsurface Tile Drainage Discharge

Approach/calculation: Selenium loads (lbs/yr) for subsurface agricultural drainage discharges from the DPA were gleaned from the report Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1997 – September 1998 (CVRWQCB)(1986-1995) and the GBP Annual Report 2003 (SFEI, 2006b)(1996-2003). Reference conditions were the total annual load limitations for the SLD (SFEI, 2006b).

Indicator results and assessment summary: presumably, selenium loads to the Grassland wetlands due to subsurface tile drainage discharge have been virtually eliminated since 1996, when they were diverted to the SLD. Se loads in the SLD have not exceeded annual load limitations since 1999.

P5. Application

Not relevant to Se issue in the Grassland region.

P6. Hydro-regime Modification

This indicator is identical with the management response indicator Flow Management (MR5, p. 80).

State Indicators

WQ 1: Water Concentrations
This indicator was designed and tested to answer three broad assessment questions:

- Are water quality and beneficial use conditions impaired by selenium?
- Are conditions improving over time and space?

- Specifically, have there been improvements since 1996 (spatially and temporally), when drainage was diverted through the bypass to Mud Slough?

Approach/calculation: For this indicator, only the datasets from sampling stations with "long-term data records (1985-2005) were included (**Figure 3.2.2**). The reference condition was set at 2 μg/L, which is the no-effect threshold for selenium surface water concentrations related to fish and bird reproduction and is used as the monthly mean objective for selenium in the wetland channels (CVRWQCB, 2000; SFEI, 2006b). Annual averages were calculated to evaluate long term trends and eliminate seasonal variations.

Indicator results: Multi-year trends in surface water selenium concentrations at Grassland sampling stations clearly show a response to the construction of the bypass in 1995. Completion of the bypass construction resulted in a drastic rise in selenium concentrations at Station D, which is at Mud Slough downstream of the San Luis Drain inflow, and a sharp decline in Salt Slough (Station F) and the wetland channel stations (J, K, L2, M2).[19] In Mud Slough, there has been a gradual and statistically significant decline in selenium concentrations after 1996 (r^2=0.71).

Assessment Summary. Overall, the Water Concentrations Indicator shows that annual mean selenium concentrations in Salt Slough and the wetland channels have dropped below or near the no-effects threshold for fish and wildlife as a result of the bypass. Water quality and beneficial use impairments are therefore greatly reduced in these waters in response to the bypass construction. On the other hand, after 1996, when the SLD began to carry drainage discharge, annual mean selenium concentrations in Mud Slough downstream of the SLD discharge have been consistently exceeding the no-effects threshold for fish and wildlife by up to tenfold.

Evaluation. The Water Concentrations Indicator is responsive and representative for diagnosing specific, contaminant-related pressures[20].

<u>WQ 2: Aquatic Toxicity</u>

This indicator addresses the assessment question:

- Is there (selenium-related) toxicity[21]?

Approach/calculation: the toxicity indicator was calculated based on available laboratory toxicity testing results from the GBP (SFEI, 2006b), as the correlation of toxicity events with selenium concentrations (see WQ 1).

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[19] The large fluctuations in the annual Selenium means in wetland channels prior to 1996 are partly due to changes in water management prior to the bypass construction (see Background section, p. 67).

[20] The toxicity of waterborne selenium is dependent on its oxidation state. However, waterborne selenium concentrations are measured as total dissolved selenium by the GBP monitoring program and information on oxidation states is not available. Additionally, there are currently no water quality objectives based on selenium speciation. Total dissolved selenium is instead used as a surrogate parameter to assess the potential of selenium toxicity due to direct exposure to selenium in water (see Appendix D, Comment 3).

[21] Toxicity testing is by design (and conceptually) not a constituent-specific indicator of water quality condition. The calculations are presented for demonstration purposes.

Toxicity testing results were available for five different tests (**Table 3.2.2**) performed on samples taken at four selected Grassland sampling sites (**Figure 3.2.4**) between December 1995 and September 2005. The toxicity indicator was calculated as the overall percentage of positive test results per year from 1997 to 2004 (all years with a complete or near-complete record of monthly sampling.) Source water from the Delta-Mendota-Canal (DMC) was used as the reference condition, because it is the ambient control for Grassland toxicity testing. Positive test results were defined as statistically significant differences ($p<0.05$) to DMC ambient control data (SFEI, 2006b).

Results: Toxicity testing was started after the bypass was opened in 1995. Therefore, it is not possible to assess a direct response in toxicity results to the construction of the bypass. For the analyzed time period 1997-2004, toxicity varies considerably from year to year as all four sampling stations show. At station B, for example, the percentage of positive test results per year ranges between 5% and 23%. At Station C, toxicity is slightly declining over time (r^2 = 0.52, p=0.02). For the other stations, there are no discernible temporal trends (**Figure 3.2.5** and **Table 3.2.3**).

There are no significant differences in toxicity at different stations. Station averages are between 12 and 16%, that is, they are close to and within error margins from each other.

The results for the toxicity indicator show no evidence linking the toxicity response to selenium concentrations (**Figure 3.2.7**). For instance, Mud Slough water is only slightly more toxic than Salt Slough, even though average selenium concentrations in Mud Slough exceed one or more toxic thresholds in most years, whereas annual mean concentrations in Salt Slough are below all effects thresholds in all years. A statistical regression analysis was not attempted.[22].

While this example illustrates that toxicity is not a representative indicator for diagnosing selenium pressures, it can also serve to demonstrate the potential use of the PSR indicator framework as a diagnostic and communication tool to facilitate adaptive watershed management:

Discussion 3: Hypothetical Example for Using the PSR Indicator Framework as a Diagnostic Tool in Adaptive Watershed Management

Figure **3.2.8** illustrates in a simplified example how the PSR model applies to adaptive management. The example assumes that toxicity is being measured to address the assessment question:

" Is there selenium-related toxicity (in Grassland surface waters)?"

[22]In this context, it should be noted that traditional toxicity testing is essentially irrelevant in detecting impacts of selenium. It cannot detect reproductive failure, teratogenicity or food web processes, all of which characterize selenium effects (see Appendix D, Comment 1). In addition, potential impairments of fish and wildlife in the Delta, which are an important potential endpoint, are not being considered in current efforts to assess GBP-related toxicity (see Appendix D, Comment 3)

The results of the Aquatic Toxicity Indicator demonstrate very clearly that within the context of the PSR model there is no strong evidence linking toxicity to selenium, and that the indicator is generally unsuitable for diagnosing a specific pressure, such as selenium impairments. Positive toxicity results may be related to a number of possible individual constituents or any combination of many pesticides and other chemicals that are applied in agricultural practices and enter the surface water system, which mainly consists of irrigated agricultural runoff/subsurface drain discharges.

Therefore, the indicator tells us that collecting samples for toxicity testing is not particularly useful for management purposes that are focused on addressing selenium-related impairments *only*. Using this conclusion as a decision basis, resource managers focused exclusively on addressing the selenium issue may want to decide to discontinue or reduce toxicity testing.

On the other hand, the implications change considerably in the context of the more general assessment question:

"Are water quality and beneficial use conditions in the Grasslands impaired?"

In this context, the water quality impairment by unknown toxicity points to the need to identify the pressure (what is causing the toxicity?) and the appropriate management response (how to address the problem?). Overall, this example also illustrates that assessment questions need to clearly articulate the water quality management goals that are to be addressed by monitoring. The better the management goals and assessment questions are defined, the more useful is the information provided by monitoring and indicators.

Assessment Summary. There is some toxicity at all Grassland stations sampled. The observed toxicity cannot be attributed to selenium.

Evaluation. General Aquatic Toxicity cannot be used as an indicator for diagnosing specific, selenium-related pressures and, for use in this example, does not meet the criteria of representativeness. See Discussion 3 and Step 4 for additional discussion of the toxicity indicator.

WQ 3: Bioaccumulation

This indicator was designed and tested to answer the broad assessment questions:

- Are fish and wildlife beneficial use conditions in Grassland wetlands impaired by selenium?
- Has diversion of agricultural drainage through the bypass to Mud Slough resulted in reduced foodweb exposure of fish and wildlife to selenium?

Approach/calculation: the bioaccumulation indicator was calculated based on available selenium bioaccumulation data for aquatic organisms from the GBP (SFEI, 2006b). Biological monitoring programs have been carried out by USFWS and DFG since 1992 to ascertain environmental impacts of elevated selenium levels in water. Bioaccumulation data included in the indicator calculations are from four active biota sampling stations along or near Mud and Salt Sloughs (**Figure 3.2.9**). Types of samples include invertebrates (quarterly), amphibians[23] (irregular collection), small fish (once to three times a year), and medium-size fish (quarterly). Table .3.2.4 has a list of all the species that were included in these sample categories.

The indicator was calculated as the annual average concentrations for each station for each of these organism groups. The recommended ecological risk guidelines for selenium concentrations (SFEI, 2006b) were used as reference conditions. They provide thresholds between no-effects levels and levels of concern, and between levels of concern and toxicity. For invertebrates, the guideline is based on effects on birds caused by dietary exposure. The thresholds are 2 mg/kg dry weight (d.w.)(no effect/concern) and 5 mg/kg d.w. (concern/toxicity). For fish, the guidelines are based on biological effects of whole body burdens in warmwater fish (growth, condition, survival). The thresholds for fish are 4 mg/kg d.w. (no effect/concern) and 9 mg/kg d.w. (concern/toxicity).

Results. 1. *Invertebrates. Sampling Stations C* (Mud Slough above the SLD outlet) and *D* (Mud Slough below the SLD outlet). Mean annual selenium concentrations in invertebrates from Mud Slough (Sampling Stations C and D, see **Figure 3.2.10**) show no visible response to the implementation of the bypass. Annual means (1993 – 2003) in invertebrates collected above the SLD outlet (Station C) are well below the level of concern threshold for the entire period (both pre- and post-bypass implementation) and display relatively little interannual variability (1.3 – 2.2 mg/kg d.w.)(**Figure 3.2.10**, top, yellow line). In contrast, annual means in invertebrates collected below the SLD outlet (Station D) show considerable interannual variability (range between 1.13 and 4.44 mg/kg d.w.) and exceed the threshold level of concern in 5 of 10 years (**Figure 3.2.10**, top, orange line). The exceedances are observed in one of three pre-bypass years (1992) and four of seven post-bypass years (1998, 1999, 2001, and 2003). There are not enough data points to tell whether this represents an actual increase due to the construction of the bypass or random variation. *Station I* (Mud Slough backwaters downstream of SLD outlet): annual means are increasing over time ($r^2 = 0.67$, $p = 0.002$) over the entire period 1993-2003 (**Figure 3.2.10**, top, maroon line). In average, annual selenium concentrations in invertebrates collected at this station have increased by 0.4 mg/kg d.w. and have been above the level of concern threshold from 1995 onward. Although the data are not entirely conclusive, it is possible to explain the observed trend as a result of the bypass construction, combined with interannual variability due to other factors. *Station F* (Salt Slough). Annual mean concentrations in invertebrates collected at Station F show a clear response to the construction of the bypass (**Figure 3.2.10**, top, green line). At Station F, annual selenium concentrations of invertebrates consistently exceed the level of concern in all sampled years prior to bypass construction and remain consistently below the threshold in years following the bypass construction. Salt Slough is a main wetland supply channel from were drainwater was removed with the bypass.

2. *Small Fish. Sampling Stations* C, *D*, and *I* (**Figure 3.2.10**, middle, yellow, orange, and maroon lines). Annual means before bypass implementation are above, near, or below the threshold level of concern. In 1996, the year of the bypass implementation, there is a sharp

[23] Amphibians were not included in the bioaccumulation indicator, due to the lack of toxicity data based on body burden for these organisms.

peak at Stations C and D, with annual means exceeding the toxicity threshold several-fold. In the post-bypass construction period, annual mean concentrations in small fish fall below the toxicity threshold by 1998, then gradually start to rise again. In 2003, annual means exceed the toxicity threshold at Station I, and are at levels of concern at Stations C and D. *Station F* (**Figure 3.2.10**, top, green line). Trends in the annual mean selenium concentrations in small fish from Station F can be linked to the construction of the bypass. Annual means consistently exceed the level of concern in all sampled years prior to bypass construction and remain consistently below the threshold in years following the bypass construction.

3. *Medium-size Fish. Sampling Stations C* and *D* (**Figure 3.2.10**, bottom, yellow and orange lines). Before bypass construction, most annual mean selenium concentrations in medium-size fish from both stations are below the level of concern threshold. After bypass construction, most annual means from both stations are above the level of concern threshold. There is considerable interannual variability both before and after bypass construction, but no obvious temporal trends. *Station I* (**Figure 3.2.10**, bottom, maroon line). In 1995, the only pre-bypass year with data for medium-size fish, the annual mean is below the level of concern threshold. In 1997, the first year after bypass construction, the annual mean is above the toxicity threshold. In subsequent years, annual means are below the toxicity threshold but above the level of concern threshold. *Station F* (**Figure 3.2.10**, top, green line). Trends in the annual mean selenium concentrations in medium-size fish from Station F correspond well to the construction of the bypass. Annual means exceed the level of concern in all sampled years prior to bypass construction (and exceed the toxicity threshold in 1992) and remain below the level of concern threshold in years following the bypass construction.

Assessment Summary. The Bioaccumulation Indicator shows reduced foodweb exposure of fish and wildlife to selenium in Salt Slough. It also indicates greater foodweb exposure and increased impairment of fish and wildlife beneficial uses in Mud Slough as a result of drainage diversion to this water body. There is significant interannual variability in the results that cannot be directly related to the bypass construction. However, the direction of the change is consistent with the conceptual model for this indicator.

Evaluation. The Bioaccumulation Indicator is specific, responsive, and can be used as a potential tool for diagnosing pressures.

Response Indicators

Management responses indicators were developed to address the basic assessment question

- What type of management measures are implemented and to what extent?

Example indicators represent the management response categories:

MR2. Land management
MR3. Water use management
MR5. Flow management

The resulting indicators are preliminary in nature and have not been subjected to testing. More data and a quantitative, or at least semi-quantitative, analysis of the relationships of these indicators to state and pressure variables are needed to conclusively accept or reject these indicators using the suggested testing criteria.

Indicators for other categories were not developed for the following reasons:

MR1. Direct application practices:	not applicable
MR4. Treatment (contaminant removal):	there has been research, but no actions yet

Indicator MR2:Land Management (**Figure 2.4**)

MR2.1 Land Retirement - Acres of Cultivated Land in the Drainage Project Area (DPA)

Significance: irrigation drainage water from the drainage project area is the main source of selenium to the Grasslands. Less irrigated agricultural land in the DPA results in less drainage discharges, which in turn results in reduced selenium loads to receiving water bodies (USBR, 2006).

Approach/calculation: Acreage of cultivated land in the drainage project area (acres/year). Reference condition is the 1970 – 1986 mean.

Indicator results: By 2000, there have been no significant reductions in the percentage of cultivated land in the DPA. Rather, the total area of cultivated land has been increasing (**Figure 3.2.11**). This trend is statistically significant ($r^2 = 0.4$, $p = 0.0002$). The average area under cultivation was 70,697 acres between 1972 and1995 versus 84,774 acres between 1997 and 2000. However, in 2003 the Broadview Water District took approximately 8,000 acres out of production (Joe McGahan, personal communication).

Assessment Summary. Overall, there has been an increase in the percentage of cultivated land in the DPA.

MR2.2 Cropping - Acres of Land Cultivated with Salt-tolerant Crops

Significance: discharge of subsurface tile drainage water can be reduced by reusing it to water salt-tolerant crops.

Approach/calculation: Acreage of land cultivated with salt- tolerant crops in the Panoche Drainage District (PDD)[24] (acres/year).

[24] The district operates the San Joaquin River Water Quality Improvement Project (SJRIP), a reuse project that serves the Panoche Water District (PWD) and other participants in the GBP to better manage subsurface drainage water.

Indicator results: No salt-tolerant crops were planted before the implementation of the bypass (**Table 3.2.6**). In 2003, 3873 acres were planted with salt-tolerant crops (less than 5% of the total cultivated area).

Status: reference condition TBD.

Assessment Summary. There has been a significant increase in salt-tolerant crops.

Evaluation. Effects of planting salt-tolerant cops on groundwater quality are unknown and there is a potential for degradative effects. The indicator may be of limited value for diagnosing the effectiveness of management practices.

MR3: Water Use Management (**Figure 2.5**)

MR3.1 Source Water Management – Water Deliveries to the DPA

Significance: source water is mainly provided for irrigation. Less source water deliveries results means less water used in irrigation and less subsurface tile drainage discharges, which in turn results in reduced selenium loads to receiving water bodies.

Approach/calculation: total water deliveries to the DPA (acre-feet/year). Reference condition is the 1970 – 1986 mean. The data were normalized for water year type by using the 1972 – 1985 average.

Indicator results: By 2000, there has been a slight reduction in total water deliveries to the DPA (**Figures 3.2.12** and **3.2.13)** over the entire period. The average annual amount of source water deliveries was 229,551 acre-feet between 1972 and 1995 (before bypass) versus 189,618 acre-feet between 1997 and 2000 (after bypass). The reduction is more apparent after 1988 ($r^2 = 0.65$, $p = 0.0008$) and after the bypass ($r^2 = 0.72$, $p = 0.07$)

Assessment Summary. Overall, there has been a reduction in total water deliveries to the DPA.

MR3.2 Water Conservation

Significance: Water conservation reduces subsurface tile drainage discharges, resulting in reduced selenium loads to receiving water bodies.

Approach/calculation: water deliveries in acre-feet per acre of cultivated land per year.

Indicator results: Water deliveries to cultivated lands in the DPA have been reduced from an average of 3.4 acre-feet per acre per year (1972-85) and 3.0 acre-feet per acre per year (1985-96) to 2.1 acre-feet per acre per year (1997-2000) The reduction over the entire period is significant ($r^2 = 0.41$, $p = 0.0002$).

Status: reference condition TBD.

Assessment Summary. Overall, there has been a significant reduction in water use over the period of record.

MR3.3 Re-use of Tile Drainage Water

Significance: re-use of subsurface tile drainage water reduces discharges to the SLD, resulting in reduced selenium loads to receiving water bodies but possible accumulation in soils.

Approach/calculation: re-used tile drainage water in acre-feet per year.

Indicator results: There was no reuse of subsurface tile drainwater until 1996. Drainwater reuse was initiated in 1997 and has continually increased over the period of records (**Figure 3.2.15**, $r^2 = 0.91$, $p = 0.001$). In 2003, approximately 20% of the total subsurface tile drainwater discharged to the bypass was reused (see Indicator P4. Discharge and **Figure 3.2.3**).

Status: reference condition TBD.

Assessment Summary. Subsurface tile drainwater reuse resulted in a significant reduction in drainage discharge to the bypass and receiving waters.

MR5. Flow Management(**Figure 2.6**)

Approach/calculation: descriptive indicator.

Indicator results: in 1996, the bypass was used to divert subsurface tile drainwater around the wetlands, as evidenced by bypass use and associated changes in the hydrologic regime of the Grasslands.

Assessment Summary. The management measure was the decision to divert flows away to the wetlands.

Step 4. Quantifying PSR Indicator Relationships: Source Water Management (MR3.1) and Water Conservation (MR3.2) vs. Drainage Discharge (P4)

As described previously (Section 2) the PSR framework serves as a tool for organizing and communicating complex environmental information by describing relationships between indicators. Potential applications include the demonstration of linkages between actions and environmental outcomes and the identification of data gaps as well as monitoring efficiencies that are not yet realized. With these potential applications in mind, relationships between indicators are investigated around the question:

Can we evaluate the environmental responses of management measures, in terms of pressures on the system (management response vs. pressure)?

For the period of record 1986 – 2000, there are weak but statistically significant linear relationships between reductions in tile drainwater discharge and both reduction in total water deliveries to the DPA and water conservation (**Figures 3.2.16** and **3.2.17**). The relationships may be affected by a general lag in response and are also subject to other factors affecting the variability in selenium loadings, such as the water year type. Data for the management response indicators are currently too limited for an in-depth analysis of these relationships. Overall, reduction in total water deliveries to the DPA is expected to be more important than water conservation for controlling Se loadings associated with subsurface tile drainwater discharges.

Step 5. Demonstration of Possible Methods for Aggregating Indicators into Multi-metric Indices

Example 1: Selenium Concentrations (WQ1)

A. *Suggested index calculations:* Monthly averages were used to calculate the *amplitude* (by how much) and *frequency* (how often) of threshold exceedance as two independent measures of variance from the reference conditions (Canadian Council of Ministers of the Environment, 2001). This method offers a more detailed analysis of temporal and spatial trends than a simple comparison of annual means and is also a step toward aggregating and scoring indicators. For example, the Canadian Council of Ministers of the Environment's Water Quality Index consists of the three factors amplitude, magnitude, and proportion of exceedances[25] In the Index, these factors are scaled to range between 0 and 100, and the values are then combined to produce an index value that is 0 or close to 0 for very poor water quality, and close to 100 for excellent water quality (Canadian Council of Ministers of the Environment, 2001).

Results: Before bypass (1986-1995, **Figure 3.2.18**): in Mud Slough (Station D), the reference condition was exceeded in 60% of all months (frequency) with an average exceedance of 5 μg/L (magnitude). In Salt Slough (station F), the reference condition was exceeded in 93% of all months with an average exceedance of 12.5 μg/L. After bypass (1997-2005): in Mud Slough (Station D), the reference condition was exceeded in 60% of all months with an average exceedance of 20.6 μg/L. In Salt Slough (Station F), the reference condition was exceeded in 0% of all months (frequency) with an average exceedance of -1.2 μg/L.

