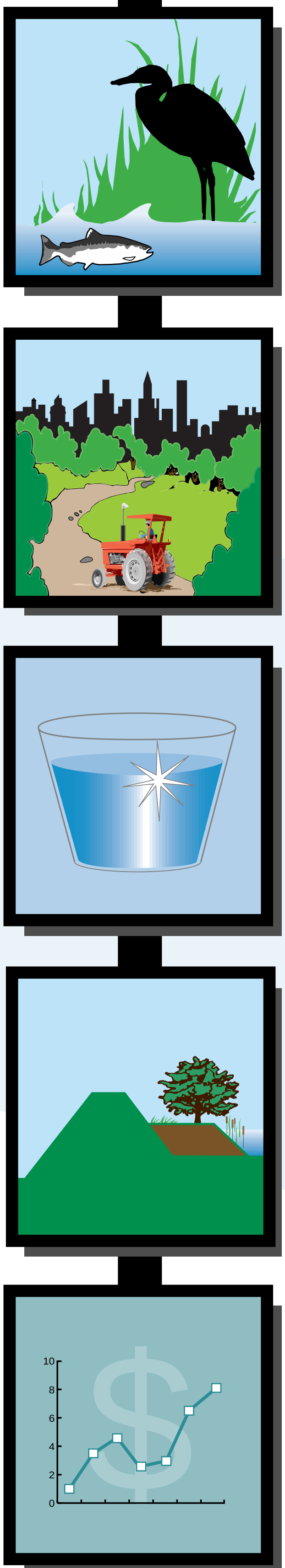

CALFED
BAY-DELTA
PROGRAM

Water Quality Program Plan

Final Programmatic EIS/EIR Technical Appendix

July 2000

Water Quality Program Plan
July 2000

To improve the quality of the waters of the Sacramento-San Joaquin Delta estuary for all beneficial uses, including domestic, industrial, agricultural, recreation, and aquatic habitat.

CALFED
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Water Quality Program Plan

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ACKNOWLEDGMENTS

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* Team Leaders

GLOSSARY

Following are working definitions of terms found throughout the Water Quality Program Plan. This section is intended to facilitate the reader's understanding of the CALFED Water Quality Program and applies only to the Water Quality Program Plan. It is not intended as a general scientific glossary of terms.

Adaptive Management - A process of modifying methods of meeting objectives through interactive decision making, and adapting future management actions according to what is learned from prior projects and studies.

Anthropogenic - Caused by human intervention or originating from human activities.

Bay Region - The Bay Region includes Suisun Bay and Marsh, San Pablo Bay, and the San Francisco Bay watershed. In addition, a zone of approximately 25 miles offshore from Point Conception to the Oregon border has been included to cover potential ocean harvest management of anadromous fish along the California coast. Certainly anadromous fish roam beyond the artificial boundary, but the purpose of the boundary is to identify the area where most anadromous fish from the Bay-Delta system occur and include the area where harvest management actions would be employed.

Beneficial Use - Refers to water uses that are included in the Water Quality Program. Specifically, these water uses are urban, agricultural, industrial, environmental, and recreational beneficial uses.

Ceriodaphnia - A fresh water cladoceran, commonly known as a water flea, which is used as a test species in toxicity bioassays.

Comprehensive Monitoring, Assessment, and Research Program (CMARP) - A program currently under development by the CALFED Bay-Delta Program to identify the monitoring, assessment, and research needed for CALFED-related projects, actions, and activities. CMARP is a critical component of the CALFED adaptive management strategy.

Delta Region - The Delta Region is defined as the statutory Delta (described in Section 12220 of the California Water Code) and is comprised roughly of lowlands (lands approximately at or below the 5-foot contour) and uplands (lands above the 5-foot contour that are served water by lowland Delta channels). The Delta Region has been carved out of the Sacramento and San Joaquin River watersheds because of the Program's focus on this region.

Disinfection By-Products - Chemical compounds that are created during the disinfection of drinking water. Some compounds may be toxic, carcinogenic, or teratogenic.

Indicators of Success - Indicators are a means of assessing progress toward endpoints or targets that are representative of when beneficial uses are no longer impaired.

Parameter Assessment Team - A technical working sub-group of the Water Quality Technical Group representing a variety of interests. See Appendix A and the Acknowledgments for a listing of Parameter Assessment Team members.

Parameters of Concern - Substances identified by the Water Quality Program as causing, or potentially causing, water quality problems to beneficial water uses based on the input of technical experts and stakeholders. Substances may be added to or deleted from the Water Quality Program parameters of concern based on new knowledge. Once a substance becomes a parameter of concern, water quality targets are established for the parameter and actions are developed to address the water quality problems associated with the parameter.

Performance Measures - A means to gauge the progress of an action. Progress may be judged based on a variety of factors, such as reduced concentrations of a parameter. Performance measures answer the question, "Is water quality improving?"

Sacramento River Region - The Sacramento River Region is essentially bounded by the ridge tops of the Sacramento River watershed or hydrologic region. The Goose Lake watershed, in the northeast corner of California, has been left out of the study area because it rarely contributes to the flow of the Pit and Sacramento Rivers—apparently Goose Lake last spilled very briefly sometime in the 1950s and only a few times between 1869 and the present — and no actions are proposed in the watershed. Although the Trinity River is connected by a pipeline to the Sacramento River system, the Trinity River does not flow naturally into the Sacramento River watershed, and no CALFED water quality actions are proposed for the Trinity River or its watershed.

San Joaquin River Region - The San Joaquin River Region includes both the San Joaquin and Tulare Lake hydrologic basins. The Tulare Lake basin only intermittently spills over into the San Joaquin River basin during wet years or a series of wet years. However, potentially significant water quality management issues are linked to the San Joaquin River watershed and ultimately, the Bay-Delta system.

Other SWP and CVP Service Areas - The Other SWP and CVP Service Areas include small portions of Santa Cruz, San Benito, and Santa Clara Counties outside the Bay watershed, served by the CVP (San Felipe Division). The SWP service areas include most of the urbanized areas of southern California, as well as Santa Barbara, San Luis Obispo, Alameda and Santa Clara Counties. The CVP and SWP service areas within the Central Valley are covered by Central Valley watersheds. In addition, Imperial Irrigation District is included in this region because the significant water use efficiency and transfer potential in the district could help to reduce the water supply and demand mismatch in southern California urban areas.

Targets or Water Quality Objectives - End points or compliance levels that when met indicate that beneficial uses are protected. These endpoints may be based on achievement of a variety of measurable factors, including numerical and narrative objectives for water, sediment, and tissue and lack of toxicity as indicated by toxicity testing. Indicators of success answer the question, "Have water quality goals been achieved?"

Toxicity of Unknown Origin - Refers to toxicity to native or laboratory test organisms due to unknown sources.

Water Quality Action - A programmatic action developed by the CALFED Water Quality Program to address impairments to agriculture, environment, drinking water, industrial, and recreational beneficial uses.

Water Quality Target - A numeric or narrative water, sediment, or tissue value associated with a parameter of concern. Water quality targets are based on existing water quality, sediment, and tissue objectives recognized by the scientific community and regulatory authorities. In general, targets have been established to represent a threshold below which beneficial uses of water are not impaired. The target represents the goal toward which the Water Quality Program will strive; realizing targets may not be possible to reach in all cases.

Water Quality Technical Group - A group of over 200 technical experts, agency representatives, and stakeholders representing the environment, agriculture, drinking water, industry, and recreation who participate in the development of the Water Quality Program. See Appendix A for a listing of Water Quality Technical Group members.

ABBREVIATIONS

BCPOS	biorational cling peach orchard systems
BIOS	biologically integrated orchard systems
BIPS	biologically integrated prune systems
BLM	U.S. Bureau of Land Management
BMPs	best management practices
BOD	biochemical oxygen demand
CALFED	CALFED Bay-Delta Program
CCC	California Coastal Commission
CCWD	Contra Costa Water District
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (federal Superfund - EPA)
cfs	cubic feet per second
CMARP	Comprehensive Monitoring, Assessment, and Research Plan
COD	chemical oxygen demand
Corps	U.S. Army Corps of Engineers
CUWA	California Urban Water Agencies
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act (Reclamation)
CVRWQCB	Central Valley Regional Water Quality Control Board
CWA	Clean Water Act (federal)

DBPs	disinfection by-products
DDT	dichloro diphenyl trichloroethane (also DDE; dichloro diphenyl dichloroethylene, and DDD; 1,1-dichloro-2,2bis(p-chlorophenyl)ethane)
DFG	California Department of Fish and Game
DHS	California Department of Health Services
DMC	Delta-Mendota Canal (CVP aqueduct)
DPR	California Department of Pesticide Regulation
DWR	California Department of Water Resources
DWRDSM	California Department of Water Resources Delta Simulation Model
EC	electrical conductivity (also known as "specific conductance")
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program (USDA)
ESA	Endangered Species Act (Federal)
FDA	U.S. Food and Drug Administration
GAC	granular-activated carbon
GIS	Geographic Information System
IEP	Interagency Ecological Program
ISDP	Interim South Delta Program (DWR)
ISDP DEIR/EIS	ISDP Draft Environmental Impact Report/Environmental Impact Statement (DWR)
Kg	kilogram
LBNL	Lawrence Berkeley National Laboratories
MAA	management agency agreement (between DPR and SWRCB)

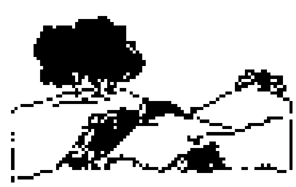
µg/g	micrograms per gram
µg/l	micrograms per liter
µm	micrometer
µmho/cm	micromhos per centimeter
mg/kg	milligrams per kilogram
MIB	methylisoborneol (taste- and odor-causing compound)
MCL	maximum contaminant level
MOU	memorandum of understanding
MPs	management practices (a non-regulatory form of BMPs)
MTBE	methyl tert-butyl ether (fuel oxygenate causing water quality contamination)
MWD	The Metropolitan Water District of Southern California
MWQI	Municipal Water Quality Investigation (a DWR program)
NAWQA	National Water Quality Assessment (a USGS program)
NAS/NAE	National Academy of Science/National Academy of Engineers
NBA	North Bay Aqueduct (SWP aqueduct)
ng	nanogram
ng/g	nanograms per gram
NPDES	National Pollutant Discharge Elimination System (federal Clean Water Act)
NPL	National Priorities List (EPA)
NRCS	Natural Resources Conservation Service
OC	organochlorine (pesticides made of chlorinated organic compounds, such as DDT)
OEHHA	Office of Environmental Health Hazard Assessment (Cal EPA)

PAM	polyacrylamide
PCA	pest control advisor
PCBs	polychlorinated biphenyls
PEIS/EIR	Programmatic Environmental Impact Statement/Environmental Impact Report (CALFED)
pH	acidity of water, log scale of 1 to 14, the lower number being the stronger acid.
ppb	parts per billion
ppm	parts per million
PLAN	West Stanislaus Sediment Reduction Plan
Program	CALFED Bay-Delta Program
Rainbow Report	"A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley" (San Joaquin Valley Drainage Implementation Program)
RCD	Resource Conservation District
Reclamation	U.S. Bureau of Reclamation
RMP	Regional Monitoring Program (San Francisco Estuary Institute)
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board (there are nine, responsible to the SWRCB)
RWCF	Stockton Regional Wastewater Control Facility
SAR	sodium adsorption ratio
SBA	South Bay Aqueduct (SWP aqueduct)
SCVWD	Santa Clara Valley Water District
SCWA	Solano County Water Agency

Se/g	selenium per gram
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SJRMP-WQS	San Joaquin River Management Program, Water Quality Subcommittee
SJVDP	San Joaquin Valley Drainage Program
SJVDIP	San Joaquin Valley Drainage Implementation Program (successor to SJVDP)
SSAC	Sanitary Survey Action Committee (SWP contractors)
Superfund	See CERCLA
SWRCB	State Water Resources Control Board
SWTR	Surface Water Treatment Rule
SWP	State Water Project
T&O	taste and odor (an objectionable characteristic of drinking water)
TDS	total dissolved solids
TIE	toxicity identification evaluation
TMDL	total maximum daily load
TOC	total organic carbon
TSMP	Toxic Substances Monitoring Program (an SWRCB-DFG program)
TTHMs	total trihalomethanes
UC	University of California
UCIPM	University of California Statewide Integrated Pest Management Project
UPC	Urban Pesticide Committee
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service

USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WDR	Waste Discharge Requirement
WQCP	Water Quality Control Plan for the Sacramento-San Joaquin Delta (SWRCB)
WWD	Westlands Water District

1. INTRODUCTION



1. INTRODUCTION

The mission of the CALFED Bay-Delta Program (Program or CALFED) is to develop a long-term comprehensive plan that will restore ecosystem health and improve water management for beneficial uses of the Bay-Delta system. The Program has identified six solution principles as fundamental guides for evaluating alternative solutions:

> The mission of the CALFED Bay-Delta Program is to develop a long-term comprehensive plan that will restore ecosystem health and improve water management for beneficial uses of the Bay-Delta system.

- ***Reduce conflicts in the system*** - Solutions will reduce major conflicts among beneficial uses of water.

- ***Be equitable*** - Solutions will focus on solving problems in all problem areas. Improvements for some problems will not be made without corresponding improvements for other problems.

- ***Be affordable*** - Solutions will be implementable and maintainable within the foreseeable resources of the Program and stakeholders.

- ***Be durable*** - Solutions will have political and economic staying power and will sustain the resources they were designed to protect and enhance.

- ***Be implementable*** - Solutions will have broad public acceptance and legal feasibility, and will be timely and relatively simple to implement compared with other alternatives.

- ***Result in no significant redirected impacts*** - Solutions will not solve problems in the Bay-Delta system by redirecting significant negative impacts, when viewed in their entirety, within the Bay-Delta or to other regions of California.

The Program addresses problems in four resource areas: ecosystem quality, water quality, levee system integrity, and water supply reliability. Each resource area forms a component of the Bay-Delta solution and is being developed and evaluated at a programmatic level. Therefore, problems and corrective actions are described in a general manner sufficient to make broad decisions on Program direction. The complex and comprehensive nature of a Bay-Delta solution requires a composition of many different programs, projects, and actions that will be implemented over time.

The Program is being completed in three phases (Figure 1). Phase I of the Program began in June 1995 and was completed in August 1996. During this phase, three conceptual alternatives were developed to solve Bay-Delta problems. These conceptual alternatives all include Program components to comprehensively address

ecosystem restoration, water quality improvements, enhanced Delta levee system integrity, and increased water supply reliability.