B. *Example Scoring Method:* an example scoring method involving color codes and numerical exposure categories is illustrated in **Figures 3.2.19**. The exposures categories are gleaned from Lemly's aquatic hazard index for selenium (Lemly, 1995). **Table 3.2.7** shows an a water quality report card that is based on this scoring method and show an example for how water quality index information can be used to report on water quality at a glance in a meaningful and accessible way.

Results: Before bypass (1986-1995, **Figure 3.2.19** and **Table 3.2.7**): based on annual mean selenium concentrations, all Grasslands surface waters are uniformly graded at the lowest score of 1 due to high exposure to selenium in water (above toxicity level for warmwater fish). After bypass: After implementation of the bypass, all Grasslands surface waters are uniformly graded at the highest score of 4 due to minimal exposure to selenium in water

[25] The proportion of water quality objectives exceeded (e.g. Se, B, salinity, nutrients, organic carbon, organophosphate pesticides, etc.). This factor is not applicable to the example here, which focuses on selenium only.

(below level of concern for warmwater fish); with the exception of Mud Slough, which receives the selenium-laden drainage form the bypass and carry selenium concentrations above the warmwater fish toxicity level.

<u>Example 2: Aquatic Toxicity (WQ2)</u>

A. *Suggested index calculations*

Assessment Question (example): Is there toxicity (in Mud and Salt sloughs)?

Reference Condition: Toxicity of source water from Delta-Mendota-Canal

Measures of Variance:

Frequency F (how often toxic?) = Frequency of positive toxicity test results

$$F = \frac{\text{Number of months with positive tests}}{\text{all months}} \times 100$$

A*mplitude A* (how toxic) = Magnitude of variance of test results from the reference condition

$$A = \frac{\text{Sum of toxic scores (all tests) per month}}{\text{Number of tests per month}} \times 100$$

Aggregation, Scaling, and Scoring: The Aquatic Toxicity Indicator considers the results of five different laboratory tests that use different kinds of organisms and yield different types of data that are expressed in different units of measurement that cannot be directly compared (see **Table 3.2.2**). Therefore, aggregation and comparison of results requires a dimensionless scale. For this example, we used toxicity categories with thresholds that are statistically defined (see **Table 3.2.8**). This is the same approach that was used to integrate multiple lines of evidence (MLOEs = chemistry, toxicity, and bioassessment) in the development of sediment quality objectives by the State of California (SWRCB, 2006)

Results (Figs 3.2.20 and 21): Overall, the results expressed by two independent measures of variance (frequency, amplitude) are consistent with the Aquatic Toxicity Indicator results discussed previously. The overall score for the factor *amplitude* (no toxicity) illustrates the risk of loss of information by using single variables in indices. For this reason, indices should never replace a detailed assessment of water quality conditions. However, they can facilitate the communication of results, given they are being used with appropriate professional judgment.

C. Conclusions

Based on the PSR model, a suite of indicators was developed to describe trends for a single contaminant, selenium, in the Grasslands, a subbasin of the San Joaquin River basin. Water concentrations and bioaccumulation (i.e. tissue concentrations) were responsive and representative indicators for water quality condition and beneficial use impairments related to selenium. Toxicity, on the other hand, it is a not a contaminant-specific indicator and was not representative of selenium impairments. Subsurface tile drainage discharge and hydro-regime (flow) modification were found adequately representative and responsive to serve as potential pressure indicators. In addition, the project identified three potential management response indicators: source water management, water conservation, and flow management. Calculated trends for these management response indicators are consistent with predicted changes based on our conceptual understanding. The presented analysis is a first step toward linking management activities to changes in water quality condition. Moreover, statistically significant linkages were demonstrated between the calculated management and water quality condition indicators. However, the indicator method does not yet allow an evaluation of how effective certain management responses are or what the most effective practices are to improve water quality condition, as these are often the result of cumulative impacts of all activities combined[26]. This is even more challenging given the current scarcity of data on management activities or the limited utility of existing data for doing these kind of analyses. Targeted data collection efforts combined with the application of landscape modeling may help to improve our ability to make more specific connections between individual activities and environmental outcomes in the future.

[26] An exemption is the flow management indicator: a drastic change in condition occurring in 1996 (Mud Slough below SLD worsens, Salt Slough improves) can be very clearly associated with the construction of the Grassland bypass.

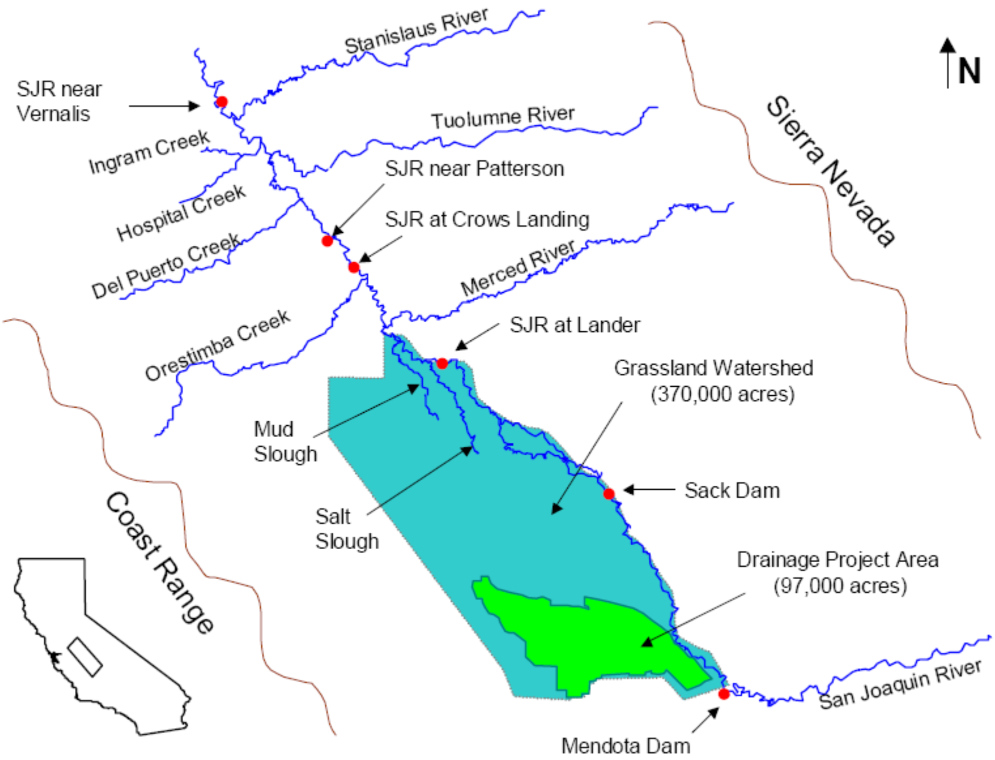

Figure 3.2.1. Grasslands subbasin (blue) and the Drainage Project Area (green).

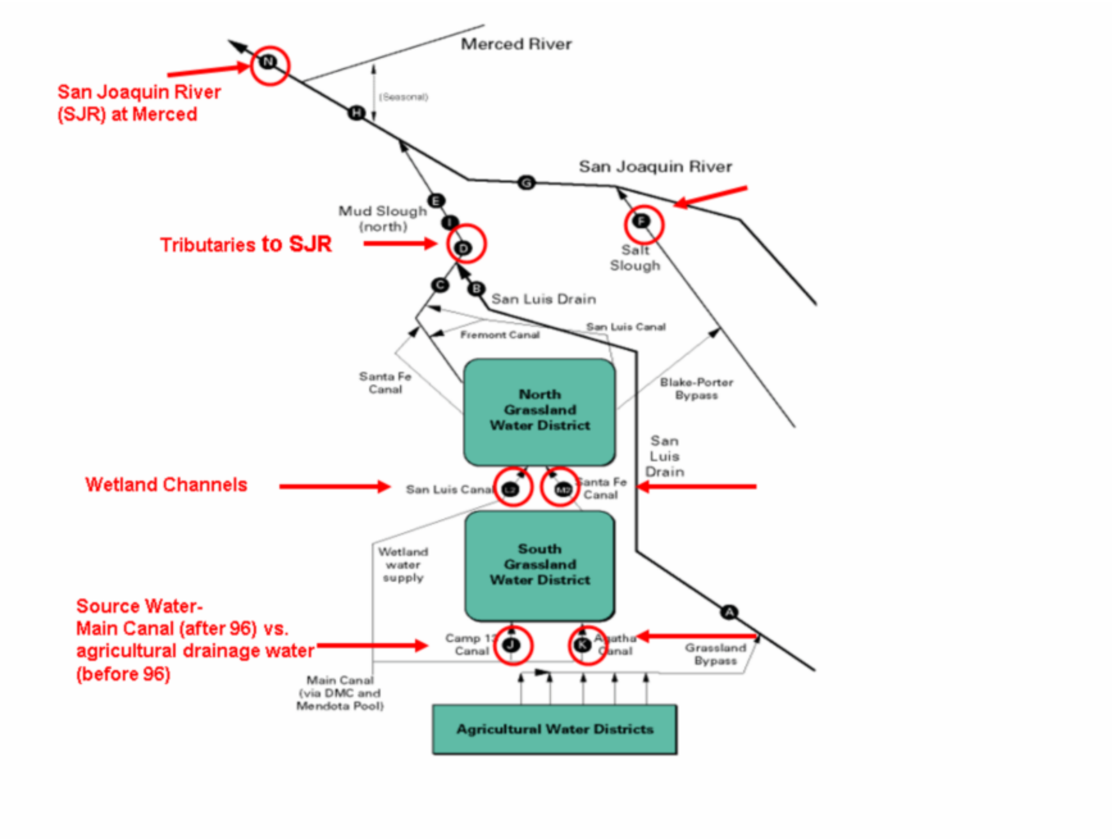

Figure 3.2.2. Grasslands Bypass Project - Schematic Diagram of the Grasslands water conveyance system. Also shown are locations of monitoring stations with long-term data relative to hydrologic features (modified from Fig 2 in SFEI, 2006b). data from monitoring stations D, F, J, K, L, M, and N (circled in red) were used in the Water Concentrations Indicator (**Figure 3.2.4**)

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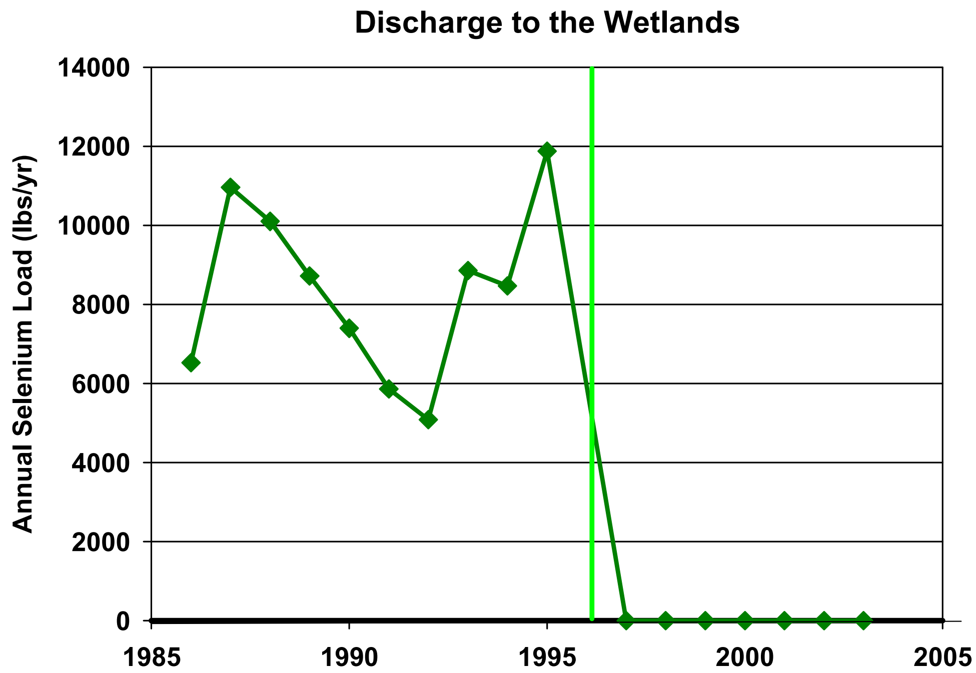

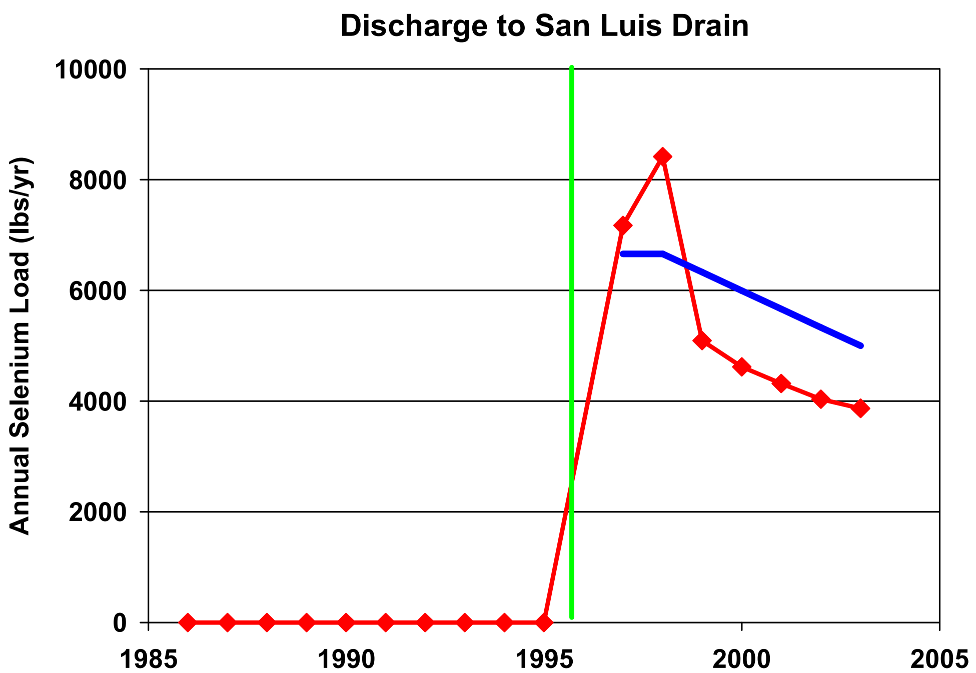

Figure 3.2.3. .Discharge Indicator– annual selenium loads (lbs/yr) from subsurface agricultural drainage to the Grassland wetlands and the SLD. Blue lines: reference conditions. Green bar: implementation of GBP.

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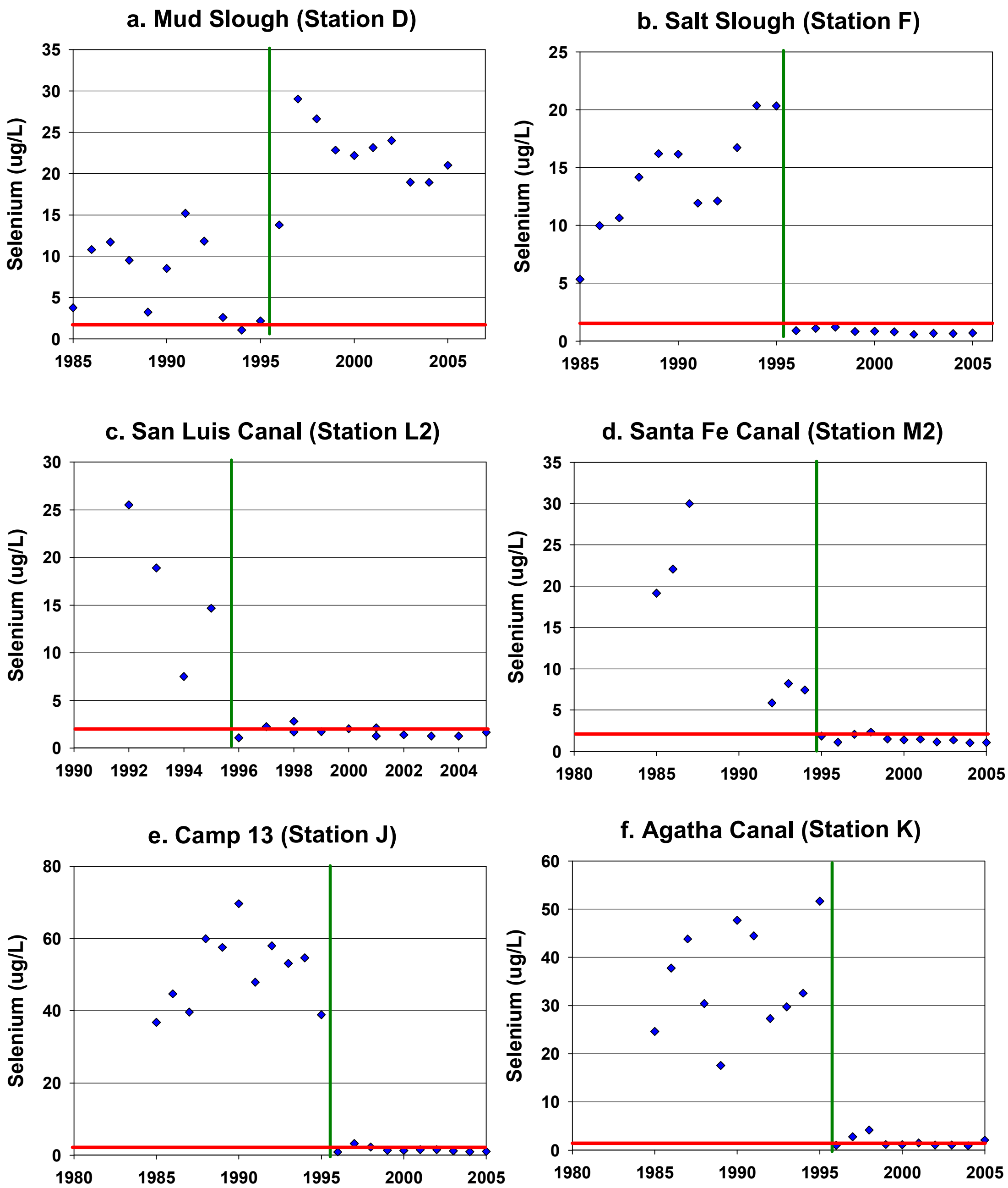

Figure 3.2.4. Water Concentrations Indicator: Mean annual selenium concentrations (μg/L) at Grassland sampling stations (see **Figure 3.2.2**): a) Mud Slough (D), b) Salt Slough (F), c) San Luis Canal (L2), d) Santa Fe Canal (M2), Camp 13 (J), and Agatha Canal (K). The green bar represents the construction of the Grasslands bypass. The red line represents the 2 μg/L reference condition, which is the no effect threshold for fish and bird toxicity and is used as the mean monthly water quality objective.

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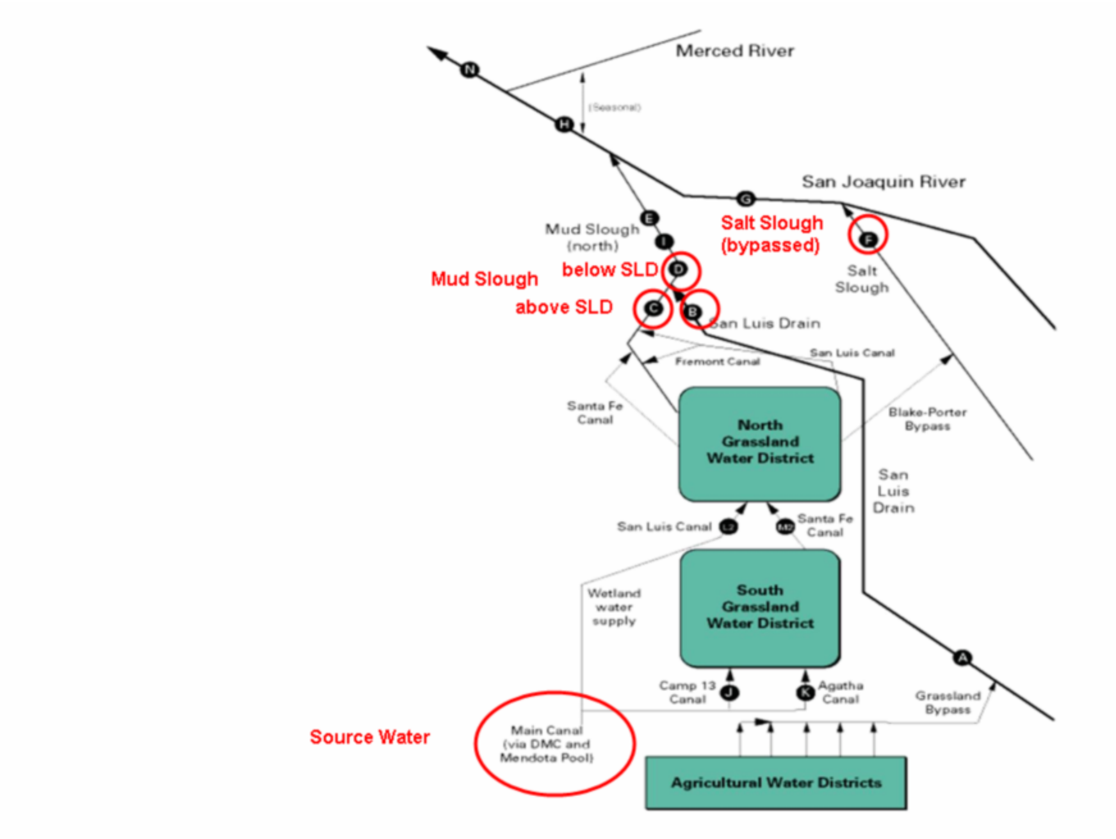

Figure 3.2.5. Sampling site locations for data used in the toxicity indicator.