Phase I 1995–1996	Phase II 1996–1999	Phase III 1999–2030
Three conceptual alternatives	Alternatives refinement Programmatic EIS/EIR Selection of Preferred Program Alternative	Project-specific environmental documentation Implementation of Preferred Program Alternative Adaptive management Assurances

STAKEHOLDER INVOLVEMENT THROUGHOUT

Figure 1. The Three Phases of the CALFED Bay-Delta Program

The Water Quality Program, like all components of the CALFED Program, is being developed and evaluated at a programmatic level. The Program is currently in what is referred to as Phase II, in which the CALFED agencies are developing a Preferred Program Alternative that will be subject to a comprehensive programmatic environmental review. This report describes both the long-term programmatic actions that are assessed in the June 1999 Draft Programmatic Environmental Impact Statement/Environmental Impact Report (EIS/EIR), as well as certain more specific actions that may be carried out during implementation of the Program. The programmatic actions in a long-term program of this scope necessarily are described generally and without detailed site-specific information. More detailed information will be analyzed as the Program is refined in its next phase.

Implementation of Phase III is expected to begin in 2000, after the Programmatic EIS/EIR is finalized and adopted. Because of the size and complexity of the alternatives, the Program likely will be implemented over a period of 30 or more years. Program actions will be refined as implementation proceeds, initially focusing on the first 7 years (Stage 1). Subsequent site-specific proposals that involve potentially significant environmental impacts will require site-specific environmental review that tiers off the Programmatic EIS/EIR. Some actions, such as construction of treatment facilities and mine remediation, also will be subject to permit approval

Implementation of Phase III is expected to begin in 2000, after the Programmatic EIS/EIR is finalized and adopted.

of treatment facilities and mine remediation, also will be subject to permit approval from regulatory agencies. Figure 2 shows the three phases of the Water Quality Program and associated program documents.

Phase I 1995–1996	Phase II 1996–1999	Phase III 1999–2030
Parameters of concern	Refinement of parameters and actions	Prioritization and implementation of actions
Preliminary set of actions	Performance measures and indicators of success	Adaptive management
	Priorities for Phase III Program implementation	
Agriculture Subteam report	Water Quality Program Plan	Water Quality Implementation Strategy
Urban Subteam report		
CALFED water quality supplemental information document		

STAKEHOLDER INVOLVEMENT THROUGHOUT

Figure 2. The Three Phases of the Water Quality Program and Associated Program Documents

The CALFED Program's goal for water quality is to provide good water quality for environmental, agricultural, drinking water, industrial, and recreational beneficial uses. To achieve this goal, CALFED has developed and is implementing a Water Quality Program. The purpose of this report is to detail the results of Water Quality Program activities conducted during Phase II of the Program and to highlight those activities planned in Phase III.

The CALFED Program's goal for water quality is to provide good water quality for environmental, agricultural, drinking water, industrial, and recreational beneficial uses.

During Phase I of the Water Quality Program, parameters of concern to beneficial uses were identified, and a preliminary set of actions to address those parameters were developed. During Phase II, currently underway, the list of parameters of concern and programmatic water quality actions were refined, performance identified, and more general plans were formulated for later implementation stages.

CALFED staff recognize that the necessity to formulate the Water Quality Program at a level of detail appropriate to a programmatic environmental document leaves many questions unanswered. Water quality problems are not spelled out in great detail, and the actions to address the problems are described in general terms. At the programmatic level of detail, the identified actions constitute a commitment to improving water quality. In many cases, this commitment cannot be fulfilled until additional study, evaluation, feasibility determination, and pilot-scale implementations are accomplished. These activities must be relegated to Phase III of the process beginning in 2000, but the intent at this stage of the program is to establish an adequate basis for project-specific work to come later.

1.1 Purpose and Need

> The value of water is determined by its potential uses. In turn, the uses that can be made of water are determined by its quality.

The value of water is determined by its potential uses. In turn, the uses that can be made of water are determined by its quality. Water of degraded quality may not adequately support the aquatic ecosystem because it may not contain sufficient oxygen; because it may contain particles that suffocate bottom-dwelling organisms; or because it may be poisonous to aquatic organisms or to other species, including humans, that consume aquatic organisms. Salinity and other constituents in the water may render it unsuitable for many uses, such as agricultural and landscape irrigation, industrial processes, and drinking. Also, water contaminated by pathogens, such as viruses, bacteria, and protozoans, may cause illnesses in animals and humans who consume the water. Clearly, therefore, if the Bay-Delta ecosystem is to be restored and conflict among beneficial users of the estuary is to be reduced, the quality of the waters must be suitable for the ecological and human uses of the resource.

The purpose of the CALFED Water Quality Program is to improve the quality of the waters of the Sacramento-San Joaquin Delta estuary for all beneficial uses (including domestic, industrial, agricultural, recreation, and aquatic habitat). Because species dependent on the Delta are affected by upstream water quality conditions in some areas, the scope of the Water Quality Program also includes watershed actions to reduce water quality impacts on these species.

The need for action to correct water quality problems in the Delta estuary and its watersheds arises from recognition that water quality degradation negatively affects, or has the potential to negatively affect, a number of beneficial uses of the waters. Section 303(d) of the federal Clean Water Act (CWA) requires states to identify water bodies with impaired quality with respect to supporting beneficial uses. This process has resulted in a number of water bodies in the Bay-Delta estuary and its tributaries being listed as impaired. Therefore, an important component of correcting the overall problems of the Delta estuary is undertaking actions to effectively reduce the toxicity of aquatic habitats and reduce constituents, such as salinity, that affect the usability of Delta water supplies.

1.2 Vision

The vision for the CALFED Water Quality Program is to create water quality conditions that fully support a healthy and diverse ecosystem and the multiplicity of human uses of the waters. To realize this vision, CALFED will strive to continually improve the quality of waters of the San Francisco Bay-Delta estuary until no ecological, drinking water, or other beneficial uses of the waters are impaired by water quality problems, and to maintain this quality once achieved.

The vision for the CALFED Water Quality Program is to create water quality conditions that fully support a healthy and diverse ecosystem and the multiplicity of human uses of the waters.

With respect to ecosystem values, the Water Quality Program envisions waters and sediments of the estuary free of toxicity to phytoplankton, zooplankton, benthic invertebrate organisms, and fish communities that inhabit the Delta estuary. Protection from accidental or intentional toxic spills would be an important feature of assurance of toxicity-free conditions. Oxygen levels in the waters of the estuary would, at all times, contain sufficient dissolved oxygen (DO) to avoid stress to aquatic organisms and to make all estuary habitats livable and attractive to aquatic species. Suspended solids loadings in the estuary would be appropriate to enable adequate recruitment of bed sediments to support a healthy and diverse community of benthic organisms, would produce water column turbidity conditions that are optimal, and would provide suspended solids in size ranges and concentrations that would avoid low DO and low oxygen exchange conditions in channel bottoms.

Waters of the estuary supplied to agricultural uses would be sufficiently low in boron to avoid toxicity to sensitive plant species, with an appropriate sodium adsorption ratio to avoid soil impermeability, and be sufficiently low in dissolved minerals (salinity) to

- Avoid toxicity to plants,
- Promote efficient water use by enabling multiple stages of tailwater recycling,

- Reduce salt loadings in agricultural drainage to eliminate impacts on downstream uses, and

- Attain long-term salt balance.

Delta waters used for industrial purposes would be sufficiently low in mineral concentrations to enable efficient water use and closed-loop recycling of process water; and to reduce costs from accretion of mineral deposits in piping, cooling, heating, and other industrial equipment. Industrial water supplies from the Delta also would be sufficiently low in other constituents, such as metals and nutrients, to avoid the necessity for costly pretreatment in order to render the waters suitable for incorporation into products to be ingested and other industrial uses.

Recreational uses of the waters of the Bay-Delta estuary will be enhanced by reduction of disease-causing organisms through better protection of Delta waters from animal and human contamination. Aesthetic values will be enhanced by reduction in nuisance algae blooms that are unsightly, cause odors, obstruct navigation, and foul boat bottoms.

Recreational uses of the waters of the Bay-Delta estuary will be enhanced by reduction of disease-causing organisms through better protection of Delta waters from animal and human contamination.

With respect to drinking water uses, waters supplied from the Delta would be protected from releases of pathogens (e.g., viruses, bacteria, and protozoa) from sources such as recreational boating, livestock grazing, stormwater runoff, sewage spills, and wastewater discharges. Watershed protection measures also would be applied to reduce known and potential sources of turbidity, nutrients, and toxic substances that contribute to reducing the safety of drinking water supplies and the reliability of water treatment. Bromide and organic carbon concentrations would be present in drinking water supplies taken from the Delta in concentrations sufficiently low as to enable meeting current and prospective drinking water regulations. Concentrations of all constituents and variability in source water quality would be sufficiently low as to enable water utilities to provide a quality of drinking water that is the equal of any in the world with respect to safety, palatability, and overall quality. Because of its high level of source protection and competent treatment, drinking water from the Delta would never be associated with outbreaks of waterborne diseases.

Municipal water supplies from the Delta would be sufficiently low in dissolved mineral content to attain record high-efficiency water use.

- Water supplies low in salinity can support multiple recyclings, thus greatly enhancing efficiency of water use and reducing dependency on importing water supplies from the Delta.

- Low-salinity water from the Delta would increase the flexibility for meeting water needs by enabling blending with alternate supplies, such as groundwater (some of which is higher in dissolved minerals than surface waters), and with other surface water supplies of lower mineral quality. The effect of this increased flexibility would reduce dependency on importing water supplies from the Delta.

The vision for water quality also includes being able to provide the critical benefits of water quality at a cost that is affordable to Californians generally and to the individual beneficiaries of the water resources of the Delta estuary.

The vision for water quality also includes being able to provide the critical benefits of water quality at a cost that is affordable to Californians generally and to the individual beneficiaries of the water resources of the Delta estuary.

The CALFED vision can be realized only with the help of the involved agencies and stakeholders. Its attainment must be an evolutionary process. CALFED has chosen the term "adaptive management" to refer to the concepts that (1) much remains to be learned about the Bay-Delta estuary and about what can be done to correct its problems, and (2) decisions will need to be continuously made over the next 30 years as the Program is implemented. The most important part of the water quality vision is that continual improvement in water quality will be achieved by maintaining the Water Quality Technical Group as the primary vehicle through which the program is guided in the coming years. Therefore, although it is not possible to predict the exact directions of the Program, maintaining close involvement of the interested parties will provide the best possible assurance that correct decisions will be made while CALFED solution principles are upheld.

Although not applicable to every situation that will be encountered by the CALFED Water Quality Program, the program endorses the following solution methodology:

- Use existing regulatory water quality standards as goals where applicable.
- Devote primary attention on defensible problem identification.
- Implement comprehensive data collection and focused research to address water quality issues of concern.
- Develop and implement analytical tools (mathematical models) to provide predictive capacity for management efforts.
- Implement demonstration projects to validate management effectiveness.
- Develop strategic plans through involvement and education of all affected parties.
- Develop and implement management tools to address water quality problems.
- Support other efforts to address identified problems.

1.3 Geographic Scope

Consistent with the CALFED Programmatic EIS/EIR, the geographic scope of the Water Quality Program encompasses five regions:

- Delta Region
- Bay Region
- Sacramento River Region
- San Joaquin River Region
- Other SWP and CVP Services Areas

Descriptions of these regions are contained in the Glossary at the front of this document. A map showing the location of these regions follows (Figure 3).

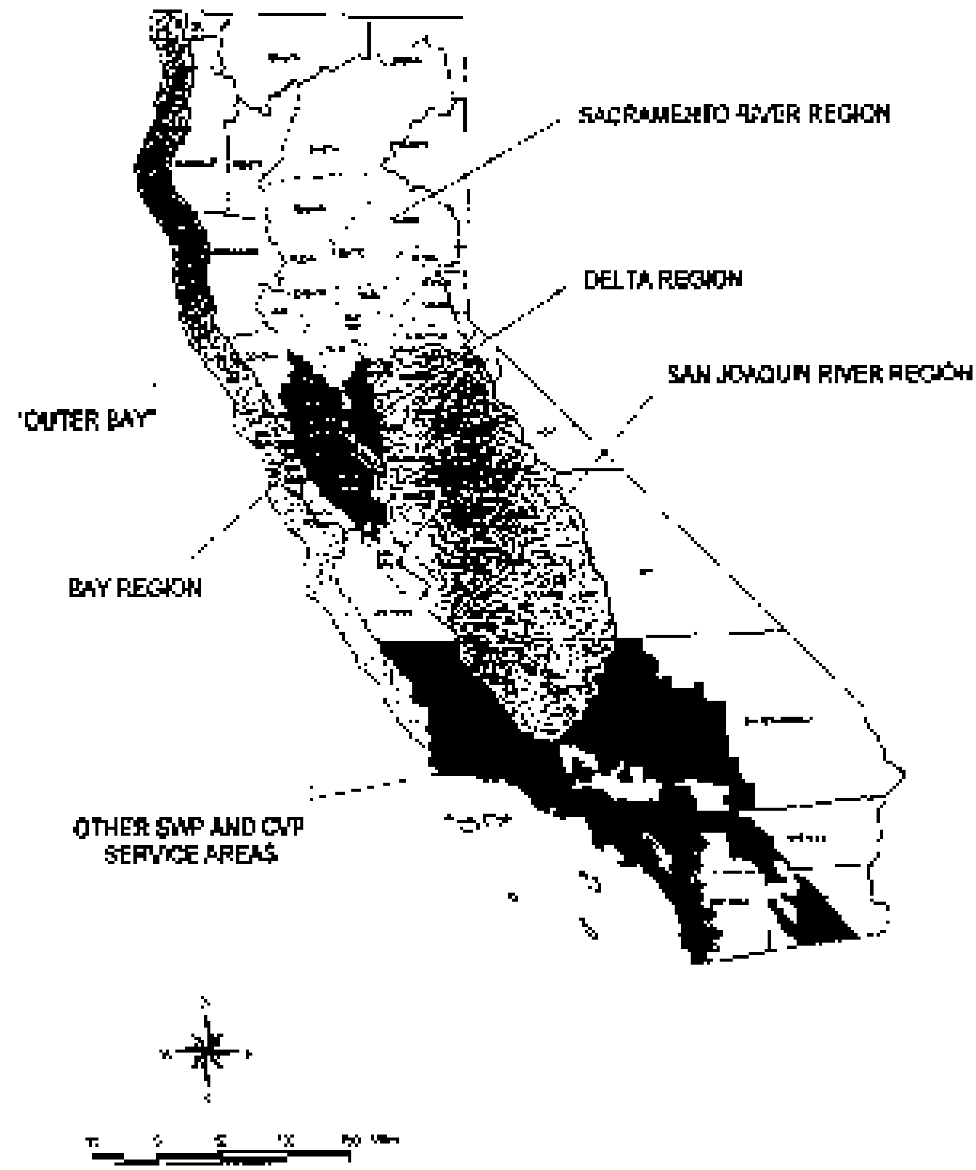
1.4 Water Quality Program Actions

1.4.1 Introduction

The Water Quality Program has developed programmatic actions to address beneficial use impairments within its geographic scope. Implementing these actions will further the program's goal of providing good quality water for environmental, agricultural, drinking water, industrial, and recreational beneficial uses of water. The water quality impact analysis of the Programmatic EIS/EIR contains a comprehensive analysis of the impacts of CALFED actions on water quality and other components of the CALFED Program.