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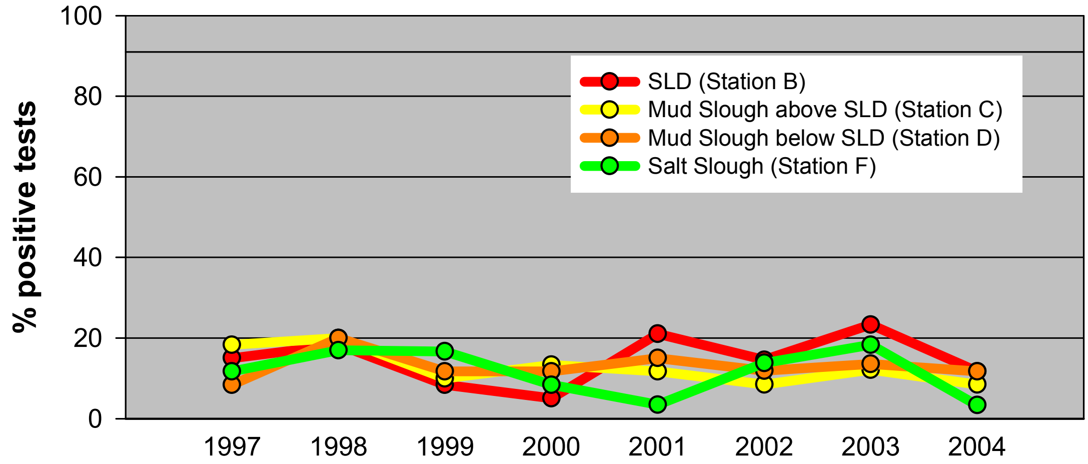

Figure 3.2.6. Aquatic Toxicity Indicator: Percentage of positive toxicity tests per year for four Grassland sampling stations: Station B (SLD, red); Station C (Mud Slough upstream of SLD terminus, yellow); Station D (Mud Slough upstream of SLD terminus, orange); and Station F (Salt Slough green).

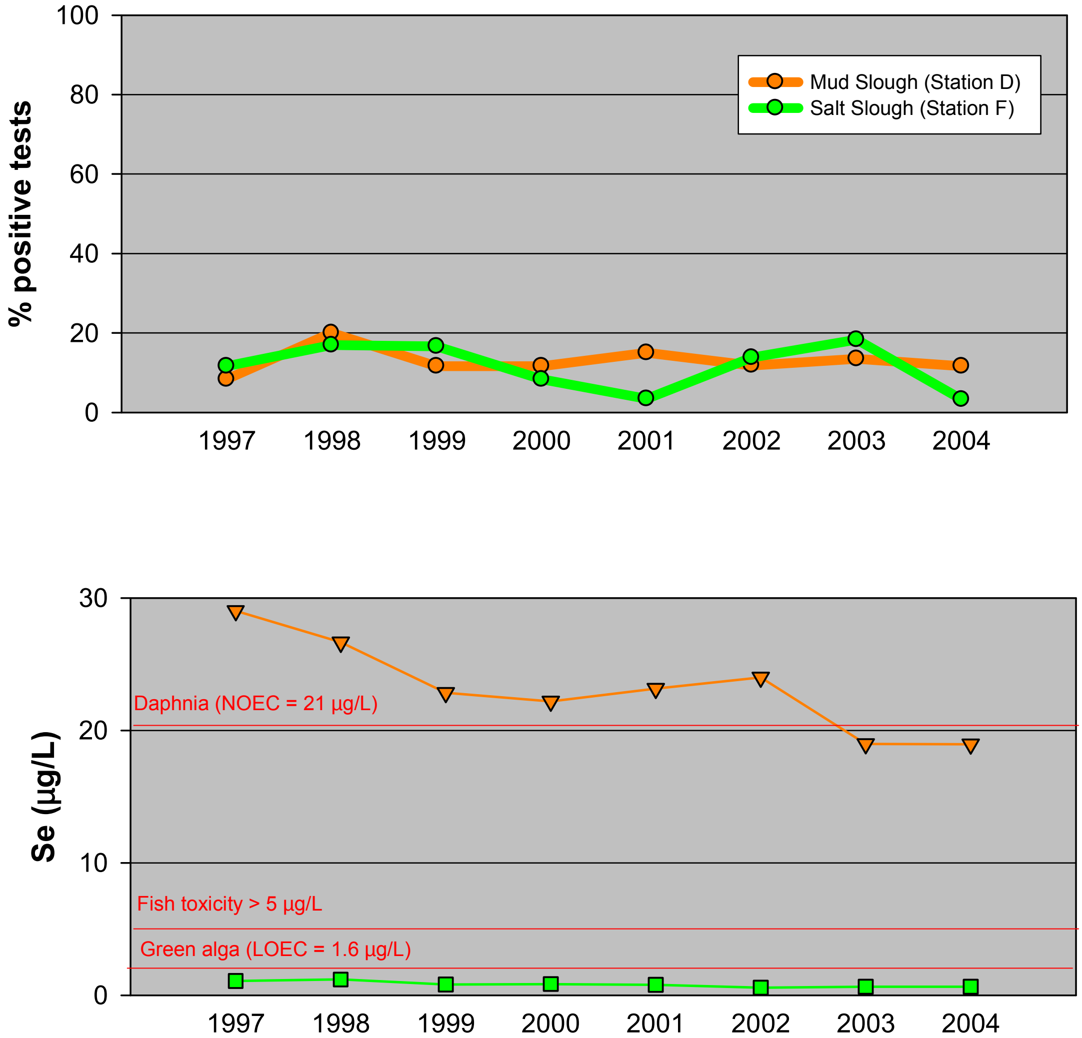

Figure 3.2.7. Comparison of Aquatic Toxicity Indicator results (percentage of positive toxicity tests per year, top) and selenium concentrations (bottom) in Mud Slough (Station D) and Salt Slough. Biological threshold concentrations for test organisms are from the ECOTOX Database (USEPA, 2007)

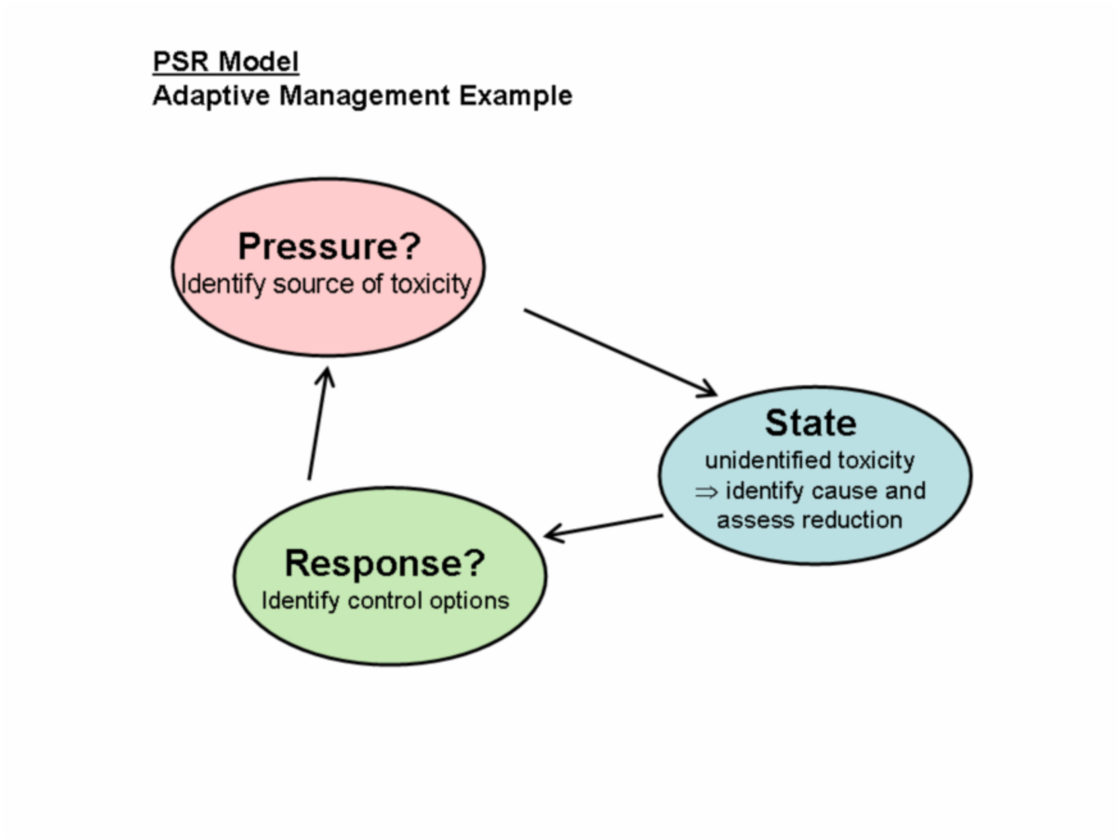

Figure 3.2.8. .This schema depicts how the PSR model applies adaptive management, assuming that the management concern is to protect overall water quality and beneficial use conditions: finding water quality impairment by unknown toxicity points to the need to identify the pressure (what is causing the toxicity?) and the appropriate management response (how to address the problem?).

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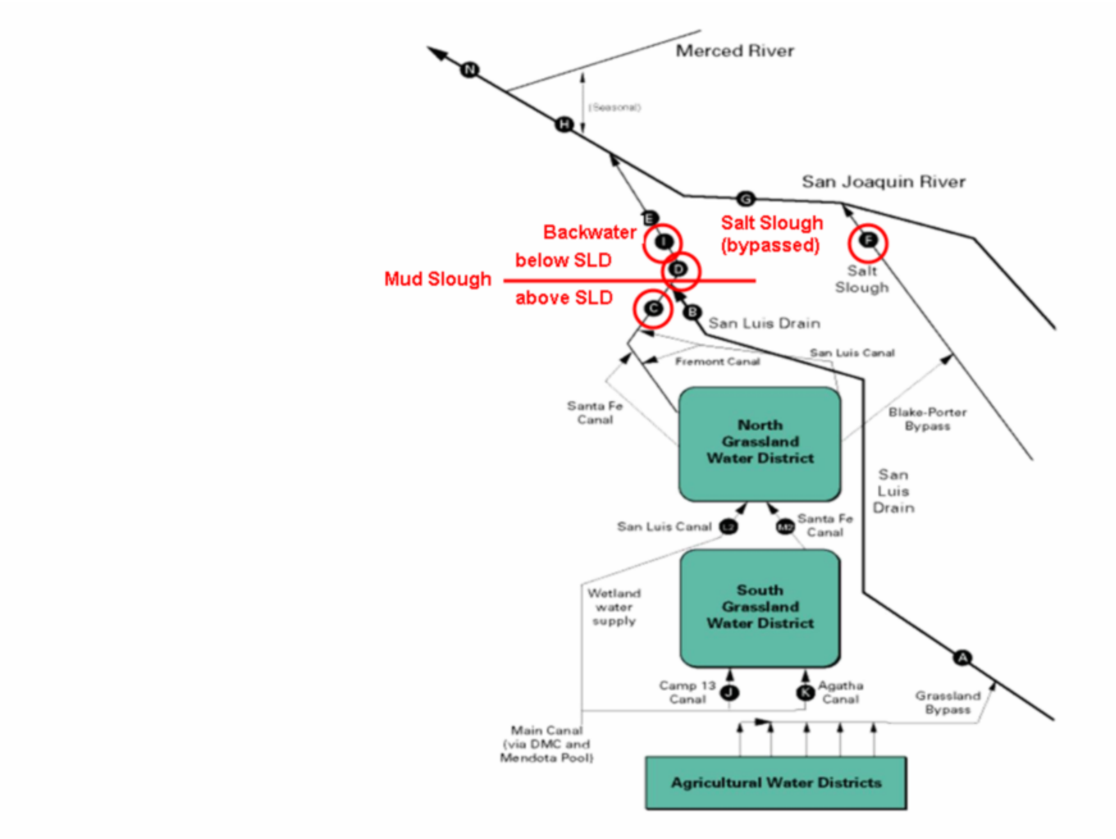

Figure 3.2.9. Sampling site locations for data used in the bioaccumulation indicator.

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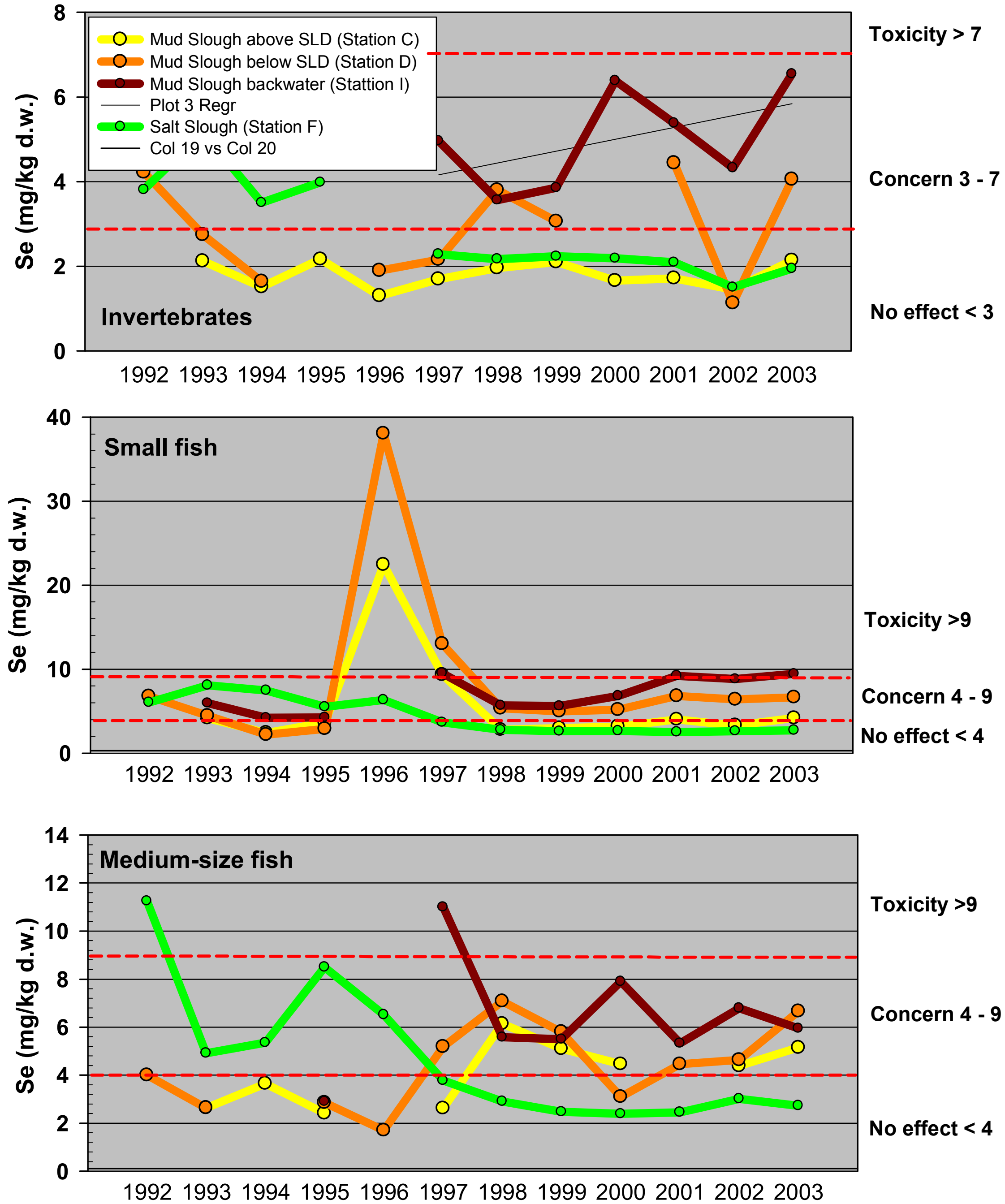

Figure 3.2.10. .Bioaccumulation Indicator – Mean annual whole body concentrations (mg/kg) of selenium in invertebrates (top), small fish (middle), and medium-size fish (bottom) at four Grassland sampling sites. The red dotted lines represent thresholds for levels of concern and toxicity.

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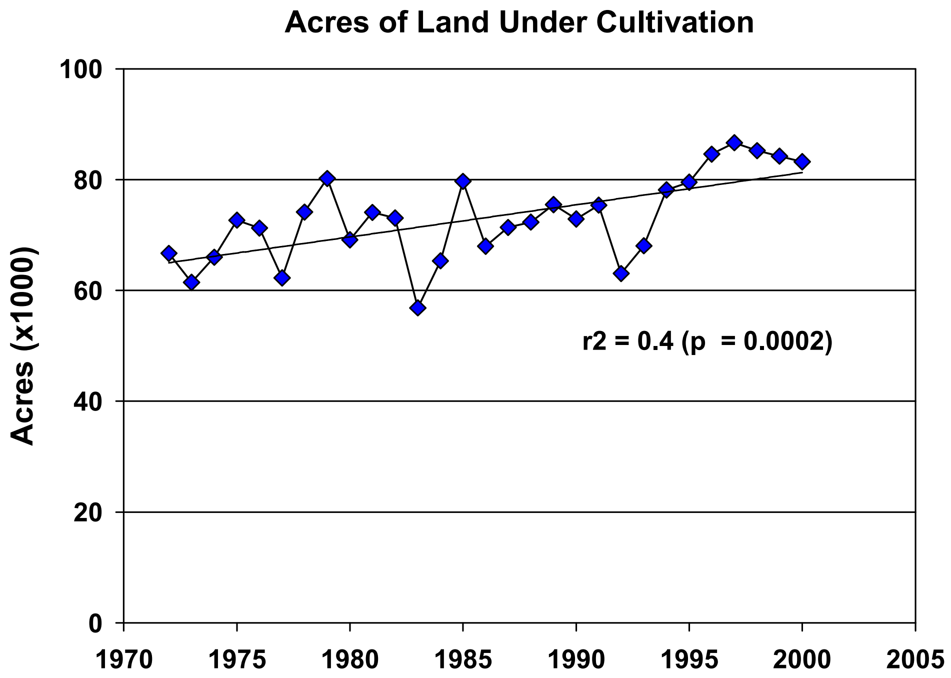

Figure 3.2.11. .Land Retirement Indicator– Acres of cultivated land in the DPA by year.
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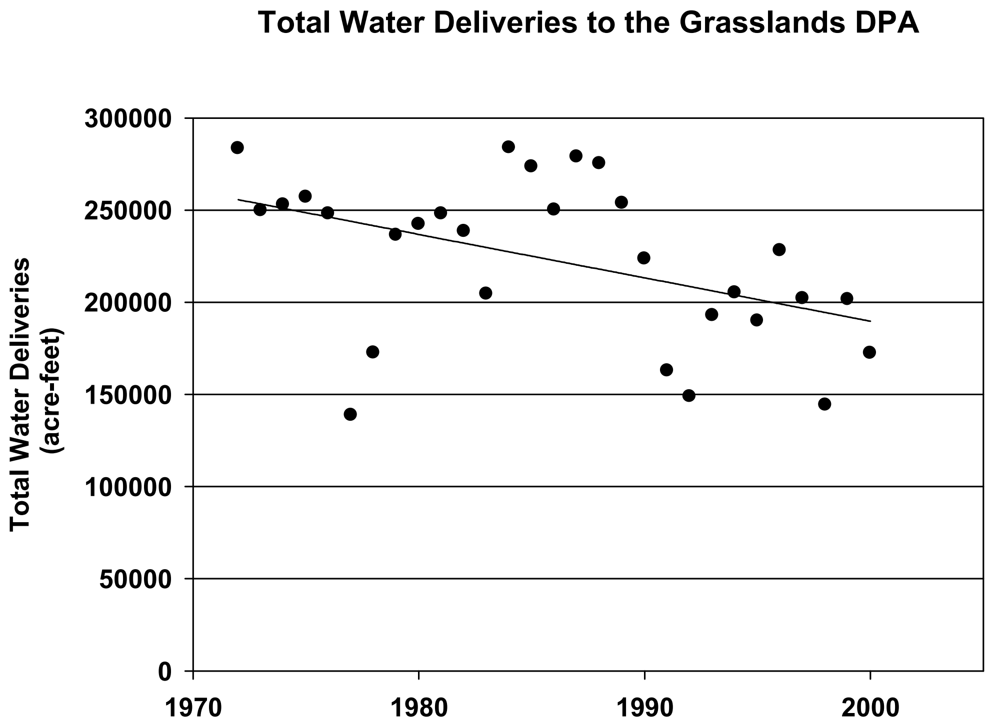