The Program has relied on the technical expertise of a variety of stakeholders representing beneficial uses.

Determining impairment to a beneficial use is almost always a difficult and complicated matter. For some beneficial uses, such as drinking water use and agricultural water use, concentrations of parameters of concern in ambient water that may affect uses are well quantified. For other beneficial uses, such as ecosystem resources, concentrations of parameters of concern in ambient water that may affect the diverse assemblages of species in the Delta Region are less well understood. As a result, the Program has relied on the technical expertise of a variety of stakeholders representing beneficial uses. These stakeholders have worked with CALFED staff to identify parameters of concern to beneficial uses, the locations of beneficial use impairments, the types of water quality actions needed to address these impairments, and the ways to assess the effectiveness of actions.



NOTE: A description of the five regions is included in the Glossary.

Figure 3. Water Quality Program Plan Geographic Scope

CALFED is a cooperative, inter-agency effort involving many state and federal agencies with management or regulatory responsibilities for the Bay-Delta. Each participating agency bears its respective authorities and responsibilities, independent of CALFED efforts. One primary purpose of CALFED is to facilitate the collaborative and cooperative use of these authorities and responsibilities, as well as CALFED resources, to better address the range of problems facing the Bay-Delta.

CALFED does not possess independent, regulatory authority over water quality. However, CALFED does recognize the need for participating agencies to exercise their responsibilities with regard to water quality. CALFED will work with all entities in support of achieving its water quality goals.

CALFED does not possess independent, regulatory authority over water quality.

CALFED's Water Quality Program calls for implementation of a range of tools by participating agencies and interested parties to accomplish its goals. These tools include, but are not limited to, voluntary efforts, use of economic incentives, and exercising regulatory authority by appropriate agencies. The appropriate mix of tools will vary, depending on the problem, existing activities, and where CALFED's Program can add value.

1.4.2 Background

Stakeholders and CALFED staff have developed a list of parameters of concern to beneficial uses (Table 1). The list of parameters of concern may be updated as new information becomes available, consistent with the adaptive management policy of the CALFED Program.

Water quality problems associated with these parameters have been identified by the State in accordance with the CWA. The program used existing information from the CWA Section 303(d) list of impaired water bodies for California to identify the locations of beneficial use impairments associated with parameters of concern. The Section 303(d) list identifies water bodies with impaired beneficial uses, the parameters of concern within each water body that are thought to be responsible for the impairment, and the likely sources of the parameters of concern. The Section 303(d) list contains only parameters of concern for which there are water quality objectives for surface waters. Much of the regulation for drinking water applies to the treated water available for consumption and does not apply to the surface water source. Therefore, the Section 303(d) list does not contain all parameters of concern for drinking water. Appendix B contains a list of the impaired water bodies within the Water Quality Program's geographic focus that were identified by the State in 1998, in accordance with the CWA Section 303(d).

The Section 303(d) list identifies water bodies with impaired beneficial uses, the parameters of concern within each water body that are thought to be responsible for the impairment, and the likely sources of the parameters of concern.

Table 1. Water Quality Parameters of Concern to Beneficial Uses

Metals and Toxic Elements	Organics/ Pesticides	Disinfection By-Product Precursors	Other
Cadmium	Carbofuran	Bromide	DO
Copper	Chlordane[1]	TOC	Salinity (TDS, EC)
Mercury	Chlorpyrifos		Temperature
Selenium	DDT[1]		Turbidity
Zinc	Diazinon		Toxicity of unknown origin[2]
	PCBs[1]		Pathogens
	Toxaphene[1]		Nutrients[3]
	Dioxins[4]		pH (Alkalinity)
	Dioxin-like compounds[4]		Chloride
			Boron
			Sodium adsorption ratio

Notes: EC = Electrical conductivity
TDS = Total dissolved solids
TOC = Total organic carbon

[1] These compounds are no longer used in California. Toxicity from these compounds is remnant from past use.
[2] Toxicity of unknown origin refers to observed aquatic toxicity, the source of which is unknown.
[3] Nutrients includes nitrate, nitrite, ammonia, organic nitrogen, total phosphorus, and soluble reactive phosphorus.
[4] These compounds may be added after review by an appropriate group of stakeholders.

Although the data used to develop the Section 303(d) list of impaired water bodies are subject to criticism (many people note that the data need to be updated), it is the most comprehensive information on beneficial use impairment available at this time. The program recognizes the need for a comprehensive analysis of beneficial use impairments to Delta waters and will use such additional information as it becomes available, consistent with the adaptive management policy of the CALFED Program. The implementation strategy for the Water Quality Program envisions ongoing assessments involving experts, regulatory agencies, and the public to ensure that the best possible understanding is applied to CALFED investment decisions. It is anticipated that a great deal of information on the status of water quality and beneficial use impairments throughout the study area will be compiled by the Comprehensive Monitoring, Assessment, and Research Program (CMARP).

Water quality actions to address beneficial use impairments may include a combination of research, pilot studies, and targeted activities. This approach allows actions to be taken on known water quality problems and sources of those problems, while allowing further research of potential problems and solutions. Table 2 summarizes Water Quality Program actions by region.

Water quality actions to address beneficial use impairments may include a combination of research, pilot studies, and targeted activities.

Table 2. Summary of Water Quality Program Actions by Region

	Region				
Topic	Delta	Bay	Sacramento River	San Joaquin River	Other SWP and CVP Service Areas
Low dissolved oxygen	✔	✔		✔	
Drinking water	✔	✔	✔	✔	✔
Mercury	✔	✔	✔		
Pesticides	✔	✔	✔	✔	
Organochlorine pesticides	✔	✔	✔	✔	
Salinity	✔			✔	
Selenium	✔			✔	
Trace metals	✔	✔	✔	✔	
Turbidity and sedimentation	✔	✔	✔	✔	
Toxicity of unknown origin	✔	✔	✔	✔	

Actions will be adapted over time to ensure the most effective use of resources. The individual indicators of success for each program action, shown in Appendix C, can be used to assess the effectiveness of water quality actions.

Actions will be adapted over time to ensure the most effective use of resources.

The Water Quality Program has identified narrative or numerical water quality targets for each parameter of concern (Appendix D). These targets represent desirable in-stream concentrations of parameters of concern that will be used as indicators of success to determine the effectiveness of water quality actions. However, the degree to which these targets are realized will depend on overall CALFED solutions. Targets may not be fully realized because of competing CALFED solution requirements or because attainment of a target is technically infeasible.

1.5 Pre-Feasibility Analysis

In general, water quality targets are based on the Water Quality Control Plans (WQCPs) (Basin Plans) of the San Francisco Bay and Central Valley Regional Water Quality Control Boards (SFBRWQCB and CVRWQCB), U.S. Environmental Protection Agency (EPA) ambient water quality objectives.

standard agricultural water quality objectives, and target source drinking water quality ranges as defined by technical experts. Other indicators of success may be used in conjunction with these targets on a project-specific basis to determine the effectiveness of actions toward protecting beneficial uses.