Figure 3.2.12. .Source Water Management Indicator – Total water deliveries to the DPA by year.
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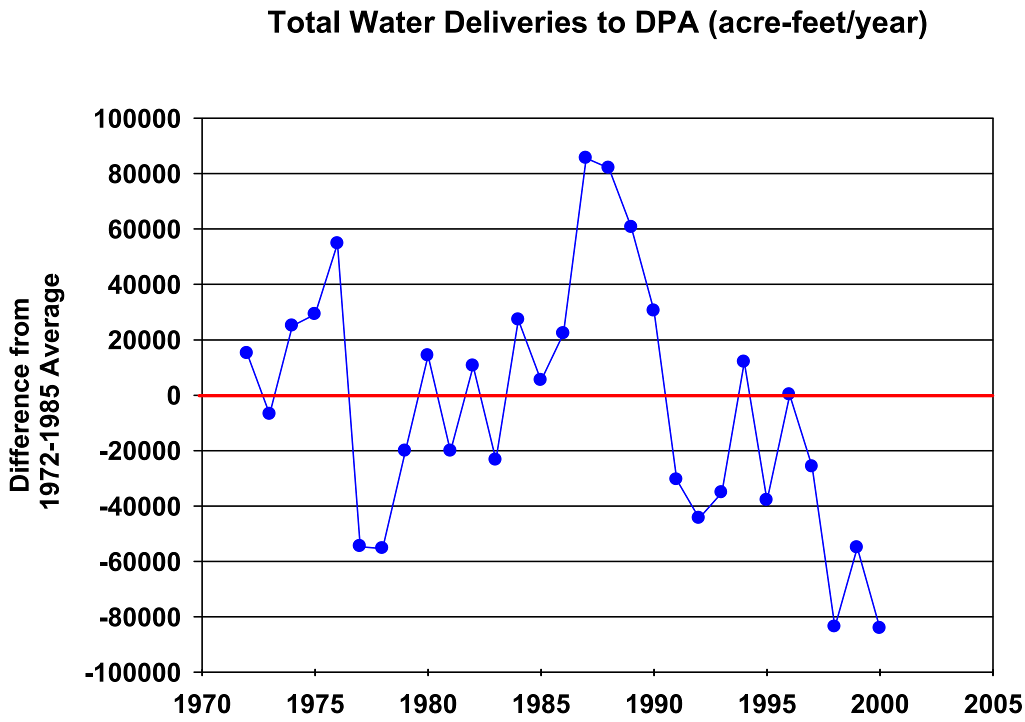

Figure 3.2.13. .Source Water Management Indicator: Normalization by water year type– Total water deliveries to the DPA are normalized by using the 1972 -1985 average (red line).
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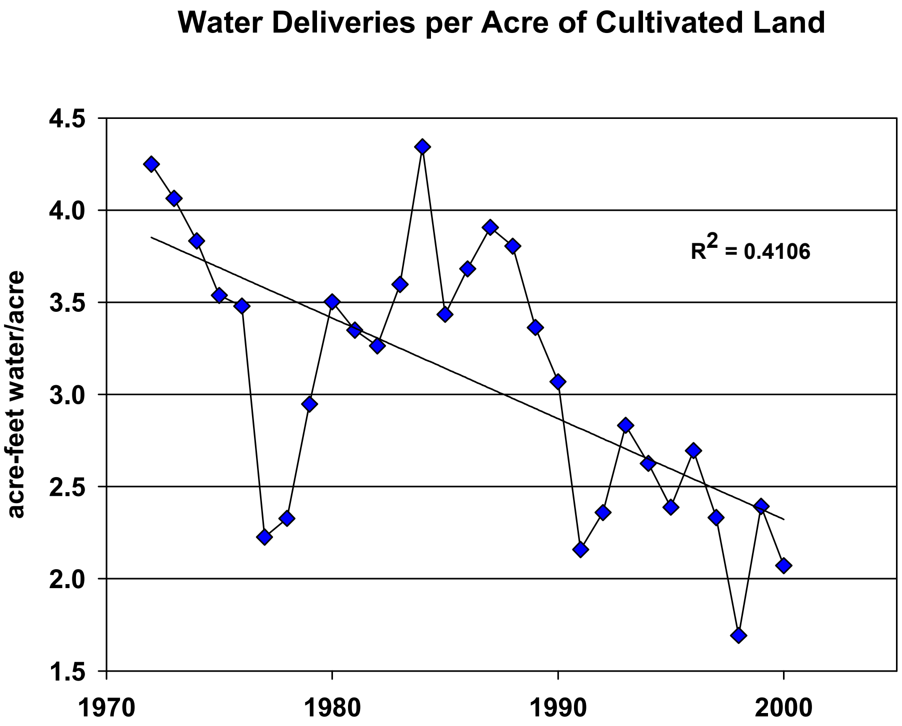

Figure 3.2.14. .Water Conservation Indicator – Total water deliveries (acre-feet) per acre of cultivated land per year.

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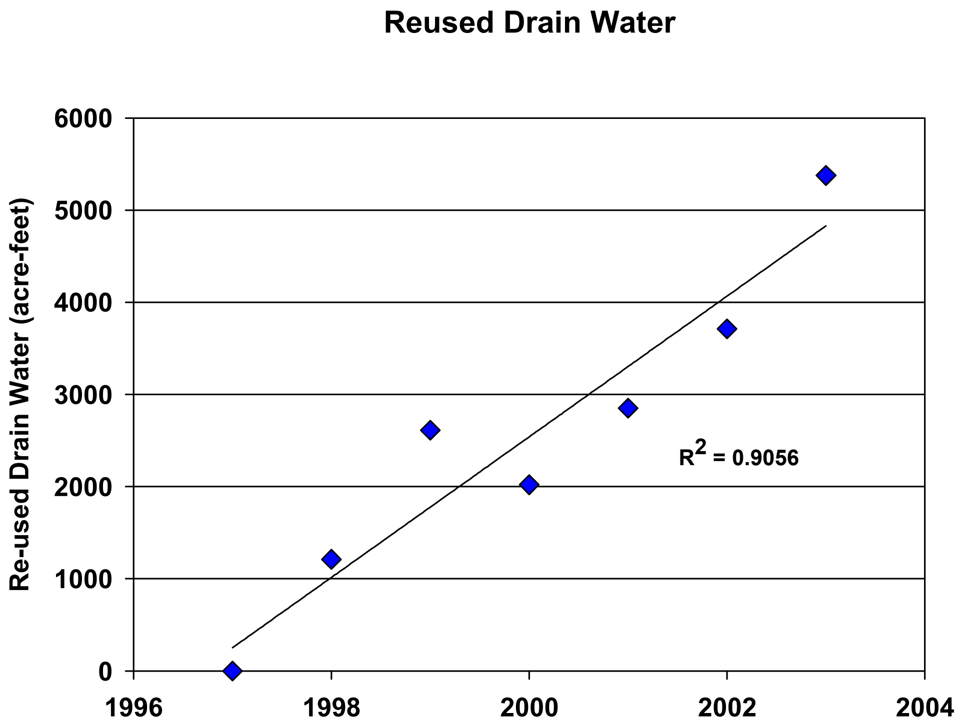

Figure 3.2.15. .Drainwater Reuse Indicator – Re-used drainwater (acre-feet) per year.
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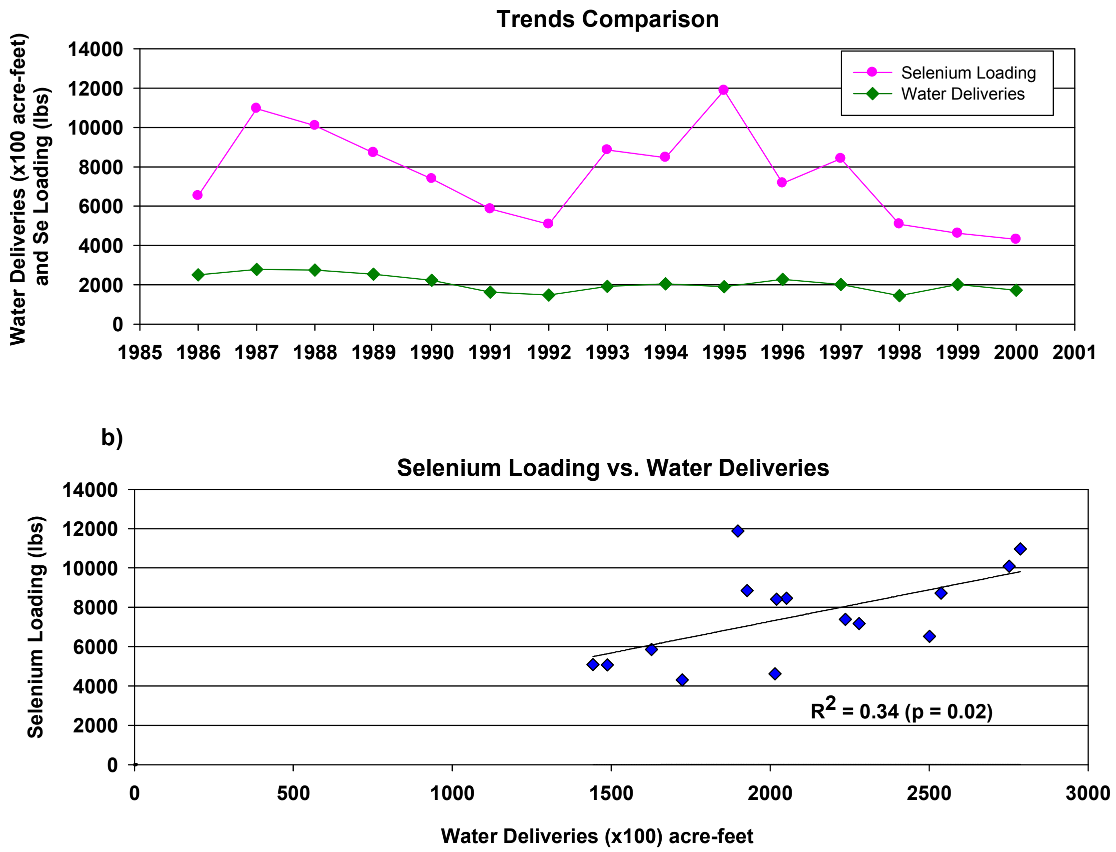

Figure 3.2.16. .Water Use Management (MR 3.1) vs. Drainage Discharge (P4). **a)** Comparison of trends in annual selenium loads (Discharge Indicator) and total annual water deliveries to the DPA (Water Use Management Indicator). **b).** Water deliveries vs. annual selenium loadings to DPA 1986 – 2000.

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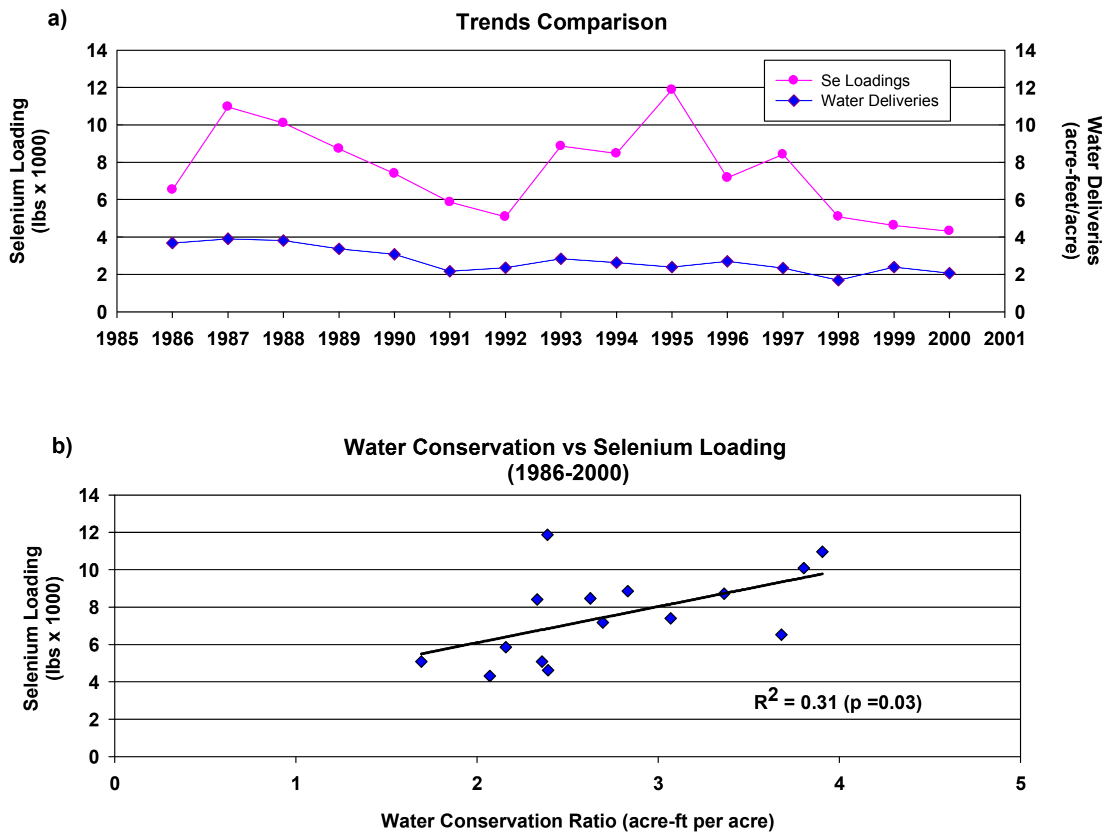

Figure 3.2.17. .Water Conservation (MR 3.2) vs. Drainage Discharge (P4). **a)** Comparison of trends in annual selenium loads (Discharge Indicator) to the DPA and total annual water deliveries per acre cultivated land in the PPD (Water Conservation Indicator) **b)**. Water conservation ratio (ratio of ??? to ???) vs. annual selenium loadings 1986 – 2000.

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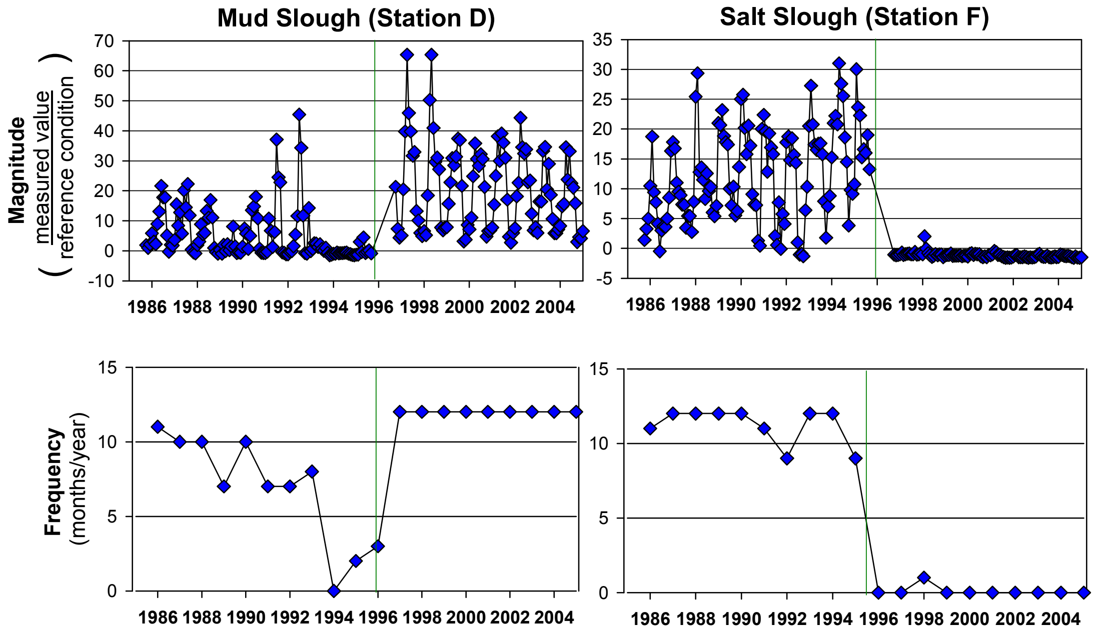

Figure 3.2.18. Water concentrations indicator: Magnitude and frequency of deviation of selenium concentrations from the reference condition (2 μg/L) in Mud and Salt sloughs. The green bar represents the construction of the Grasslands bypass.

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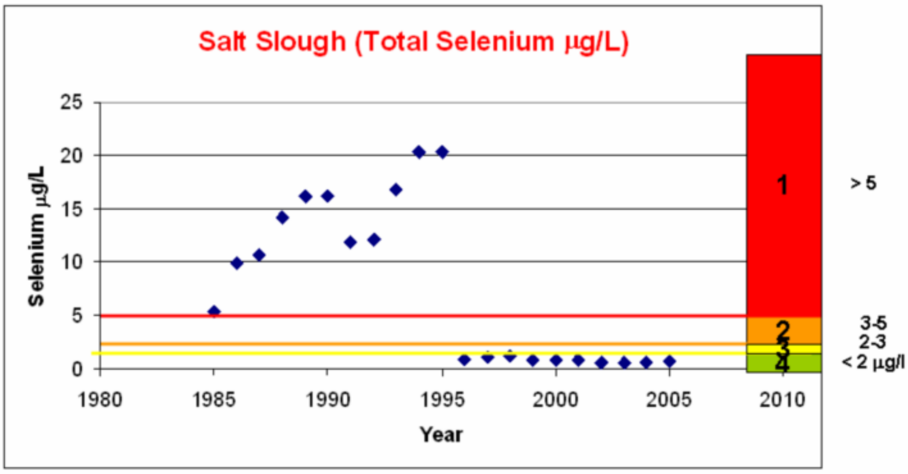

Figure 3.2.19. Water Concentrations Indicator: Example scoring method involving numerical exposure categories(1-4) and color coding (red, orange, yellow, green) with 1 (red) = high exposure (above toxicity threshold for warmwater fish), 2 (orange) = moderate exposure (below toxicity threshold for warmwater fish, but exceeding the level of concern 1.5 times or more), 3 (yellow) = low exposure (exceeding the level of concern for warmwater fish by no more than 1.5 times), and 4 (green) = minimal exposure (below level of concern for warmwater fish). The exposures categories are gleaned from Lemly's aquatic hazard index for selenium (Lemly, 1995)

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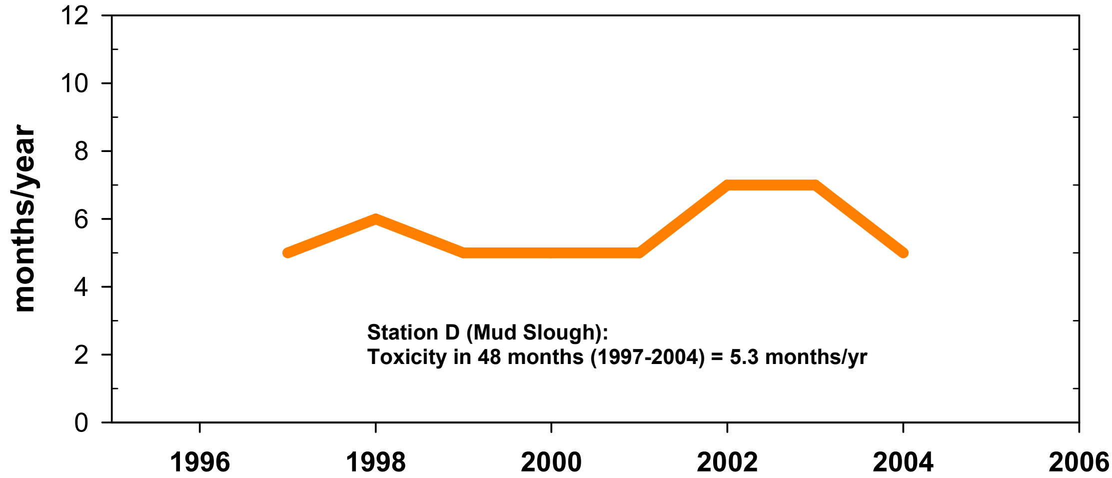

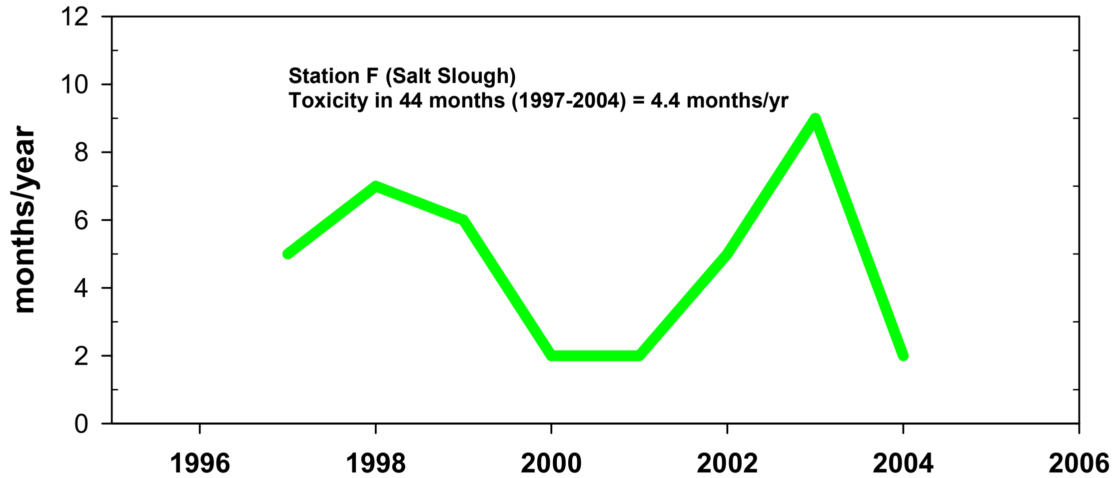

Figure 3.2.20. Aquatic Toxicity Indicator: Frequency of Toxicity. Overall, toxicity was observed just slightly more frequently (~20%) in Mud Slough (Station D) than in Salt Slough, in terms of months with positive toxicity testing results.