Individual programmatic actions may vary in cost, technical feasibility, and other respects that may affect the final choices for implementation. Therefore, actions will be subjected to a pre-feasibility analysis to determine which programmatic actions are most appropriate to be implemented. This analysis has begun and will continue into Phase III of the CALFED Program. Full feasibility analysis in conjunction with project-specific environmental documentation will be performed in Phase III. The process by which actions will be implemented is discussed in Section 12, "Implementation Strategy."

Actions will be subjected to a pre-feasibility analysis to determine which programmatic actions are most appropriate to be implemented.

1.6 ORGANIZATION OF THIS REPORT

This Water Quality Program Plan contains the following sections:

- Section 1, "Introduction," provides an introduction to the CALFED Program and discusses the Water Quality Program, including its purpose and need, vision, geographic scope, and an overview of Water Quality Program actions.

- Section 2, "Low Dissolved Oxygen Concentration and Oxygen-Depleting Substances," addresses sources of oxygen-depleting substances and their effects on water quality.

- Section 3, "Drinking Water," elaborates on strategies to protect and improve source water quality for drinking water production. The section discusses pollutants and their effects on drinking water.

- Section 4, "Mercury," focuses on water quality problems associated with mercury.

- Section 5, "Pesticides," identifies the toxic effects of pesticides currently in use and proposed approaches to address pesticide problems related to water quality.

- Section 6, "Organochlorine Pesticides," presents the residual effects of organochlorine pesticides on water quality.

- Section 7, "Salinity," primarily addresses the effects of salinity on agricultural and drinking water beneficial uses of water.

- Section 8, "Selenium," identifies the sources and effects of selenium related to water quality.

- Section 9, "Trace Metals," addresses the aquatic toxicity of copper, cadmium, and zinc.

- Section 10, "Turbidity and Sedimentation," identifies existing and potential turbidity and sedimentation concerns for water quality.

- Section 11, "Toxicity of Unknown Origin," discusses elements causing toxicity in the Sacramento and San Joaquin River watersheds and the Delta that have not been identified in current evaluations.

- Section 12, "Implementation Strategy," contains an implementation strategy for the Water Quality Program.

Technical appendices follow the report.

For most sections, the discussion is separated into the following topics:

Summary. Provides an overview of the section.

Problem Statement. Presents a concise statement of the problem.

Objective. States the objective of the Water Quality Program for the topic being discussed.

Problem Details. Elaborates on the problem defined in the "Problem Statement."

Approach to Solution. Identifies activities appropriate to the Water Quality Program that can minimize impacts, identifies opportunities for implementation of these activities, and determines data gaps and necessary data-gathering activities. The "Approach to Solution" section includes three subsections: "Priority Actions," "Information Needed," and "Existing Activities." When information is not available or applicable, the subsection heading is not included.

2. LOW DISSOLVED OXYGEN CONCENTRATION AND OXYGEN-DEPLETING SUBSTANCES

2. Low Dissolved Oxygen Concentration and Oxygen-Depleting Substances

2.1 Summary

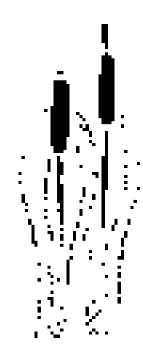
Low DO concentration and the presence of oxygen-depleting substances appears to occur in isolated areas of designated impaired water bodies. The following water bodies are listed in the January 1998 CWA Section 303(d) list as impaired from low DO concentration: Delta waterways, Sacramento River, San Joaquin River, and Bay Regions. Each region is discussed below, along with recommended approaches to solve the problems caused by low DO.

Low DO concentration and the presence of oxygen-depleting substances appears to occur in isolated areas of designated impaired water bodies.

Oxygen-depleting substances originate from a variety of sources. Common sources are degrading organic material from in-stream plants or plant matter from stormwater systems. Usually, stormwater-introduced plant material does not substantially affect DO, since most material is introduced during the wet season. However, stormwater systems also discharge during the dry season due to urban irrigation and water use. Dry season discharge is more concentrated than its winter counterpart. Agricultural drain water (irrigation return) also may carry oxygen-depleting substances. Unpermitted wastewater from industries also contains oxygen-depleting substances and nutrients. Nutrients promote the growth of algae and other water organisms. When these organisms die, they degrade and exert a demand on oxygen in the stream. Some industrial wastewater and some eroded soil in the river water contain nutrients.

2.2 Problem Statement

Oxygen depletion occurs at isolated locations in the Delta, causing DO concentrations to fall below water quality criteria (5 milligrams per liter [mg/l]). Oxygen depleting substances are found in various discharges. The substances may either exert a direct oxygen-depleting effect (i.e., biochemical oxygen demand [BOD]) or decrease oxygen by an indirect method (i.e., nutrients that cause algal growth, which eventually dies off and exerts an oxygen demand.) Low DO impairs or blocks fish migration, kills aquatic organisms, including fish, creates odors, and impairs fish reproduction and juvenile rearing.



2.3 Objective

The objective is to correct the causes of oxygen depletion in affected areas, to reduce incidences of low DO, and to reduce the impairment of beneficial uses.

2.4 Delta Waterways

This section on Delta waterways addresses:

- the San Joaquin River near Stockton;
- Stockton tributaries, including Little Johns, Lone Tree, and Temple Creeks, and
- Urban waterways near Stockton, including Smith Canal, Mosher Slough, 5-Mile Slough, and the Calaveras River.

2.4.1 Problem Description

San Joaquin River near Stockton

DO concentrations have decreased to below the 5-mg/l standard between June and November in the San Joaquin River near Stockton. The main channel near Stockton has been identified as a candidate Bay Protection and Toxic Cleanup Program hot spot. It appears that low DO concentrations occur over a 10-mile reach of the San Joaquin River and can reach as low as 2.5 mg/l in fall. These low DO concentrations are called an "oxygen sag" and may act as a barrier to upstream migration of adult San Joaquin River fall-run chinook salmon that migrate upstream to spawn in the Merced, Tuolumne, and Stanislaus Rivers between September and December.

The main channel near Stockton has been identified as a candidate Bay Protection and Toxic Cleanup Program hot spot.

The San Joaquin River population of chinook salmon has declined, is considered a "species of concern" by the U.S. Fish and Wildlife Service (USFWS), and is a candidate for listing by the National Marine Fisheries Service. Low DO concentrations also can stress, kill, or block migration of other fish.

Oxygen depletion in the San Joaquin River is highest in late summer and fall, when high water temperature reduces the oxygen-carrying capacity of the water and increases biotic respiration rates. Low or negative streamflow past Stockton reduces dilution and mixing, which reduces re-aeration of the water. Respiring algal blooms create a high oxygen demand during these months, which exacerbates other factors. Organic carbon or nutrients from algal blooms, petroleum products, wastewater effluent, or confined animal operations deplete oxygen due to microbial digestion of the carbon. Redox (reduction oxidation) reactions also may contribute to the oxygen depletion in the river through chemical conversion of oxygen. In addition, San Joaquin River tributaries add oxygen-depleted water after stormwater runoff events in the critical period (late summer). The tributaries introduce low DO water, and they introduce more of the same oxygen-depleting substances. Urban stormwater facilities also may contribute oxygen-depleting substances when the facilities discharge urban irrigation runoff and other urban non-point source effluent.

Oxygen depletion in the San Joaquin River is highest in late summer and fall, when high water temperature reduces the oxygen-carrying capacity of the water and increases biotic respiration rates.