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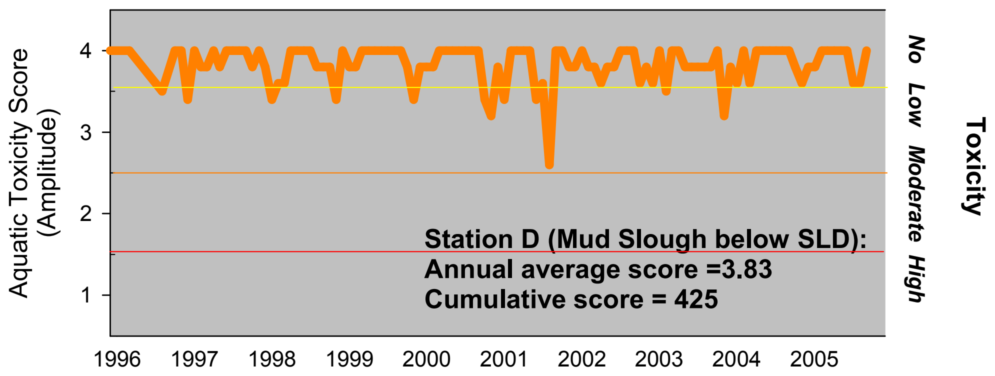

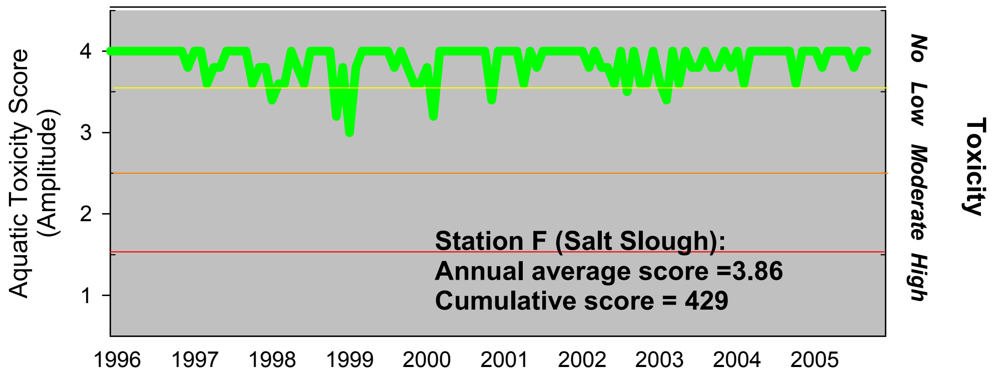

Figure 3.2.21. Aquatic Toxicity Indicator: Amplitude of Toxicity. Using this measure of variance, there is only a minute difference between Mud Slough (Station D) and Salt Slough (Station F) and overall score for both sampling stations is 3.86 = no aquatic toxicity.

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Table 3.2.1. .Timeline of the regulatory and management context for the Grassland/selenium case study.

	Water Year Type[27]	Events	Regulatory/Policy	Management
1933	**D**		State legislature passes the California Central Valley Project Act	
1934	C			
1935	AN			
1936	AN			
1937	**W**			
1938	**W**			
1939	**D**			
1940	AN			
1941	**W**			
1942	**W**			
1943	**W**			
1944	BN			
1945	AN			
1946	AN			
1947	**D**			
1948	BN			
1949	BN			
1950	BN			
1951	AN			
1952	**W**			
1953	BN			
1954	BN			
1955	**D**			
1956	**W**			
1957	BN			
1958	**W**			
1959	**D**			
1960	C			
1961	C			
1962	BN			
1963	AN			
1964	**D**			
1965	**W**			
1966	BN			
1967	**W**			
1968	**D**			
1969	**W**			
1970	AN			
1971	BN			
1972	**D**			
1973	AN			
1974	**W**			
1975	**W**			

[27] AN = above normal, BN = below normal, C = critical, D = dry, N = normal, W = wet.

	Water Year Type[28]	Events	Regulatory/Policy	Management
1976	C			Construction of Westlands and Grassland drainage collector system begins
1977	C			
1978	**W**			
1979	AN			
1980	**W**			
1981	**D**			
1982	**W**			
1983	**W**	Tile drain discharges from the alluvial fan lands on the west side were discovered to contain elevated levels of selenium, causing death and deformity in birds in Kesterson Reservoir.		
1984	AN			
1985	**D**			Wetland managers use a complicated "flip-flop" system to alternately transport agricultural drainage and wetland supply water through the Grasslands conveyance system.
1986	**W**			
1987	C			
1988	C			
1989	C		SWRCB approves selenium, boron, and molybdenum water quality objectives for the Lower San Joaquin River, Mud Slough (north), Salt Slough, and wetland water supplies	
1990	C			
1991	C			
1992	C		Congress passes the Central Valley Project Improvement Act (CVPIA), which mandates an increased volume of fresh water be allocated to the wetlands in Grassland Water District (GWD)	
1993	**W**			
1994	C			

[28] AN = above normal, BN = below normal, C = critical, D = dry, N = normal, W = wet.

	Water Year Type[29]	Events	Regulatory/Policy	Management
1996	**W**		The Regional Board amends its Basin Plan for control of agricultural subsurface drainage discharges. This Basin Plan Amendment prohibits discharge of subsurface drainage water to Grassland wetland supply channels if the discharge results in concentrations exceeding the selenium water quality objective of 2ppb.	Several irrigation districts form the Grassland Area Farmers, a drainage entity that implements a wide variety of practices to meet selenium load limits, including an active land management program to use subsurface drainage on salt-tolerant crops, installation of improved irrigation systems, installation and use of drainage recycling systems to mix subsurface drainage water with irrigation supplies under strict limits, and tiered water pricing.
1997	**W**			
1998	**W**			Some Grassland Area districts adapt "zero-tailwater discharge" policy
1999	AN		USBR proposes to purchase up to 137,500 acre-ft of water annually from the San Joaquin River Group Authority in support of VAMP and to increase instream flows in the San Joaquin River and its tributaries (Stanislaus, Tuolumne, and Merced rivers) in accordance with measures authorized by the CVPIA (i.e., provide protective measures for fall-run Chinook salmon)	

29 AN = above normal, BN = below normal, C = critical, D = dry, N = normal, W = wet.

	Water Year Type[30]	Events	Regulatory/Policy	Management
2000	AN		VAMP officially initiated in 2000 as part of SWRCB Decision 1641	
2001	**D**			
2002	**D**			
2003	BN			
2004	**D**			
2005	**W**			

References: CVPIA (1992), CVRWQCB (1998c), DWR (2007), SFEI (2006a), SWRCB (2000), USBR (1999), USBR (2007), USEPA (2002), Westlands Water District (2004).

[30] AN = above normal, BN = below normal, C = critical, D = dry, N = normal, W = wet.

Table 3.2.2. .List of laboratory toxicity tests performed for Grassland Bypass Project.

Organism	Test	Units of Measure
Daphnia magna	Short-term Acute Survival	% survival
Fathead minnow	7-day Acute Larval Survival	% survival
Daphnia Magna	Short-term Chronic Reproduction	Neonates/female
Fathead minnow	7-day Chronic Larval Growth	mg
Green alga *Selenastrum capricornutum*	96-hour growth test	Cells/mL

Table 3.2.3. Summary of aquatic toxicity indicator results – Percentage of positive toxicity tests per year.

Year	Station B	Station C	Station D	Station F
	SLD near terminus	Mud Slough upstream of SLD	Mud Slough downstream of SLD	Salt Slough
1997	15%	18%	8%	12%
1998	18%	20%	20%	17%
1999	8%	10%	12%	17%
2000	5%	13%	12%	8%
2001	21%	12%	15%	3%
2002	15%	8%	12%	14%
2003	23%	12%	14%	18%
2004	12%	8%	12%	3%
Mean $\pm$ SD (97-04)	15$\pm$6%	13$\pm$4%	13$\pm$3%	12$\pm$6%

Table 3.2.5. .Species included in bioaccumulation indicator..

Category	Species
Invertebrates:	Amphipod, backswimmer, Chinese mitten crab, crayfish, damselfly, dragonfly, giant waterbug, isopod (aquatic sowbug), red crayfish, Siberian freshwater shrimp (Exopalaemon modestus), snail, waterboatman, zooplankton
Medium fish:	Black crappie, bluegill sunfish, carp, catfish, channel catfish, goldfish, green sunfish, largemouth bass, log perch, pikeminnow, Sacramento blackfish, sculpin, splittail, striped bass, sunfish (unidentified, mixed), threadfin shad, white catfish, white crappie
Small fish:	Inland silverside, fathead minnow, mosquitofish, red shiner

Table 3.2.6. .Cropping Indicator – Acreage of land cultivated with salt-tolerant crops in the PDD.

Year	Acres
1985 - 1995	0
2001	3863
2003	3873

Table 3.2.7. Water Concentrations Indicator: Example for a water quality report card based on the scoring method illustrated in **Figure 3.1.19**. * estimated of total area of surface water in the Grasslands.

Site	Trend	Score (Before Bypass)	Score (After Bypass)	% surface water area*
Mud Slough (Station D)		1	1	<1%
Salt Slough (Station F)	↑	1	4	<1%
Camp 13 (Station J)	↑	1	4	
Agatha Canal (Station K)	↑	1	4	> 98%
San Luis Canal (Station L2)	↑	1	4	
Santa Fe Canal (Station M2)	↑	1	4	
Overall	↑	1.00	3.9	

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Table 3.2.8. Aquatic Toxicity Indicator: Example for toxicity categories and thresholds that are statistically defined. The example is adapted from the MLOE approach for development of sediment quality objectives by the State of California (SWRCB, 2006)(see text).

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Toxicity Category	Threshold
1 – High Toxicity	50% of the lowest control value
2 – Moderate Toxicity	Significantly different from controls AND below the lowest control value.
3 – Low Toxicity	Not significantly different from control AND below the lowest control value, OR significantly different from control and above the lowest control.
4 - Not Toxic	Not significantly different from controls AND above the lowest control value for the test-type

References

Brush, C. F., Berlitz, K. and Phillips, S. P. 2004. Estimation of a Water Budget for 1972–2000 for the Grasslands Area, Central Part of the Western San Joaquin Valley, California. Scientific Investigations Report 2004–5180--Version 1.1. U.S. Geological Survey, Reston, VA.

Central Valley Improvement Act (CVPIA). October 30, 1992. 34 USC 3401-3412 (PL 102-575).

CVRWQCB. 1998a. Loads of Salt, Boron, and Selenium in the Grassland Watershed and Lower San Joaquin River, October 1985 to September 1995, Raw Data Supplemental Appendix. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 1998b. Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1997 – September 1998. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 1998c. Compilation of Electrical Conductivity, Boron, and Selenium Water Quality Data for the Grasslands Watershed and San Joaquin River: May 1985– September 1995. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2000. Selenium TMDL for Grasslands Marshes. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2001. Total Maximum Daily Load for Selenium in the Lower San Joaquin River. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2004a. Amendments to the Water Quality Control Plan for the Sacramento and San Joaquin River Basins for the Control of Salt and Boron Discharges to the Lower San Joaquin River. Final Draft Staff Report. California Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

CVRWQCB. 2004b. Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for The Control of Salt and Boron discharges into the Lower San Joaquin River. Draft Final Staff Report. Appendix 1. Technical TMDL Report. California Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

CVRWQCB. 2006. Water Quality Control Plan for the Sacramento River and San Joaquin River Basins. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

Environmental Defense, E. 2000. A success story. *http://www.environmentaldefense.org/article.cfm?ContentID=2021*.

DWR. 2006. California Data Exchange Center. *http://cdec.water.ca.gov/*.

DWR. 2007. Water Data Library (WDL). *http://wdl.water.ca.gov/*.

Canadian Council of Ministers of the Environment. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0. In Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB, 13p.

IEP. 2006. Dayflow. *http://www.iep.ca.gov/dayflow/index.html.*

Lee, G. F. and Jones-Lee, A., "Groundwater Quality Protection Issues," Report of G. Fred Lee & Associates, El Macero, CA, February (2007).

Lemly, A. D. 1995. A protocol for aquatic hazard assessment of selenium. Ecotoxicology and Environmental Safety 32: 280-288.

Quinn, N. W. T., Linneman, J. C., and Tanji, K. K. 2006. The San Joaquin Valley Westside Perspective. Paper LBNL-60613. Lawrence Berkeley National Laboratory, University of California, Berkeley, CA.

SFEI. 2006a. Grassland Bypass Project. *http://www.sfei.org/grassland.*

SFEI 2006b. Grassland Bypass Project Annual Report 2003. San Francisco Estuary Institute, Oakland, CA.

SJRWQMG. 2005. Summary Recommendations of the San Joaquin River Water Quality Management Group for Meeting the Water Quality Objectives for Salinity Measured at Vernalis and Dissolved Oxygen in the Stockton Deep Water Ship Channel. San Joaquin River Water Quality Management Group.

SWRCB. 1995. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. State Water Resources Control Board, Sacramento, CA.

SWRCB. 2000. Revised Water Right Decision 1641. State Water Resources Control Board, Sacramento, CA.

SWRCB. 2006. Development of Sediment Quality Objectives for Enclosed Bays and Estuaries. State Water Resources Control Board, Division of Water Quality, Sacramento, CA.

Tanji, K. K., Wallender, W. W. and Rollins, L. T. 2002. Irrigation drainage water management options: San Joaquin Valley case study. 17th World Congress of Soil Science, Bangkok, Thailand.

Thelander, C.G. and M. Crabtree. 1994. Life on the Edge. A Guide to California's Endangered Natural Resources: Wildlife. BioSystems Books, Santa Cruz, California.

USBR. 1999. Meeting Flow Objectives for the San Joaquin River Agreement, 1999 – 2010.. Final EIS/EIR. U.S. Bureau of Reclamation, Sacramento, CA..

USBR. 2005. Grassland Bypass Project. *http://www.usbr.gov/mp/grassland/*.

USBR. 2006. San Luis Drainage Feature Re-evaluation. Final Environmental Impact Statement. U.S. Bureau of Reclamation, Sacramento, CA.

USBR. 2007. Central Valley Project (General Overview). *http://www.usbr.gov/dataweb/html/cvp.html.*

USEPA. 2002. Section 319 Success Stories, Vol. III. *http://www.epa.gov/nps/Section319III/CA.htm*

USEPA. 2007. ECOTOX Database Release 4.0. *http://cfpub.epa.gov/ecotox/*.

Westlands Water District. 2004. Westlands Water District Historical Timeline. *http://www.westlandswater.org/wwd/aboutwwd/timeline.pdf.*

Section 4. Conclusions and Recommended Next Steps

The project applied PSR to develop and test example indicators for salt in the San Joaquin basin and selenium in the Grasslands and also provided examples for aggregating indicators of water quality condition into multi-metric indexes.

For each of the two examples, we believe the indicators that were developed were adequate to demonstrate the feasibility of using PSR to identify and evaluate (1) what types of assessment questions, indicators, and associated measurements are needed to create a meaningful line of evidence between water quality state, pressures, and management response ; and (2) if appropriate data are being collected to inform the assessment questions. For many state and some pressure variables, data were sufficient to subject the indicators to rigorous "testing" against indicators selection and evaluation criteria that were previously establish, for example, through the EPIC process and EPA's Evaluation Guidelines for Indicators.

One of the major strengths of PSR is that it provides a systematic representation for organizing, categorizing, and identifying monitoring and assessment questions and potential indicators. Its use can thus be instructive by helping to identify data needed and variables to be measured to address a specific assessment question. Depending on user needs and interests, it can be employed as an instructional or strategic tool in the facilitation of water quality management planning. Potential applications of the framework may include, for example, the design of a process for tracking and assessing effects of management actions on a large (e.g., basin-wide) scale, the development of testable hypotheses regarding effects of management action, or as shown in the toxicity example, the identification of data needs or potential monitoring efficiencies.

On the other hand, some potential indicators could not be calculated and/or tested, because data were not available, insufficient, or needed greater compilation or development than the resources of this project allowed[31]. This was especially an issue for management response indicators, for which the data or documentation usually not exist to establish indicator specificity or responsiveness to an assessment question. In addition, there is often no appropriate or established reference condition for these indicators. Although we were able to demonstrate trends in management response indicators, cause-effect relationships between pressure and state on one hand, and management response on the other, cannot be readily quantified with available data. Because there are usually a multitude of management responses intended to reduce pressures and improve conditions, the difficulty of quantifying linkages between individual management responses and environmental variables remains as a challenge.

Recommended next steps include the development of pilot projects for testing the Framework that involve a more systematic tracking of investments in management responses versus environmental outcomes. Testing on the pilot scale should involve the

[31] For the same reason, it was also not possible to test in more detail how to framework applies to multiple temporal and geographical scales as well as multiple contaminants.

careful development of hypotheses regarding effect of management actions. Due to the difficulties of developing meaningful indicators on the basin scale, an aggregation method should be developed and tested that would allow “upscaling” of watershed scale indicator/indexes for basinwide assessments

WATER QUALITY AND MANAGEMENT RESPONSE INDICATORS FOR THE SAN JOAQUIN RIVER (SJR) BASIN

Project Update
August 1, 2006

Prepared for the Project Steering Committee
by
Thomas Jabusch
San Francisco Estuary Institute

Dear Committee,

As we are in the process of planning and rescheduling our second and final steering committee meeting, we also provide you with a short synopsis of our progress since the first meeting on April 5. In this progress update, you can see and review how we addressed your questions, requests, and suggestions from the first meeting. It will also give you an opportunity to review several completed products and the tentative agenda for our upcoming meeting.

Where we were: First Steering Committee Meeting on April 5, 2006

The discussion of the first meeting focused mainly on three elements

1. **Conceptual Model**
   Pressure-State-Response (PSR) model, blended with the EPA Science Advisory Framework for Assessing and Reporting on Ecological Condition, as a conceptual framework to characterize water quality and management responses in the San Joaquin River basin
2. **Assessment Questions and Potential Indicators**
   Adaptation and use of the conceptual model for developing indicators and assessment questions; and
3. **Data Sources**
   Identification of data sources and availability for indicators and assessment

Carolyn Yale (project coordinator and grant manager, EPA Region IX Water Division) previously distributed the meeting minutes. They are attached (Attachment A) for reference. Attachments B-E summarize work completed since then in response to your questions and recommendations.

A tentative agenda for the next steering committee meeting is also included (Attachment F). We are planning to present real-world examples of how the developed indicator framework can be applied and used to think about:

1) Are we collecting the right kinds of data?
2) Are there surrogates that are cheaper to collect and analyze, but that could provide us with the same or more information at a greater weight of evidence?
3) Can we relate management actions to environmental results (i.e. changing the conditions to a more desirable state)?
4) Are the data/information being used to change management actions, environmental condition targets, or hypotheses?

Attachments:

A. Meeting notes from first SC meeting
B. Revised conceptual models
C. Refined project scope
D. Revised assessment questions
E. Revised glossary
F. Tentative agenda

San Joaquin River Watershed Indicator Project
Summary: Steering Committee Meeting 4/5/2006

NOTE: materials for the project are posted at:
ftp://anonymous@ftp.sfei.org/pub/outgoing
click on
San Joaquin Indicators Steering Committee Package.

Purpose of first Steering Committee meeting:

To receive comments on:

* PSR
* draft indicators and assessment questions
* data sources for indicators and assessment

Key discussion points:

1. The project is intended to establish and test, in the San Joaquin Basin, an indicator framework which can address water quality conditions at differing scales and which is generally applicable across major watersheds in California.

2. The pressure-state-response model is intended to express iterative cause-effect relationships between state/condition (in this case water quality, including physical, chemical, and biotic factors), pressures ("anthropogenic" factors which affect state), and responses (management actions with respect to pressures which, in turn, affect state/condition).

3. The framework used by this project (PSR model, indicators, assessment questions) should be transferable to other indicator/performance measure efforts.

4. In consideration of time (completion in 2006) and funding limits, the project needs to focus on and test the indicator framework for a few key water quality parameters.

5. At this meeting we are considering what parameters and geographic areas might provide sufficient data for application of the PSR framework. Also, who should be contacted for further information on management practices, baseline existing water quality data, assessments and the like?

6. How can the project product help improve future management activities on the ground and by regional, state, and federal agencies? Will there be difficulties in assessing effects of management actions? How can we deal with uncertainties and data gaps in a scientifically credible way?

Outcomes and tasks:

7. Improve the conceptual model for pressure-state-response (especially Figures 2 and 4): Distinguish between management response (change in an action, such as irrigation practice or municipal discharge) and system response (measured effect in the environment). Discussion: There are at least three potential metrics here. First, there is the change in the management activity (e.g., reduced water application). Next, the action will have an intended result (or output), such as reduction in salt loading, as well as an effect on the system (which may differ from the output). It may be difficult to detect that effect; also, the intended outputs and effects may not come about for a variety of reasons (scale, intervening variables, etc.). Hypotheses and assumptions regarding the outputs and effects of an action (and ways in which these effects occur) need to be explicit.

8. Given limited time and resources, focus on two water quality parameters and (for one of the parameters) three scales:

Selenium—Grasslands watershed

Salt—municipal level (e.g., Modesto), Grasslands watershed, lower SJ Basin

These subjects and areas were selected for expected data-richness, importance to the overall management of water in the basin, and progress made to date on TMDLs. They should allow development and testing of indicators and evaluation of a monitoring framework. Additionally, extensive data collection in the Grasslands should allow the project to consider "how much data is sufficient" for various management purposes.

9. Table 3 revisions:

-- Reorganize and revise Table 3 (Assessment questions and indicators). Reflect different scales (i.e., nest the questions, with reference to selected scales identified above). Also revise assessment questions/indicators to track the revised PSR model (distinguishing between the management response and the system response). Consider which assessment questions are most useful for on-the-ground management.

-- Solicit additional entries for the list of assessment questions and indicators. (Look for questions which would be relevant to management activities such as TMDL implementation, the Irrigated Lands Waiver Program, watershed programs, etc.)

10. Revise the Glossary to include:

baseline (starting point, basis of comparison for gauging changes)

uncontrollable

11. We set aside Steering Committee consideration of review question #5 [Are the conceptual models and lists of indicators generic enough to be transferable to other programs (e.g., TMDL) and watersheds?] However, EPA and other agencies should provide guidance to the project on this subject.

Details of discussion:

12. The Science Advisory Board (SAB) framework used by the Resources Agency and CalEPA to develop watershed condition indicators provides a way of classifying watershed attributes. In this context, our project focuses on physical, chemical, and hydrological attributes
13. This project is not designed to test cause-effect relationships (for example, the relationships between drivers such as management activities and water quality changes); it will rely on previous studies and other evidence. The project is looking for information to document the basis for hypothesized/assumed cause-effect linkages and measures (preferably quantitative) of effects of actions.

14. There were questions regarding outreach and whether the project anticipates involving local stakeholders. The project provides for some outreach in the last task (presenting and discussing results). It was suggested that earlier engagement of parties such as watershed groups which have completed some assessment/planning/implementation might assist in developing and testing indicators at the local level. Also, representatives of the Great Valley Center should be kept apprised of the project throughout all tasks and encouraged to participate.

15. Will the final product of this grant inform better management decisions? How? Will it be possible to make statements about the relative effectiveness of management practices, for example? This is desirable. However, availability of data distinguishing specific activity-level outputs may be limited.

16. The Table 3 component Indirect Management Measures elicited discussion. Several SC members pointed out that social and economic information may help explain management responses (e.g., adoption of nonpoint source best management practices). However, several advised against including indirect management measures, such as policy and regulation, in the Table; instead, information on these factors should be provided along with the response indicators.

Follow up for Steering Committee:

Committee members are encouraged to submit additional comments on workshop topics to Thomas Jabusch (thomasj@sfei.org) and Max Delaney (max@sfei.org).

Specific requests:

Information to expand the data summary table (data sources, contacts).
Additional assessment and indicator entries for Table 3.

1. <u>Steering Committee Request 1:</u> Improve the conceptual model for pressure-state-response:

a. Distinguish between management response (change in an action) and system response (measured effect in the environment).
b. Formulate specific hypotheses and assumptions regarding the outputs and effects of an action (and ways in which these effects occur).

A revised version of the PSR conceptual model for the San Joaquin River is presented in **Figures 1** and **2**. The rationale for this framework is as follows:

- Adaptive management can only happen if we can develop a line of evidence that links actions with environmental outcomes (are we collecting the right kinds of data to help answer the right kinds of questions? Are all data being used in decision-making either at the site-specific scale, such as a particular management area, or at the policy scale, such as adjusting TMDL targets, or focusing on pro-active prevention of emerging issues?)
- Systematically organizing information according to an agreed-upon framework can help identify critical gaps as well as potential monitoring efficiencies that might currently not be realized.
- The framework can be used as a communication tool and road map with the various stakeholders to avoid "getting lost" in the complexity of issues.

A main objective for the revisions was to more clearly illustrate how the individual components of the conceptual framework, the boxes in **Figure 2**, relate to the generic PSR triangle of **Figure 1**. Individual components of each part of the PSR are now graphically grouped together and systematically indexed:

- Water quality pressure categories P1-5:
  - P1. Soil & land use
  - P2. Water
  - P3. Air
  - P4. Discharge
  - P5. Application
  - P6. Hydro-regime modification
- Water quality state categories WQ1-4:
  - WQ1. Water and sediment quality
  - WQ2. Toxicity
  - WQ3. Sublethal effects
  - WQ4. Bioaccumulation
- Management response categories MR1-5:
  - MR1. Direct application practices

MR2. Land management
MR3. Water use management
MR4. Treatment
MR5. Flow management

In this model description, management responses address impairments of water quality and beneficial uses by reducing pressures on water quality (**Figure 1**). The system response to reduced pressure is measured as the resulting change in water quality condition (state)(see **Figure 1**).

Figures 3 and **4** provide examples that illustrate the conceptual linkage of individual management response categories and pressure categories.

Hypotheses and assumptions regarding the outputs and effects of management response actions (and ways in which these effects occur) are based on the specific conceptual models for water quality impairments, and these will be demonstrated for selected examples (Selenium in Grasslands, salinity in the SJR basin) at the upcoming meeting. However, it has already been clarified during the previous meeting, that this project is not designed to test cause-effect relationships such as those between management activities and water quality changes. We rely on the findings of previous studies and other evidence.

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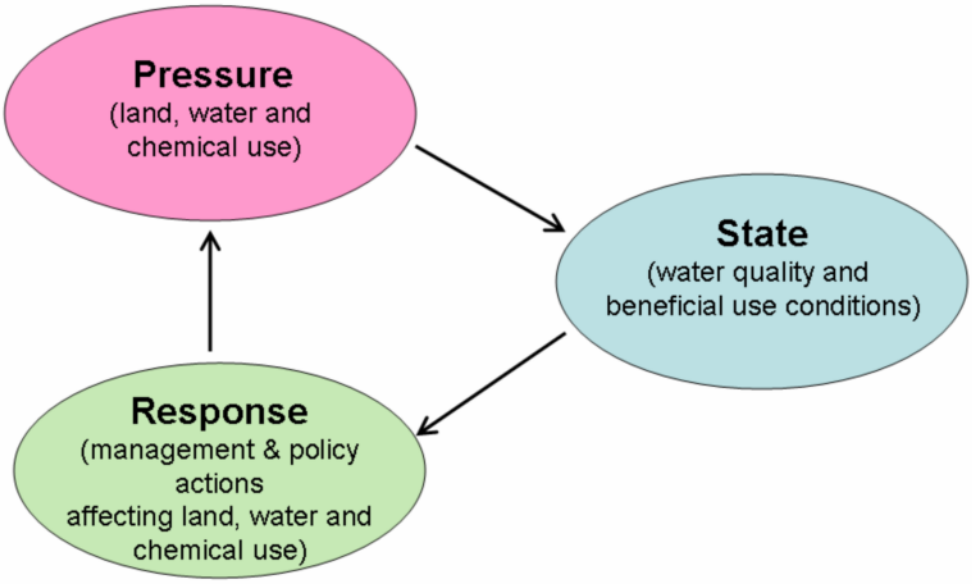

Figure 1. The PSR model as a conceptual framework for development of water quality and management response indicators.

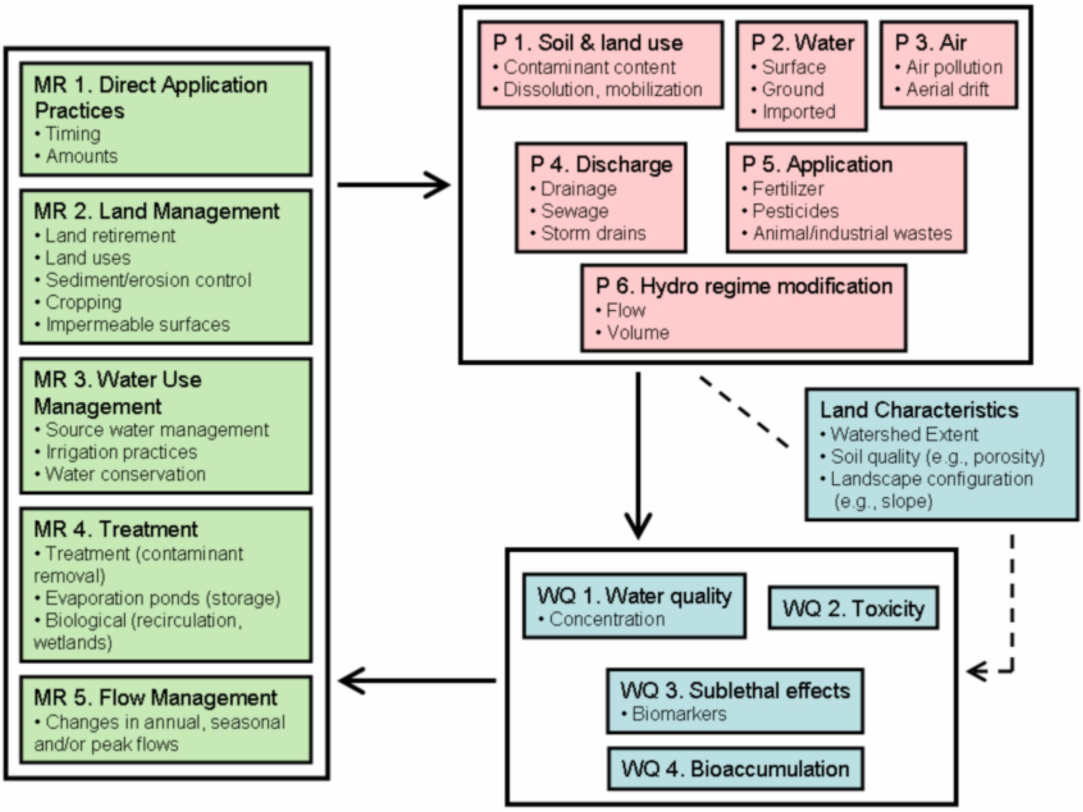

Figure 2. PSR model of contaminant sources, water quality conditions, and management practices in the San Joaquin River basin. The model broadly categorizes water quality pressures, state, and management responses as follows: Pressures (P1-P6, pink boxes) are direct and indirect sources of contaminants as well as other "controllable" factors that affect the amounts of a contaminant delivered to surface waters and the concentration of contaminant in the water. State is the condition of water quality and beneficial uses and is characterized by water quality (concentrations of constituents), toxicity, sublethal effects, and bioaccumulation (tissue levels of constituents) in the water (WQ1-WQ5, blue boxes). Management responses are practices that control the reduction of contaminant loads to waters and/or affect their concentrations in basin waters (MR1-MR5, green boxes). Uncontrollable factors such as ambient temperature or hydrology are omitted from this representation. Land characteristics are shown as a state component (blue) that mediates the link between the pressure and water quality state. While land characteristics affect water quality, indicators for this component are outside the scope of this project.

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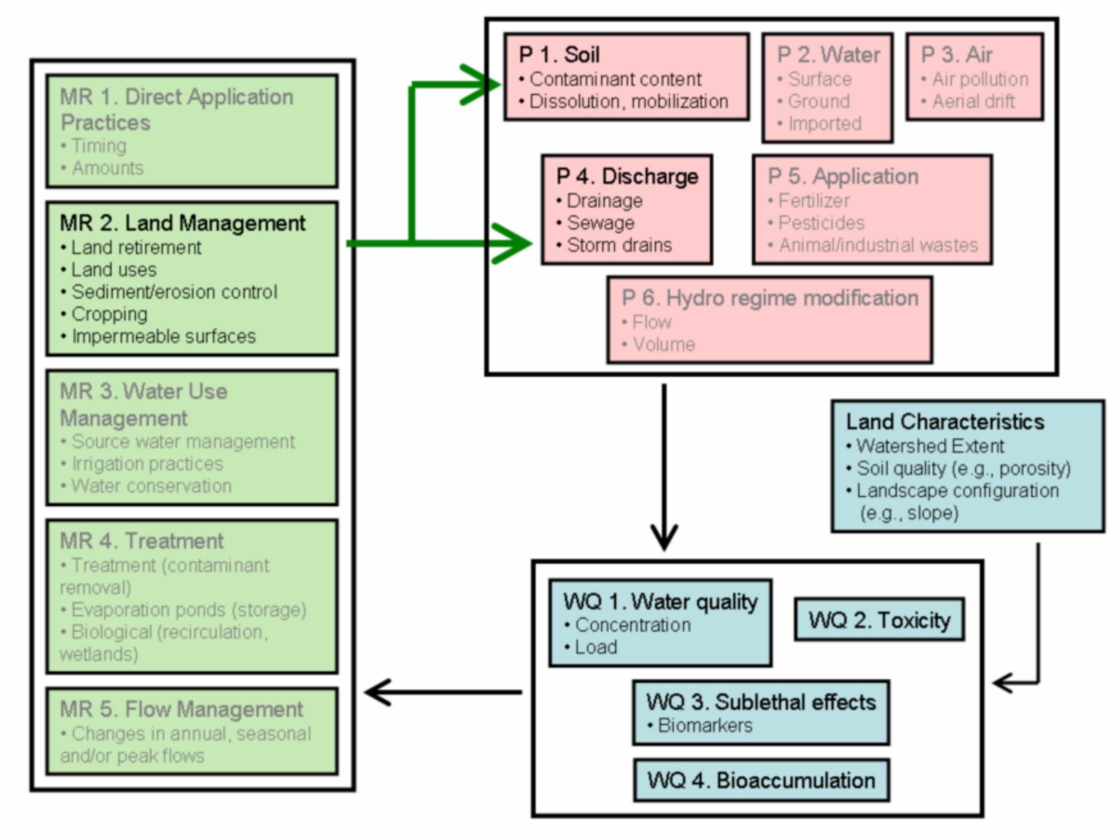

Figure 3. Land management practices (MR2), for example land retirement, land uses, erosion control, or cropping, affect pressures on water quality condition from soil (P1) and discharge (P4). Examples are the reduction of selenium and salinity loads in return waters from irrigated fields.

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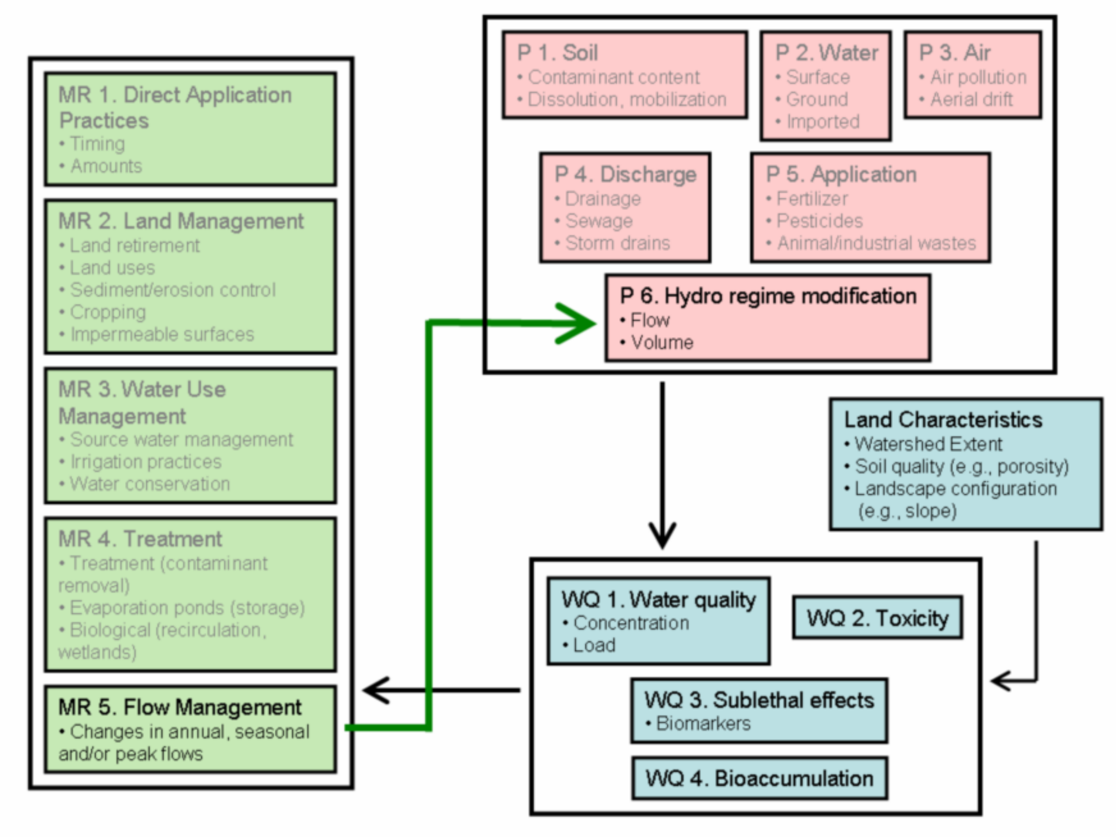

Figure 4. Flow management affects pressures on water quality condition (e.g., contaminant concentration) related to hydro-regime modification (P5). An example is the release of water from tributary reservoirs (for example New Melones Reservoir) to increase flow and reduce downstream pollutant concentrations (e.g., salinity at Vernalis).

<u>Steering Committee Request 2:</u> **Given limited time and resources, focus on two water quality parameters and (for one of the parameters) different geographic scales:**

Selenium—Grasslands watershed

Salt—municipal level (e.g., Modesto), Grasslands watershed, lower SJ Basin

As directed, the project team is now focusing on these two parameters.

<u>Steering Committee Request 3:</u> **Reorganize and revise assessment questions and indicators to track the revised PSR model (distinguishing between the management response and the system response). Reflect different scales (i.e., nest the questions, with reference to selected scales identified above). Consider which assessment questions are most useful for on-the-ground management. Solicit additional entries for the list of assessment questions and indicators.**

A revised list of assessment questions is included (Tables 1-3). The revised list sorts the assessment questions corresponding to the pressure, state, and response categories of the conceptual model. The proposed management response questions will be refined pending feedback from agency management and key stakeholders.

The use of assessment questions for the selection of indicators will be demonstrated with the salinity and selenium examples that will be presented at the upcoming steering committee meeting.

Table 1. Generic assessment questions and potential indicators for evaluating and tracking the pressures that affect water quality and beneficial use conditions in the San Joaquin River basin.

PRESSURE: Human activities that affect contaminant concentrations and loads	
Assessment Question	**Potential Indicators**
P1. Contaminant Application (i.e., fertilizers, pesticides, animal wastes)	
What types of contaminants are applied (e.g., short-lived vs. persistent contaminants)?	Numbers and types of contaminants
How much contaminant is applied directly to the land or water?	Pounds of pesticides used Pounds of fertilizer applied Pounds (or volume) of animal or food processing waste applied to land
What is the area of land where contaminants are being applied?	Area (and geographic extent) of land where contaminants are applied?
What is the area of land used to spread/dispose of animal and food processing wastes?	Area (and geographic extent) of land used for disposal
P 2. Land Uses (causing impairment)	
What are the land uses that impair the landscape, leading to impaired water quality?	Numbers and types of land uses
What is the area (extent) of these land uses?	Area (and geographic extent) and percent of landscape utilized. i.e., area of crops that exacerbate impairment, grazing, erosion-causing practices, area of impermeable surfaces
P3. Air Pollution	
How much of the contaminant is imported from the air?	Volume, quality (e.g., total dissolved solids), and/or pounds of contaminants contained in the air.
P 4. Water Use (causing impairment)	
Contaminants from source water	
How much of the contaminant is imported from the Delta?	Volume, quality (e.g., total dissolved solids), and/or pounds of contaminants contained in imported water
How much of the contaminant is imported from groundwater?	Volume, quality (e.g., total dissolved solids), and/or pounds of contaminants contained in pumped groundwater
Water Use	
How much irrigation water is applied to contaminant-impaired (or drainage-impaired) land?	Volume of water applied to contaminated lands *Volume of water applied in relation to predicted evapotranspiration volume*
P5. Discharge	
What types of discharge sources occur in the watershed?	Number and types of point and non-point source discharges
How much water drains from contaminant-impaired	Volume of drainage water (absolute or per acre of

land directly into surface waters?	land irrigated)
How much of the contaminant is in the drainage water discharged into surface waters?	Concentration of contaminant (total and/or dissolved) Amount of contaminant delivered to surface waters (concentration x volume)
P 6. Receiving Water Flow Regime ***(note: this could be a state variable as well)***	
Flow volume	
How much have flows been reduced or changed relative to historical conditions and particularly as they relate their ability to dilute contaminants?	Reduction in flow volume (annual, seasonal, daily) Timing of flow volume
Export of Contaminants?	
How much of the contaminant is removed from the basin in outflowing surface waters?	*Concentration of the contaminant at Vernalis* *Amount of contaminant contained in water at Vernalis in relation to amount applied and discharged*

Table 2. Generic assessment questions and potential indicators for evaluating and tracking water quality and beneficial use conditions in the San Joaquin River basin including other waters impinging on watershed water quality (i.e., source water, tributary waters and drainage water quality)

STATE: Water Quality and Beneficial Uses	
Assessment Question	**Potential Indicators**
WQ 1. Concentration (water and benthic sediments; source water, land, and air)	
What is the concentration of the contaminant relative to regulatory or biological objectives?	Concentration of contaminant (total and/or dissolved)
Over what geographic range does the contaminant exceed regulatory or biological objectives (geographic scope)?	Number of sampling sites with exceedances relative to total sites or area sampled
How frequently do contaminant concentrations exceed regulatory or biological objectives (frequency)?	Percentage of samples that exceed objectives
By how much does the contaminant concentration exceed regulatory or biological objectives (magnitude)?	Ratio of concentration of contaminant to regulatory or biological objective
How many contaminants exceed regulatory or biological objectives (contamination scope)?	Number and/or percentage of tested contaminants that exceed regulatory or biological objectives per sample, site, or region
WQ 2. Toxicity (restricted to water)	
Is the water toxic to aquatic plants and/or animals?	Bioassay results, number and/or percentage of samples that show reduced survival or growth of selected test organisms
Over what geographic range is the water toxic to plants and/or animals?	Bioassay results, number and/or percentage of sites or geographic areas that show reduced survival or growth of selected test organisms
WQ 3. Sublethal Effects on Indicator Organisms (biomarkers)	
Does exposure to the water have sublethal effects on aquatic plants and/or animals?	Number and/or percentage of plants and/or animals exhibiting biomarkers indicative of exposure to one or more contaminants
Over what geographic range does exposure to the water have sublethal effects on aquatic plants and/or animals?	Number and/or percentage sites or geographic areas from which plants and/or animals exhibit biomarkers indicative of exposure to one or more contaminants
WQ 4. Bioaccumulation (animal tissue)	
What is the concentration of the contaminant in invertebrate, fish and/or bird tissues, relative to regulatory or biological objectives of screening levels?	Concentration of contaminant in animal tissues
How many bioaccumulative contaminants have been identified in the tissues of invertebrates, fishes, and/or birds (scope)?	Number of contaminants present in animal tissues at levels greater than regulatory or biological objectives of screening levels

Table 3. Generic assessment questions and potential indicators for evaluating the management "responses" designed to change the levels of the pressures and improve water quality.