Effluent from the Stockton Regional Wastewater Control Facility (RWCF) is considered to be a relatively large anthropogenic (of human origin) source of the oxygen-depleting substances in the San Joaquin River. The City of Stockton has invested considerable time and money to develop and test an accurate water quality model for the San Joaquin River near Stockton. This model is being used to investigate and evaluate alternative river management strategies. The model suggests that the RWCF is a source of BOD and ammonia in the river, but that sediment oxygen demand and algal respiration may be the dominant mechanisms causing low DO during simulated low flow periods. The contribution of the RWCF discharge to organic sediment deposits appears relatively small compared to river loads of organic materials, although further studies are warranted to determine the factors involved.

The City of Stockton has invested considerable time and money to develop and test an accurate water quality model for the San Joaquin River near Stockton.

The City of Stockton model results also suggest that:

- A flow of 500 cubic feet per second (cfs) will increase DO by 1-1.3 mg/l.
- A temperature decrease of 2 degrees will increase DO by 1 mg/l.
- A 50% reduction of sediment oxygen demand will increase DO by 1.2 mg/l.
- An algal bloom can decrease DO concentrations by 3 mg/l.
- Removal of the entire RWCF discharge would increase DO concentration by only 1 mg/l and would not be sufficient to meet DO standards for the San Joaquin River.

The Turning Basin is another important source of oxygen-depleting substances in the San Joaquin River in late summer. Each year, the Department of Water Resources (DWR) monitors top and bottom concentrations of DO in the ship channel between Prisoner's Point and the Turning Basin. DO concentrations are lowest in the highly stratified Turning Basin, where they reach <1 mg/l near the bottom. This oxygen-depleted water moves downstream with the tide and into the main channel. The oxygen-depleted water forms a plume at the bottom of the main channel that has a minimum at the mouth of the Turning Basin before placement of the flow restriction barrier in Old River. A depression in the channel at the mouth of the Turning Basin probably accumulates oxygen-depleting substances from the bottom of the Turning Basin.

The Turning Basin is another important source of oxygen-depleting substances in the San Joaquin River in late summer.

It is uncertain whether the low DO concentrations observed in the Turning Basin near the bottom are substantially affecting DO concentrations in the San Joaquin River. The water movement between the Turning Basin and the ship channel, as well as the concentrations of DO and BOD in the water, should be more intensively monitored.

Another suspected source of oxygen depletion is unpermitted discharges of waste from concentrated animal feedlots and other less specific industrial sources. These sources are not confined to the Stockton area but are found throughout the Central Valley and beyond. They are mentioned here only because they are suspected of contributing to low DO levels in the San Joaquin River. Wastewater from such sources exert a demand on DO by introducing organic material that is consumed by micro-organisms and by introducing material that is chemically oxidized. Nutrients from confined animal facilities (and other similar wastes) contribute to algal production, which can intensify oxygen depletion as the algae respires. Confined animal facilities and some agriculture-based industry (fertilizer manufacturers and users) also can introduce significant quantities of ammonia, which is lethal to fish at various concentrations, and pH. Data on unpermitted discharges are not readily available. Documenting sources in this portion of the program will include locating these unpermitted discharges.

Another suspected source of oxygen depletion is unpermitted discharges of waste from concentrated animal feedlots and other less specific industrial sources.

Several agencies have contributed in attempts to solve the low DO problem in the Stockton reach of the San Joaquin River during late summer. One strategy was to reduce oxygen depletion in the San Joaquin River by (1) controlling the effluent from the RWCF and Port of Stockton, and (2) forcing more water down the main channel with a rock barrier placed at the head of Old River, thus improving dilution and re-aeration capacity of the river. DWR constructed the barrier. The Regional Water Quality Control Board (RWQCB) has reduced the City of Stockton's effluent limit for carbonaceous BOD to 10 mg/l during this period (from 4/1 to 10/31). Pre- and post-barrier DO concentration measurements by DWR (1987-1992) in fall, however, indicate that the increased streamflow created by the barrier has little effect on DO concentrations in the oxygen sag in dry and critically dry years. The higher streamflow merely moves the DO sag downstream. The oxygen sag persists in the channel throughout fall until cool water temperature and high mixing and streamflow from seasonal precipitation dissipate the sag. Further studies, including DWR longitudinal DO profiles, are needed to confirm findings.

Stockton Tributaries

Data from the 1980s indicate that BOD concentrations frequently exceeded 30 mg/l in Little Johns Creek, Lone Tree Creek, and Temple Creek. A maximum BOD of 136 mg/l was measured in Temple Creek. These high BOD levels are believed to be caused by waste discharge from dairies and have the potential to reduce DO concentrations.

California ranks number one in the country for dairy, number one for chicken egg production, and number three for sheep and lamb production. The total livestock and poultry value for California is $6.3 billion. With these numbers comes the animal wastes that need to be properly managed. San Joaquin Valley's 1,600 dairies with 850,000 head, create as much waste as 21 million people, yet state inspectors to regulate these activities are few. Chronic and catastrophic discharges of these wastes into Central Valley and Bay-Delta waterways contributes to problems such as nutrient loading, elevated ammonia, algal blooms, and low dissolved oxygen. Antibiotics, hormones, and selenium as drugs or feed additives also have been considered potential problems of concern.

Chronic and catastrophic discharges of animal wastes into Central Valley and Bay/Delta waterways contributes to problems such as nutrient loading, elevated ammonia, algal blooms, and low dissolved oxygen.

Urban Waterways near Stockton

Urban stormwater discharge into waterways around the City of Stockton may contribute to decreases of oxygen concentrations to less than 5 mg/l. After storms, DO concentrations as low as 0.34 mg/l have been recorded in Smith Canal, Mosher Slough, 5-Mile Slough, and the Calaveras River. The lowest concentrations occur after the first storm of the year. Low DO concentrations were associated with fish kills in the field, and laboratory tests demonstrated death of threadfin shad at 3.3–4.7 mg/l. Urban stormwater runoff from the City of Stockton and San Joaquin County is the probable source of the low DO concentrations, but the actual sources and mechanisms are unknown. Chen and Tsai (1999) conducted a study of DO depletion in Smith Canal after stormwater events. They concluded that scour of the sediments and other constituents during storm events and the oxygen demand associated with sediments are primary factors in DO depletion. Chen and Tsai (1999) concluded that DO depletion in Smith Canal affects aquatic life within Smith Canal but there was little impact on the San Joaquin River Deep Water Ship Channel, where Smith Canal discharges

In urban waterways near Stockton, the lowest DO concentrations occur after the first storm of the year.

2.4.2 Approach to Solution

San Joaquin River near Stockton

Priority Actions

1. Encourage continued removal of oxygen-depleting substances from the RWCF, the Port of Stockton, and other National Pollutant Discharge Elimination System (NPDES) and Waste Discharge Requirement (WDR) permittees, to improve water quality during chinook salmon migration.

2. Develop best management practices (BMPs) with information gathered as a result of implementing the "Information Needed" portion of this section.

3. Provide technical and financial assistance and regulatory incentives for implementing BMPs to control oxygen depletion.

4. Work in conjunction with the RWCF and the Port of Stockton to develop and test new physical or operational management practices (MPs).

   Possible management actions include (1) physical mixing or other methods to decrease stratification and increase aeration in the ship channel and Turning Basin during periods of low DO, (2) changing the effluent discharge location, (3) changing the channel configuration (i.e., filling the hole at the end of the Turning Basin or deepening the main channel), and (4) constructing wetlands to increase treatment of effluent.