RESPONSE: Management Responses including BMPs, to reduce contaminant levels[32]	
Assessment Question	**Potential Indicators**
MR 1. Application Practices	
What methods are used to apply the contaminants (e.g., aerial spray)?	Types of methods
How long is the contaminant held on the land before discharged as drainage or runoff?	Number of days Number of days relative to contaminant break-down
MR 2. Land Management Practices	
Land Retirement: What percent of (contaminant laden) land is retired from irrigation?	Area of land retired from irrigation
Cropping methods: What alternate cropping techniques have been employed to reduce contaminants?	Practices or area affected by alternative cropping techniques designed to improve water quality.
Runoff Management, Sediment and Erosion Control: What types of sediment and erosion control practices have been implemented (structural, grazing practices, vegetated buffers, cover crops, wetland restoration)?	Numbers and types of sediment and erosion control practices Area (and geographic extent) of land with runoff and erosion control measures
Grazing Management:	Changes in area, duration and frequency of grazing
MR 3. Water Use Management	
Source Water Quality Management	
Implementation of techniques to reduce contaminants in the source water	
Water Use, Conservation and Recycling	
What types of irrigation practices (e.g., drip, spray, flood) are used in the watershed?	Area of land irrigated with "Efficient irrigation systems"
How much irrigation water is applied to contaminant-impaired (or drainage-impaired) land?	Volume of water applied to land Volume of water applied in relation to predicted evapotranspiration volume
Tiered pricing for water	**Number of districts with tiered pricing practices**
Drainage	
How much irrigation drainage is recirculated or reused? **(Tailwater return?)**	Volume of recirculated water (absolute or per acre of land irrigated) Volume of water discharged after recirculation (absolute or per acre of land irrigated)
Are discharges of drainage timed in relation to stream flows?	Volume of drainage discharged in relation to stream flow
MR 4. Treatment	
Discharge treatment:	
How many and what types of water treatment practices are used in the watershed?	Number and types of water treatment facilities. Numbers of districts with water treatment facilities

[32] All categories of management measures should be linked to indirect measures (MR6)

How much water is treated to remove contaminants before discharge into surface waters?	Volume of water treated (total, and/or as % of total drainage and/or stormwater runoff volume)
In-basin storage	
How much drainage water is diverted into evaporation ponds (i.e., in-basin storage of contaminants)?	Volume of water diverted to evaporation pond Amount of contaminant diverted into evaporation pond
MR 5. Flow Management	
Flow volume	
What are the annual and seasonal flows in drainage-receiving streams and rivers?	Flow volume (annual, seasonal, daily)
How variable is the flow within and between years?	Range of flow volumes, within and between years
MR 6. Indirect Management Measures (These can be applied to specific MRs and associated Pressures)	
Education and Outreach	
What educational measures have been implemented to inform contaminant users and/or land and water managers of practices to reduce contaminant use and/or pollution prevention?	Number (and/or geographic extent) of workshops conducted Number (and/or geographic extent) of participants receiving education materials Number (and/or geographic extent) of educational signage programs Number (and/or geographic extent) of participants indicating change in behavior due to educational materials
Policy and Regulation	
What public policy measures have been implemented to reduce water pollution from urban, industrial and agricultural sources and practices?	Number (and/or geographic extent) of public policy measures (e.g., formation of watershed associations)
What “best management practices” have been identified?	Number of “best management practices” identified
What regulatory measures have been adopted to reduce water pollution from urban, industrial and agricultural sources and practices? (Stringent regulatory standards)	Number (and/or geographic extent) of regulatory measures adopted.
Economic Incentives	
What economic incentives have been adopted to promote water pollution reduction from urban, industrial and agricultural sources and practices??	Number (and/or geographic extent) of economic incentives adopted Dollars expended (by pollution reduction program type, geographic area)
Monitoring	
How many sites are sampled regularly for water quality condition (geographic scope)?	Number (and/or geographic extent) of water quality sampling sites
How many contaminants are measured at each site (contaminant scope)	Number of contaminants tested
How frequently are water quality measurements made (frequency)?	Number of times per years site sampled

<u>Steering Committee Request 4:</u> Revise the Glossary to include:

baseline (starting point, basis of comparison for gauging changes)
uncontrollable

SAN JOAQUIN RIVER BASIN INDICATORS PROJECT: GLOSSARY

(primarily derived from SWRCB, EPA Watershed Academy, CALFED Science Program, and EPIC.)

Actions	Specific activities taken to achieve incremental progress toward a goal.
Adaptive Management	Managers use the information provided by scientists (i.e., indicators) on ecosystem status and trends to adapt and improve upon management strategies (Holling 1978)
Assessment	Assessment is the ongoing process of documenting, often in measurable terms, the progress of your activities.
Assessment Questions	Questions that focus information-gathering activities to document measurable progress
Baseline	A starting point which establishes a basis of comparison for gauging changes
Beneficial or Designated Use	Water use taking place within a waterbody and/or protected for continued future utilization; e.g., hydro-electric power generation, navigation, drinking water supply, fish reproduction, recreation (swimming, boating, fishing, etc.).
Best Management Practices (BMPs)	Methods or practices selected by entities managing land and water to achieve the most effective, practical means of preventing or reducing pollution from diffuse sources, such as pollutants carried off the landscape via urban runoff, excessive hill slope or stream bed and bank erosion, etc. BMPs include but are not limited to structural and nonstructural controls and operation and maintenance procedures. BMPs can be applied before, during and after pollution-producing activities to prevent, reduce, or eliminate the introduction of pollutants into receiving waters. BMPs is a term that is more specific than Management Measures and refers to demonstrated, effective, and practical sets of measures to achieve certain goals.

Biological parameters	Include measures related to the plant and animal life of the water body, such as fish species diversity and abundance, or the presence or absence of indicator fishes, aquatic invertebrates, or aquatic plants.
Chemical parameters	Include contaminants such as metals, dissolved nutrients, oils, and pesticides, and also include chemical properties of the aquatic system such as dissolved oxygen, chemical oxygen demand, and acid neutralizing capacity.
Conceptual model	A visual interpretation (usually a schematic diagram) that describes the components of a system and how the components are believed to interrelate and interact to function as a whole. The model may be conceptual or numerical and often serves to indicate the linkages and interrelationships between metrics, actions, and goals.
Ecological condition	The degree of functionality or health of an ecosystem, measured by a broad array of indicators of condition that include biotic characteristics (e.g., native plant communities, fish or invertebrate populations, species and habitat biodiversity) and abiotic characteristics (e.g., streambank stability and erosion, assimilation and cycling of nutrients, maintenance of sufficient flow and water temperature).
Evaluation	A process of collecting data and information and keeping records that are used to demonstrate project performance and compare your achievements to your goals and desired outcomes. Outcome evaluation is often characterized by quantitative assessment methods. This can be done simply through recording and documenting, or in a more scientific approach which involves comparison and rigorous experimental design.
Goal	Goals are broad statements of ideal future conditions that are desired by society and represent the ultimate intention of agreed-upon actions and targets. Goals can range from being explicitly quantitative to more qualitative and subjective, depending on the inherent degree to which the goal can be quantified and the availability of needed metrics. In most cases, goals are in the form of broad statements of ideal future conditions that are desired by society.

Impaired Waters List	A list that is compiled by the State Water Resources Control Board that identifies water bodies that fail to meet state water quality standards.
Index	A composite of measures or indicators that track changes over time.
Indicator	A value that presents scientifically based information on the status of, and trends in, relevant metrics or parameters. An indicator conveys complex information in a concise, easily understood format, and has a significance extending beyond that directly associated with the metrics or parameters from which it is derived. Indicators are physical, chemical, biological, or socio-economic metrics (parameters) that represent the key elements of a complex system. Indicators simplify metrics, or data, into readily usable information that can be used to show trends or changes in a particular environmental or social condition.
Management Measures (Management Response)	Actions taken to meet environmental protection goals. Also part of the PSR framework approach.
Measure	Raw or analyzed data obtained from monitoring, surveys, and other valid data collection methods. Measures form the basis of indicators.
Measurement Quality Objectives	Statements about the tolerated error and desired sensitivity of a measurement. They include extent of values for the measures of precision, accuracy, detection limit, and resolution. Monitoring Quality Objectives (MQOs) are a subset of Data Quality Objectives (DQOs).
Metrics	Units of measurement (data) that can be collected, monitored, and interpreted to track the progress or effectiveness of a specific action in achieving a particular goal. Metrics and indicators are linked in that indicators simplify metrics into more readily usable and meaningful information. That is, an indicator points to the ultimate intention or goal that defines success.
Model	A representation of a process or system that attempts to relate the most important variables in the system in such a way that analysis of the model leads to insights into the system.

Monitoring	Periodic or continuous collection of data (measured parameters) using consistent methods to determine the status (or condition) and trends of environmental or socio-economic characteristics.
Objectives	Objectives are statements of attainable, quantifiable, intermediate-term achievements that help accomplish goals contained in the comprehensive plan. Generally, objectives are more specific than goals.
Outcome Indicators	o Site-specific indicators track the simple, direct responses of specific projects or groups of projects relative to a stated goal or target (e.g., reduction in toxic samples, increase in community awareness, acres restored to native vegetation). o Multi-site indicators track the collective responses of groups of projects on a locality or sub-region (e.g., reduction in nitrate concentrations in stream reach; increase in gravel permeability in stream reach; increase in watershed volunteers). o System-wide indicators track the broad, often complex responses of groups of projects on a region (increase in native riparian bird species diversity; increase in Chinook salmon escapement; decrease in statewide acreage of tamarisk infestations).
Output Indicators	o Administrative output indicators track the administrative actions of a specific project (e.g., number of progress reports written, permits obtained).
Parameter	A property, [feature, or characteristic] that is measured or observed.
Performance (assessment)	The process of establishing performance measures, collecting and analyzing performance data, reviewing progress using the collected data, reporting on that progress, and periodically reevaluating project or program goals based on the evaluation of progress.
Performance measures	Information used to translate goals into measurable indicators of success. Performance measures are synonymous with indicators. They must track activities at multiple geographic scales and across different time frames, and must link individual and collective actions to specific environmental and institutional changes. Performance measure selection is based on having metrics as a basis for tracking and evaluating progress. There are several types of performance measures (See outcome/output indicators)

Physical parameters	Include general conditions such as temperature, flow, sediment characteristics, water color, and within-channel habitat structure.
Pressure	Human-induced stressors that adversely impact ecological systems.
PSR Indicators Framework	This simple PSR framework merely states that ***human activities exert pressures*** (such as pollution emissions or land use changes) on the environment, which can ***induce changes in the state of the environment*** (for example, changes in ambient pollutant levels, habitat diversity, water flows, etc.). ***Society then responds*** to changes in pressures or state with environmental and economic policies and programs intended to prevent, reduce or mitigate pressures and/or environmental damage. *Note the DPSIR model further divides this category into drivers and pressures.*
Reference condition	A level of a parameter that reflects a desired goal or target, historic and/or pristine condition which is supported by science.
State	Condition
Target	A level of performance that is sought within a given time frame. A specific and measurable aim relating to an objective.
Total Maximum Daily Load (TMDL)	A calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Water quality standards are set by States, Territories, and Tribes. They identify the uses for each waterbody, for example, drinking water supply, contact recreation (swimming), non-contact recreation (fishing, nature enjoyment) and aquatic life support, and the scientific criteria to support that use. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the waterbody can be used for the purposes the State has designated. The calculation must also account for seasonal variation in water quality (from federal Clean Water Act). Also see: Load Reduction.

Uncontrollable	1. Incapable of being controlled or managed. 2. Refers to variables, pressures, or states in a system which are unable to be managed due to a lack of understanding or to the sheer magnitude or uncontained prevalence of these factors.
Water quality assessment	The determination whether a water body is attaining its designated uses for such purposes as drinking, contact recreation, fisheries, and irrigation, based on state Water Quality Standards as provided for in the Clean Water Act of 1987. Also see: Beneficial Use.
Water quality monitoring	An integrated activity for evaluating the physical, chemical, and biological characteristics of water in relation to human health, ecological conditions, and designated water uses.
Water quality standards	State-adopted and EPA-approved ambient standards for water bodies that prescribe the use of the water body and establish the water quality criteria that must be met to protect these uses. The three components of water quality standards include the beneficial designated use or uses of a water body (for example, drinking water supply, contact recreation (swimming), and aquatic life support), the numerical and narrative water-quality criteria that are necessary to protect the use or uses of that particular water body, and an antidegradation statement (from federal Clean Water Act).
Watershed	The geographical area which drains to a specified point on a watercourse, usually a confluence of streams or rivers (also known as drainage area, catchment, or river.
Watershed monitoring	Monitoring primarily designed to sample and assess the characteristics and/or condition of a watershed or watersheds, or to sample and assess specific entities on a watershed basis (i.e. as a geographic unit for sampling). For example, water quality monitoring conducted on a watershed basis would include monitoring physical, chemical, and biological condition of the water body as well as specific watershed characteristics (e.g., stream corridor traits, wetlands, and watershed land use/land cover patterns) that may be related to observed water quality.

San Joaquin Indicators Steering Committee Meeting (Tentative Agenda)

Objective: To review and validate the indicator development process and its results by examining two examples, basinwide indicators for salinity and selenium indicators for the Grasslands. The main purpose is to obtain your guidance for the final report and how to best communicate the use of indicators to those who manage water quality in the basin.

Date TBD
Location: TBD (Sacramento or Davis)
10:00 – 3:00

10:00 Welcome and Introductions (*Carolyn*)

10:10 Review of Project (Scope of work, project objectives, and outcomes from the last Steering Committee meeting) (*Rainer or Thomas*)

10:30 Revisions to the conceptual framework (*Tina and Anitra*)

11:00-12:00 Example Indicators #1. Salinity in the San Joaquin Basin (*Tina*)

1. Salinity specific conceptual models
2. Geographic setting and scale
3. Identification and quantification of "Pressures", example indicators
4. Example water quality indicators
5. Example management response indicators

12:00-1:00 Lunch and discussion

1:00-2:00 Example Indicators #2. Selenium in the Grasslands area (*Anitra*)

1. Rationale
2. Geographic setting and scale
3. Grasslands specific conceptual models
4. Identification and quantification of pressures (i.e., example indicators)
5. Example water quality indicators (water quality, toxicity, tissue concentration) and ideas for an index
6. Relationship(s) of water quality conditions to selected pressures
7. Examples of management response indicators

2:00 Indicator evaluation, scoring and aggregation (*Anitra and Tina*)

2:45-3:00 Wrap up and Next Steps (*Rainer and Thomas*)

Meeting notes-- DRAFT
San Joaquin Indicators Steering Committee Meeting
October 17, 2006
CalEPA, Sacramento

Participants: Jeanne Chilcott (RB5), Phil Crader (RB5), Chris Eacock (USBR), Terry Fleming (USEPA), Lisa Holm (CBDA), Charlie Kratzer (USGS), Rafael Maestu (SB), Sam Ziegler (USEPA), David Cory (on phone); Rainer Hoenicke and Thomas Jabusch (SFEI), Tina Swanson and Anitra Pawley (SFEI); Carolyn Yale (USEPA)

Key topics and next steps:

Purposes of the project: There are varying perspectives on purposes and potential uses of the project. Generally, the project should provide an example of how the Framework [systematic representation of pressures (P), states (S), and management responses (MR) and the potential/hypothesized linkages of P-S-R] can be applied. However, there are a number of potential applications of the Framework which vary with respect to user interest and need, and feasibility (e.g., data requirements). These potential uses are reflected in the “target audience” list below.

The discussion diverged over whether (and at what level of detail) (1) to focus on the MR component of the Framework to create a tool which is instructive in manipulating pressures, and by extension, state, or (2) to use the Framework to structure a broad, watershed-wide assessment of conditions. The latter application might report on management activities, but likely not at a level of detail to reliably link cause-effect The former application would, in theory, be helpful in remedying specific water quality impairments (e.g., TMDL implementation).

Note-taker’s comment: The Final Report could consider this question.

Emphasizing that the project is a test of the Framework suggests that the testing process has been instructive regarding successes and limitations; this is information to include in the final project Report.

Target “audiences”/ uses of the product (no SC consensus):

- Water managers and the Regional Board, for TMDL implementation. The Framework would be a tool to instruct which management practices might be/ are most effective.
- Represent watershed conditions in a consistent way; provide a structure for meaningful comparisons across watersheds.
- Water managers, to design a process for tracking and assessing effects of actions on a large (e.g., basin-wide) scale (USBR, e.g.); to help develop testable hypotheses regarding effects of management actions.
- Possibly applicable to SWAMP as an assessment tool.
- CALFED support/applications for performance measures/monitoring.

Final Report contents: The project is scheduled to conclude in early 2007. By November 2006 (roughly) there will be a draft Final Report which documents the development and applications of the Framework (salinity and salt). Based on the Steering Committee (SC) discussion, SFEI will revise the current outline for the Report and distribute it by e-mail for review and comment by the SC. Some of the topics identified by the SC are:

- Clarifying who potential future users and audience may be.
- Clarifying, based on potential users, what next steps might be needed to refine or further test the Framework.
- Clarify what works, what doesn't work (and why).
- Clarifying what is meant by "indicators."
- Clarifying steps in applying the Framework and analytical sequence (such as the formative role of "assessment questions").

Follow-up:
CYale: Circulate (e-mail) draft SC meeting notes for clarification and correction.
SFEI/TBI: E-mail draft Final Report for review and comment.
SFEI/TBI: Direct follow-up with individual SC members on specific questions and issues.
SFEI/TBI: Distribute draft Final Report to SC in late November for review and comment.

Details of meeting:
Meeting materials are available on the SFEI website at:
ftp://anonymous@ftp.sfei.org/pub/outgoing
Note-taker observation: I omit here some specific discussion on agenda topics, assuming that SFEI/TBI can follow up with individual SC members if there are lingering questions. I do have some of this information in my meeting record if needed, however.

Review of a "meaningful indicator system" (Rainer Hoenicke): The goals of the project include testing development of indicators at multiple scales (from BMPs to policies); identifying data gaps.

> *Note-taker's observation: Review slides 2 and 5 (goals and challenges) to provide material for findings and recommendations in the Final Report.*

Presentation on salt in the SJ Basin and discussion (Tina Swanson):

Observation: The framework helps identify what to measure: Start with assessment questions, which then help define the indicators.
Question: What has been learned about scaling (limits, uses), given that the project has not succeeded in testing the Framework at the range of geographic scales initially intended?

- Basin-wide scale is often (?) not feasible for looking at management responses. However, this depends on the scale of the response: If one needs to aggregate from sub-watersheds, this is difficult (e.g., lack of data); on the other hand, some MRs are undertaken on a basin-wide scale and can be tracked.
- Typically, it's easier to scale down than up.

- There are often data gaps at certain scales. One could do sensitivity analyses to understand whether these gaps would affect results.

Comment: We need better guidance for determining what data are needed/most important to address assessment questions.
Comment: Using annual (or other time step) flow-adjusted concentration would be a good alternative to adjusting by year-type.
Comment: Clarify how the design flow is calculated and used in the TMML for salt at Vernalis. (Significance of conclusions based on design flow as a reference condition might change.)
Question: In what sense is Concentration of Salt Imported a management response, as opposed to a state/condition?

- Answer: Salt concentration can be, and is, manipulated through Delta project operations (management of source water). In other contexts, however, Delta water quality can be seen as an outcome/state resulting from other activities within and upstream of the Delta. (It just depends on how one stitches together P-S-R processes.)

Observation: The exercise in assessing effects of tributary (Stanislaus) flows suggests an inability to detect effects of a much-used MR.

Presentation on selenium, and general discussion:

This presentation included a discussion of scoring—e.g., assigning numerical rankings to—indicator values. This scoring can be used to then assemble overall watershed scores, across indicators.
Steering Committee members will follow up with help on some data gaps (e.g., source water load to wetlands in the assessment area).

Much of the discussion following the selenium presentation covered topics summarized above.
In a roundtable survey of SC views on the utility of the current Framework, several members could identify no application for their work. Others saw some opportunities for further development and application of the Framework.

- No clear SWAMP transferability. SWAMP generates data regarding state (water quality condition) but is not directly concerned with MR or P data; other programs (e.g., NPDES) document stressors (P); water managers are more likely to be concerned with MRs. It is not clear whether the Framework could be applied to data analysis and assessment through SWAMP (inconclusive discussion).
- In its current form, this Framework is not a tool for determining water quality compliance—e.g., for RB TMDLs. Further, the RB has already established monitoring requirements in its basin plans.
- Water managers would like a way of selecting promising (cost-effective) practices and evaluating results. Cost information (not included in this analysis) is important.
- The State Board indicator work focuses on water quality condition (state). Establishing cause-effect relationships (i.e., MR-induced changes) is hard; one cannot do it through the Framework methodology.

- The Framework is consistent with the CALFED Performance Measures framework.
- Some agencies currently lack a tool to help design and test the effects of management actions; the Framework could be of interest.
- Pilot projects testing the Framework and tracking of MR inputs/outputs would be helpful.

Question: What information is already available on BMP costs and results (outputs)? Has there been a good literature search (NRCS, University work, etc.)?

- Answer: The project surveyed practices to identify a range to include as MRs, but did not examine the subject comprehensively or in great detail. Cost information was not collected.

Comment: Generally, a lot of data are collected. Attention should turn to assessment and adaptive response.
Question: What is the point of calling these measures indicators? Isn't it sufficient to apply practices designed to affect water quality and to monitor for water quality?

Appendix B. Conceptual Models

1. Average Daily Delta Methylmercury Inputs and Exports (Figure 6.11 on p.91 *in* CVRWQCB, 2005).

2. Conceptual model of mercury sources and cycling in the San Francisco Bay-Delta ecosystem (Figure 3 on p.7 *in* Wiener et al, 2003). Available at: http://www.science.calwater.ca.gov/pdf/MercuryStrategyFinalReport.pdf.

3. Delta Conceptual Model (Figure 1 on p. 14 *in* The Delta Biogeochemistry Group, 2002). Available at: http://loer.tamug.tamu.edu/calfed/Report/DraftFinal/Delta%20Biogeochemical%20Conceptual%20Model.pdf.

4. Monomethyl mercury fluxes in the Bay-Delta Estuary. Figure 2 on p.15 *in* The Delta Biogeochemistry Group, 2002). Available at: http://loer.tamug.tamu.edu/calfed/Report/DraftFinal/Delta%20Biogeochemical%20Conceptual%20Model.pdf.

5. Total Hg fluxes in the Bay-Delta Estuary. Figure 3 on p.16 *in* The Delta Biogeochemistry Group, 2002). Available at: http://loer.tamug.tamu.edu/calfed/Report/DraftFinal/Delta%20Biogeochemical%20Conceptual%20Model.pdf.

6. Dissolved Hg fluxes in the Bay-Delta Estuary. Figure 4 on p.17 *in* The Delta Biogeochemistry Group, 2002). Available at: http://loer.tamug.tamu.edu/calfed/Report/DraftFinal/Delta%20Biogeochemical%20Conceptual%20Model.pdf.

7. Conceptual Model of DO Depletion Reactions in (Lee and Jones-Lee, 2002; p.17). Available at: http://www.gfredlee.com/tmdl_07.2002.pdf.

8. Sources/Sinks of Oxygen Demand in SJR_DWSC Watershed. San Joaquin River: Dissolved Oxygen Total Maximum Daily Load (SJR DO TMDL) Stakeholder Process (Lee, 2001). Available at: http://www.sjrtmdl.org/technical/conceptual_model/cm_dwsc_o2demand.pdf.

9. Factors Affecting Dissolved Oxygen in the Ship Channel (Figure 2 on p.5 *in* Lee and Jones-Lee, 2000). Available at: http://www.gfredlee.com/SJRsynopsis.pdf.

10. Algae and organic detritus as sources of oxygen depletion (Figure 3 on p.5 *in* Lee and Jones-Lee, 2000). Available at: http://www.gfredlee.com/SJRsynopsis.pdf.

11. Box Model of Estimated DO Sources/Sinks in SJR-DWSC August 1999. Figure 6 on p.9 *in* Lee and Jones-Lee, 2000). Available at: http://www.gfredlee.com/SJRsynopsis.pdf.

12. Conceptual model of San Joaquin River Basin (Nutrient Sources). (Figure 7A; Kratzer et al, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/.

13. Schematic representation of algal growth in the San Joaquin River. San Joaquin River: Dissolved Oxygen Total Maximum Daily Load (SJR DO TMDL) Stakeholder Process (Lee, 2001). Available at: http://www.sjrtmdl.org/technical/conceptual_model/cm_dwsc_o2demand.pdf.

14. Water Quality Model (RCA) (Lee and Jones-Lee, 2003). Available at: http://www.gfredlee.com/SynthesisRpt3-21-03.pdf.

15. Conceptual model of San Joaquin River Basin (OC Pesticides Sources). (Figure 10A; Kratzer et al, 1998). Available at: www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/sjb1105f10a.ppt.

16. Conceptual model of San Joaquin Basin (Dormant Spray Pesticides Sources). (Figure 9A; Kratzer et al, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/ (Pdf in Conceptual Models Folder).

17. Conceptual model of San Joaquin Basin (Selenium Sources). (Figure 8A; Kratzer et al, 1998). Available at: www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/sjb1105f8a.ppt.

18. Conceptual Model for Sources of Contaminants. Figure 1 *in* CMARP Water Quality Workteam Workplan and Draft Products (CMARP, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/ecowt/workplans/contamcm1015.ppt.

19. Conceptual Model for Sources of Contaminants. Figure 2 *in* CMARP Water Quality Workteam Workplan and Draft Products (CMARP, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/ecowt/workplans/contamcm1015.ppt.

20. Animal/Sediment Contaminant Model (SFEI, 2000). Available at: http://www.sfei.org/rmp/reports/sediment_recs/sediment_recs.html#models.

21. Sediment Fate and Transport Contaminant Model (SFEI, 2000) Available at: http://www.sfei.org/rmp/reports/sediment_recs/sediment_recs.html#models.

22. Conceptual model of San Joaquin Basin (Sediment Sources). (Figure 6A; Kratzer et al, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/.

23. Gravel bed (unconfined) disturbed by dam and in-stream mining conceptual model. (Figure 21; Stillwater Sciences, 2003).

24. Gravel bed (unconfined) disturbed by dam with managed peak flows and gravel augmentation conceptual model. Figure 22; Stillwater Sciences, 2003). Available at: http://www.calwater.ca.gov/Programs/EcosystemRestoration/EWP/pdf/high_flow/text.pdf.

25. Sources of EC in Modeled Reaches of the San Joaquin River (Figure 9.1 on p.79; DWR, 2003, Chapter 9). Available at: http://modeling.water.ca.gov/branch/annual.html.

26. Conceptual model of San Joaquin River Basin (Salinity Sources). (Figure 5A; Kratzer et al, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/.

27. Conceptual model of San Joaquin Basin (Base Case). (Figure 2; Kratzer et al, 1998). Available at: http://www.iep.water.ca.gov/cmarp/groups/wqwt/workplan/sjbmoke/.

28. Delta Pelagic Species Conceptual Model. (Figure 6 on p.17 *in* California Resources Agency, 2005). Available at: http://www.publicaffairs.water.ca.gov/newsreleases/2005/10-19-05DeltaSmeltActionPlan.pdf.

References

California Resources Agency. 2005. Delta Smelt Action Plan. State of California, The Resources Agency, Sacramento, CA.

CMARP. 1998.Comprehensive Monitoring, Assessment and Research Program. *http://iep.water.ca.gov/cmarp/*.

CVRWQCB. 2005. Sacramento – San Joaquin Delta Estuary TMDL for Methyl & Total Mercury. Staff Report. Draft Report. California Environmental Protection Agency, Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

DWR. 2003. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. California Department of Water Resources, Bay-Delta Office, Modeling Support Branch, Sacramento, CA.

The Delta Biogeochemistry Group. 2002. Conceptual Model and Working Hypotheses of Mercury Cycling and Transport in the Bay-Delta Ecosystem and its Tributaries.

Kratzer, C., Alemi, M., Cummings, E., Grober, L., Lee, M. and Zanoli, M. 1998. CMARP Water Quality in the San Joaquin Basin. Interagency Ecological Program.

Lee, G. F. 2001. Conceptual Model for Oxygen Demand in the DWSC (Diagrams). G. Fred Lee & Associates, El Macero, CA.

Lee, G. F. and Jones-Lee, A. 2000. Synopsis of Issues in Developing the San Joaquin River Deep Water Ship Channel DO TMDL. G. Fred Lee & Associates, El Macero, CA.

Lee, G. F. and Jones-Lee, A. 2002. An Integrated Approach for TMDL Development for Agricultural Stormwater Runoff, Tailwater Releases, and Subsurface Drainwater Discharge G. Fred Lee & Associates, El Macero, CA.

Lee, G. F. and Jones-Lee, A. 2003. Synthesis and Discussion of Findings on the Causes and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel near Stockton, CA: Including 2002 Data. G. Fred Lee & Associates, El Macero, CA.

Stillwater Sciences. 2003. Environmental Water Program: Restoring Ecosystem Processes Through Geomorphic High Flow Prescriptions. Final Draft. Stillwater Sciences, Berkeley, CA.

SFEI. 2000. 1998 Annual Results: San Francisco Estuary Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute, Oakland, CA.

Wiener, J. G., Gilmour, C. C. and Krabbenhoft, D. P. 2003. Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration. University of Wisconsin-La Crosse, LaCrosse, WI.

Appendix C. Data Sources Summary

Table C.1 provides a summary of available water quality monitoring data in the San Joaquin River basin.

Table 3.1 Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
National Water Information System Web (NWIS Web)[a)]	USGS	n/a	Throughout SJR Basin	Flow data	1900-present	http://waterdata.usgs.gov/nwis/	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005[b)]	CVRWQCB	Mercury Project/ CALFED	Mainstem SJR, East Valley Floor, Grasslands, Westside Basin	Mercury and total suspended solids	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	CVRWQCB	Intensive Basin Monitoring/ Surface Water Ambient Monitoring Program (SWAMP	Westside Basin & Delta	Physical parameters	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	CVRWQCB	Salt/Boron (B)/Selenium (Se) TMDL	Grasslands	Physical parameters; trace elements	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	CVRWQCB	Salt/B/Se TMDL	Mainstem SJR, East Valley Floor, Grasslands, Westside Basin	Physical parameters; trace elements; bacteria	WY2004 - WY2005	n/a	

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	CVRWQCB	Organophosphate Pesticide (OPP) Study	Delta & Mainstem SJR	Physical parameters; pesticides	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	CVRWQCB/UC Davis	SWAMP	Westside Basin	pesticides, total organic carbon and toxicity data	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	CVRWQCB/UC Davis	TMDLs/Bioassessment	Throughout SJR Basin	Physical parameters; bioassessment data	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	Department of Pesticide Regulation (DPR)	Biological Reference Site Study	Westside Basin	Physical parameters; nutrients; trace elements; pesticides; water column toxicity data	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	DPR/CVRWQCB	n/a	Northeast Basin & Delta	Physical parameters; pesticides; bioassessment data	WY2004 - WY2005	n/a	

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	UC Davis/USFWS/ CVRWQCB	Dissolved Oxygen (DO) TMDL Study/CBDA	Delta	Physical parameters; nutrients, minerals; and Chlorophyll A data	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	University of the Pacific (UOP)/ California Bay-Delta Authority (CBDA)	DO TMDL Study/CBDA	Throughout SJR Basin	Physical parameters; nutrients, minerals; and Chlorophyll A data	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	USGS	NAWQA	Mainstem SJR, East Valley Floor, Northeast Basin, Westside Basin	Physical parameters; nutrients	WY2004 - WY2005	n/a	
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	West Stanislaus Irrigation District	n/a	Westside Basin	Physical parameters	WY2004 - WY2005	n/a	

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
CVRWQCB SJR Basin Anticipated/Current Monitoring Sheet for 2004-2005	Westside Coalition	Coalition fees/grant	Mainstem SJR, Grasslands, Westside Basin	Physical parameters; nutrients, minerals; pesticides; trace elements; bacteria; and chlorophyll A data	WY2004 - WY2005	n/a	
10 Year Load Report[c)]	CVRWQCB	Grasslands Bypass Project; Agricultural Subsurface Drainage Management Program	Grasslands; Mainstem SJR	Physical parameters; EC, salinity and boron	1985-1995	http://www.swrcb.ca.gov/rwqcb5/available_documents/index.html#wqstudies	
Agricultural Drainage Contribution to Water Quality in the Grassland Watershed of Western Merced County, CA: OCT 1998 - SEPT 2000[d)]	CVRWQCB	n/a	Grasslands	Physical parameters; EC, salinity and boron	1986-2000		

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
Parametric and Probabilistic Analysis of Historical Chlorpyrifos Surface Water Monitoring Data From The San Joaquin River Watershed: 1991–2001[e)]		n/a		Chlorpyrifos	1991-2001		
Storet Legacy Data Center[f)]	EPA	n/a	Throughout SJR Basin	Flow data	1950-1992	http://www.epa.gov/storpubl/legacy/	Contains data from number of sites in the SJR Basin; data submitted by EPA, USACE, and most from CA SWRCB
Pesticides in the Nation's Streams and Ground Water, 1992–2001[g)]	USGS	NAWQA	Throughout SJR Basin	Pesticides	1992-2001	http://ca.water.usgs.gov/sanj/	Data and further details of data analysis methods available at http://ca.water.usgs.gov/pnsp/pubs/circ1291/

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
Genotoxicity in Native Fish Associated with Agricultural Runoff Events[h)]	UC Davis (Bodega Bay Marine Labs)	n/a	Mainstem SJR	Mutagenicity	2000-2001		
California Data Exchange Center (CDEC)[i)]	DWR	n/a	Throughout SJR Basin	Flow data	1932-present	http://cdec.water.ca.gov/	
Water Data Library[j)]	DWR	n/a	Throughout SJR Basin	Flow data	1980-present	http://wdl.water.ca.gov/	Data available: Sites listed by county, dates sampled for each site, parameters collected at each site
Benthic Macroinvertebrate Bioassessment of San Joaquin River Tributaries: Spring and Fall 2002[k)]	CVRWCB	SWAMP	Throughout SJR Basin	Bioassessment	2002	http://www.swrcb.ca.gov/rwqcb5/available_documents/waterqualitystudies/SJR02_Bioassess_final_083005.pdf	

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
DPR Water Quality Database[n)]	DPR	n/a	Throughout SJR Basin	Pesticides	1991-2001	http://www.cdpr.ca.gov/docs/sw/sites.htm	
USGS National Water Quality Assessment Data Warehouse: Inputs of the Dormant-Spray Pesticide, Diazinon, To The San Joaquin River[o)]	USGS	NAWQA	Throughout SJR Basin	Diazinon	1950-1992	http://ca.water.usgs.gov/water_quality/pest/sj_diaz.html	
USGS National Water Quality Assessment Data Warehouse: Nonpoint sources of pesticides in the San Joaquin River, California -- Input from winter storms, 1992-93[p)]	USGS	NAWQA	Mainstem SJR	Organochlorine insecticides (diazinon, chlorpyrifos, methidathion)	1992-2001	http://ca.water.usgs.gov/sanj_nawqa/pub/abs/sw-abs_jd_OFR95-165.html	
Diazinon and Chlorpyrifos Runoff Into The Lower San Joaquin River - TMDL Report (Final Staff Report October 2005)[q)]	CVRWCB	Diazinon and Chlorpyrifos TMDL Study	Mainstem SJR	Diazinon and chlorpyrifos	2000-2001	http://www.waterboards.ca.gov/centralvalley/programs/tmdl/DeltaOP/index.html	

Table 3.1 (continued) Summary of available water quality monitoring data in the San Joaquin River basin.

Data Source	Agency/Data Steward	Associated Study(s) or Funding Source (if applicable)	Geographic Area	Brief Data Description	Approximate Time Span of Data	URL	Notes
TMDL For Selenium for the Lower San Joaquin River (Staff Report Aug 2001)[s]	CVRWCB	Selenium TMDL Study	Lower SJR	Se	1985-present	http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/Se%20TMDL%20Report.pdf	
TMDL for Methyl & Total Mercury: Draft Staff Report (August 2005)[t]	CVRWCB	Mercury TMDL Study	Delta	Mercury	1992-present	http://www.waterboards.ca.gov/centralvalley/programs/tmdl/deltahg.html	
San Joaquin River Dissolved Oxygen TDML Report: Final Staff Report Feb 2005)[u]	CVRWCB	DO TMDL Study	Mainstem SJR; Stockton Deep Water Ship Channel	DO	1983-present	http://www.waterboards.ca.gov/centralvalley/programs/tmdl/sjr_do/index.html	
TMDL Report for Salt and Boron Discharges Into The Lower San Joaquin River: Final Staff Report (July 2004)[v]	CVRWCB	Salt and Boron TMDL Study	Lower SJR	Flow data; salt and boron	Flow data 1977-1997; salt and boron data 1985-1997	http://www.waterboards.ca.gov/centralvalley/programs/tmdl/vernalis-salt-boron/index.html	

a)USGS, 2007; b)CVRWQCB, 2005;c)CVRWQCB, 1998; d)CVRWQCB, 2000a; e)Hall and Anderson, 2003; f)USEPA, 2006; g)USGS, 2007; h)Whitehead et al; i) DWR, 2006; j) DWR, 2007; k)Markiewicz et al, 2002; l)SFEI, ; SFEI, ; SFEI, ; SFEI, ; USBR et al, ; SFEI, 2006; m) Stokes, 2006; n) DPR, 2006; o)USGS, 1995; p)Domagalski, 1995; q) CVRWQCB, 2006a; r) CVRWQCB, 2000b; s) CVRWQCB, 2001; t)CVRWQCB, 2006b; u)CVRWQCB, 2004b; v)CVRWQCB, 2004a.

References

CVRWQCB. 1998. Loads of Salt, Boron, and Selenium in the Grassland Watershed and Lower San Joaquin River, October 1985 to September 1995, Raw Data Supplemental Appendix California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2000a. Agricultural Drainage Contribution to Water Quality in the Grassland Watershed of Western Merced County, California: October 1997 - September 1998 (Water Year 1998). California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2000b. Selenium TMDL for Grasslands Marshes. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2001. Total Maximum Daily Load for Selenium in the Lower San Joaquin River. California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2004a. Amendments to the Water Quality Control Plan for the Sacramento and San Joaquin River Basins for the Control of Salt and Boron Discharges to the Lower San Joaquin River. Final Draft Staff Report. California Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

CVRWQCB. 2004b. Amendments to the Water Quality Control Plan for the Sacramento and San Joaquin River Basins for the Control Program for Factors Contributing to the Dissolved Oxygen Impairment in the Stockton Deep Water Ship Channel. Final Draft Staff Report. California Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

CVRWQCB. 2005. SJR Basin Monitoring Water Year 2005 (Oct. 04 - Sept. 05). California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA.

CVRWQCB. 2006a. Amendments to the Water Quality Control Plan For the Sacramento River and San Joaquin River Basins For The Control of Diazinon and Chlorpyrifos Runoff into the Sacramento-San Joaquin Delta. Final Staff Report. California Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

CVRWQCB. 2006b. Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury. Staff Report. Draft Report for Scientific Peer Review. California Environmental Protection Agency, Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

Domagalski, J. 1995. Nonpoint sources of pesticides in the San Joaquin River, California -- Input from winter storms, 1992-93. Open-File Report 95-165. U.S. Geological Survey, Sacramento, CA.

DPR. 2006. Surface Water Database. California Department of Pesticide Regulation, Oakland, CA.

DWR. 2006. California Data Exchange Center. California Department of Water Resources, Oakland, CA.

DWR. 2007. Water Data Library (WDL). California Department of Water Resources, Oakland, CA.

Hall, L. W. and Anderson, R. D. 2003. Parametric and probabilistic analysis of historical chlorpyrifos surface water monitoring data from the San Joaquin River watershed: 1991 - 2001. Water, Air, & Soil Pollution 150(1-4): 275-298.

Markiewicz, D., Goding, K., de Vlaming, V. and Rowan, J. 2002. Benthic Macroinvertebrate Bioassessment of San Joaquin River Tributaries: Spring and Fall 2002. UC Davis Aquatic Toxicology Laboratory and California Regional Water Quality Control Board, Rancho Cordova, CA.

SFEI. Grassland Bypass Project Annual Report 1998-99. San Francisco Estuary Institute, Oakland, CA.

SFEI. Grassland Bypass Project Annual Report 1999-2000. San Francisco Estuary Institute, Oakland, CA.

SFEI. Grassland Bypass Project Annual Report 2000-2001. San Francisco Estuary Institute, Oakland, CA.

SFEI. Grassland Bypass Project Annual Report 2001-2002. San Francisco Estuary Institute, Oakland, CA.

SFEI. 2006. Grassland Bypass Project Annual Report 2003. San Francisco Estuary Institute, Oakland, CA.

Stokes & Jones. 2006. Irrigated Lands Program Existing Conditions Report (Draft). Prepared for the Central Valley Regional Water Quality Control Board, Sacramento, CA.

USBR, USEPA, USFWS, USGS, CVRWQCB, DFG and SLDMWA. Grassland Bypass Project Annual Report October 1, 1997 through September 30, 1998. San Francisco Estuary Institute, Oakland, CA.

USEPA. 2006. STORET Legacy Data Center. U.S. Environmental Protection Agency. *http://www.epa.gov/storpubl/legacy/*.

USGS. 1995.Inputs of the Dormant-Spray Pesticide, Diazinon, To The San Joaquin River. *http://ca.water.usgs.gov/water_quality/pest/sj_diaz.html.*

USGS. 2007. National Water Information System. Department of the Interior, U.S. Geological Survey, *http://waterdata.usgs.gov/nwis/*.

Whitehead, A., Kuivila, K. M., Orlando, J. L., Kotelevtsev, S. and Anderson, S. L. Genotoxicity in native fish associated with agricultural runoff events. Environmental Toxicology and Chemistry 23(12): 2868-77.

Appendix D. External Review of Draft Final Report

The external reviewers were sent the following questions along with the draft report:

1. Study design and overall methodology:
   Are the objectives of the project and the study method described clearly?
   In your assessment, how successful was the methodology in meeting objectives?
   Can you suggest ways to improve the methodology or adapt it to other situations?
   Is the method described with sufficient clarity to be applied by others?
   Other observations.

2. Case studies
   Are the selected cases instructive / suited to study purpose?
   What was successful, or could be improved, in developing indicators for the test cases?
   Other observations.

3. Results and future uses of indicators
   Provide your assessment of the results of the project, and what was learned.
   Do you see opportunities to transfer or adapt this analysis to other watersheds?
   Can you suggest potential applications of this work in the future (such as developing indicators of status and trends, or tracking effects of management practices)?
   Other observations.

Reviews were received from:

Jeanne Chilcott, Phil Crader, Rudy Schnagl (Central Valley Regional Water Quality Control Board)
Terry Fleming (U.S. Environmental Protection Agency)
G. Fred Lee (G. Fred Lee & Associates)
Stefan Lorenzato (California Department of Water Resources)
Samuel N. Luoma (U.S. Geological Survey)
Barbara Washburn (Office of Environmental Health and Hazard Assessment, California Environmental Protection Agency)
Terry F. Young, Independent Consultant
Sam Ziegler (U.S. Environmental Protection Agency Region 9)