The goals of the proposed actions are to:

- Eliminate the occurrences of DO concentrations below 5 mg/l throughout the water column.

- Reduce the impairment or blockage of fish migration past Stockton.

- Reduce the occurrence of algal blooms.

- Reduce stress to fish due to low DO concentrations near Stockton, and

- Eliminate fish kills near Stockton.

Performance of all of these measures can be determined by appropriate monitoring programs.

Information Needed

Field studies are needed to help support the following ongoing activities:

- Quantify and identify the relative contribution of various sources of oxygen-depleting substances or oxygen-depleted water to the oxygen sag in the San Joaquin River.
- Determine the mechanisms that produce the oxygen depletion or the oxygen-depleting substances at these sources.
- Evaluate the importance of the channel depression at the mouth of the Turning Basin to the oxygen depletion.
- Compare causes and characteristics of spring and fall oxygen sag.
- Determine two- and three-dimensional flow patterns.
- Develop accurate models to determine what substances introduced to the river will produce DO sags downstream and where.
- Identify and test new MPs.
- Evaluate the effectiveness of current MPs.
- Evaluate the sources and loadings of nutrients contributing to oxygen-depleting algal blooms. (Also see Section 3, "Drinking Water.")

Existing Activities

The City of Stockton has been testing and modeling low DO in the San Joaquin River for several years. DWR has been sampling the San Joaquin River and the Turning Basin for several years and has compiled extensive data.

The City of Stockton has been testing and modeling low DO in the San Joaquin River for several years. In addition, the City of Stockton is actively involved in the technical evaluation of DO conditions and alternatives for managing water quality in the lower San Joaquin River channels in the Delta. The recent report by the City of Stockton, "Potential Solutions for Achieving the San Joaquin River Dissolved Oxygen Objectives," provides a summary of recent DO conditions (1985-1996), based on the combination of DWR monitoring and routine measurements by the City.

DWR has been sampling the San Joaquin River and the Turning Basin for several years and has compiled extensive data. Some oxygen depletion is emanating from the ship channel Turning Basin; however, the exact cause of such depletion is unknown. Studies are ongoing and expanding.

The U.S. Army Corps of Engineers (Corps) placed an aeration jet at the mouth of the Turning Basin as mitigation for DO effects from the ship channel. The aeration system has since been removed. Data may still be available regarding the efficacy of the aeration system. Any further studies should be coordinated with the Corps' efforts.

The CVRWQCB has established a watershed-based stakeholder group to assist in developing technically based comprehensive total maximum daily load (TMDL) evaluation and allocation for sources of BOD and nutrients. CALFED has awarded an $860,000 grant to determine causes and loads contributing to causes of low DO in the lower San Joaquin River. Study plans are being finalized, and work is expected to begin in various stages during the first half of 2000. The stakeholder group includes representatives from municipalities, state and federal agencies, agricultural interests, environmental interests, local industry, and academic institutions. This ongoing effort will help to identify management actions that will best achieve the established water quality objectives.

CALFED has awarded an $860,000 grant to determine causes and loads contributing to causes of low DO in the lower San Joaquin River.

Stockton Tributaries

Priority Actions

1. Assess the current water quality impairment due to high BOD in these creeks.

2. Develop new strategies to assist farmers in containing wastes on the fields, including financial incentives such as low-interest loans to upgrade their systems.

3. Undertake further efforts to enforce the WDRs of permitted and unpermitted dischargers.

The goals of these actions are to maintain DO concentrations above the 5-mg/l standard, maintain BOD concentrations below 30 mg/l, and restore natural ecosystem processes and functions in the creeks.

Information Needed

Monitoring data are needed to determine the current BOD and chemical oxygen demand (COD) loads in these creeks, the associated DO concentration, and the potential impact of current BOD levels on the ecosystem.

Urban Waterways near Stockton

Priority Actions

- Develop strategies with the City of Stockton and other stakeholders to eliminate the DO problem.

The goals are to maintain DO concentrations in the sloughs above the 5-mg/l standard, avoid fish kills, and restore natural ecosystem processes and function.

Information Needed

More information is needed to verify that low DO concentrations are produced by urban stormwater runoff, to determine the causal substances and mechanisms of low DO concentrations, and to determine the impact of low DO concentrations on the ecosystem.

Special studies need to be conducted in 5-Mile Slough, Mosher Slough, and the Calaveras River to determine the substances and mechanisms causing low DO concentrations.

2.5 East Side Delta Tributaries

East side Delta tributaries include the Mokelumne, Cosumnes, and Calaveras Rivers.

2.5.1 *Problem Description*

High deposition of fine sediments from channel disturbance on the Mokelumne River affects sediment permeability and, in combination with high water temperature, may cause low inter-substrate DO concentrations that negatively affect spawning and rearing habitat of salmonids and other fish. Other activities such as cattle grazing and agricultural runoff in the watershed could contribute to the problem. Studies are needed to determine the causes of low inter-substrate DO and the extent of impacts on aquatic life. East Bay Municipal Utilities District, in partnership with other agencies, is actively engaged in salmon habitat restoration efforts and data collection along the lower Mokelumne River. This work will add to the information base on DO problems in the river and should be expanded. CALFED supports these efforts. No information is currently available on the DO status of the Calaveras River.

High deposition of fine sediments from channel disturbance on the Mokelumne River affects sediment permeability and, in combination with high water temperature, may cause low inter-substrate DO concentrations that negatively affect spawning and rearing habitat of salmonids and other fish.

2.5.2 *Approach to Solution*

Priority Actions

1. Assess the extent and severity of this problem and develop strategies to reduce the problem. MPs should include decreasing the fine-sediment load.

The goal is to reduce fine-sediment loads that may cause low inter-substrate DO concentrations and impair the spawning and rearing habitat of salmonids and other fish.

> The goal is to reduce fine-sediment loads that can cause low inter-substrate DO concentrations and impair the spawning and rearing habitat of salmonids and other fish.

2.6 LOWER SACRAMENTO RIVER TRIBUTARIES

2.6.1 *Problem Description*

Poor inter-substrate permeability and the resulting low DO concentration are primary stresses for salmon and steelhead spawning habitat in the American River. Impervious clay lenses below the gravel may contribute to the low permeability.

> Poor inter-substrate permeability and the resulting low DO concentration are primary stresses for salmon and steelhead spawning habitat in the American River.

2.6.2 *Approach to Solution*

Priority Actions

1. Possible management actions include development of gravel enhancement programs, channel restoration programs, and river corridor assessments and MPs; and regulation of high water temperature reservoir releases.

The goals are to reduce sediment loads, which may cause low inter-substrate DO concentrations that affect salmon spawning and rearing habitat, and to establish full salmon spawning and rearing activity.

2.7 San Joaquin River Region

The San Joaquin River Region includes the Merced, Tuolumne, and Stanislaus Rivers.

2.7.1 *Problem Description*

The Merced, Tuolumne, and Stanislaus Rivers are tributaries of the San Joaquin River. A history of erosive land use practices and mining activities for aggregate and minerals is associated with depositing large amounts of fine sediment. High sediment deposition affects sediment permeability and causes low inter-substrate DO concentrations that negatively affect spawning and rearing habitat of salmonid and other fish.

A history of erosive land use practices and mining activities for aggregate and minerals is associated with depositing large amounts of fine sediment.

2.7.2 *Approach to Solution*

Priority Actions

1. Possible management actions include development of gravel enhancement programs, channel restoration programs, and river corridor assessments and MPs; and regulation of high water temperature reservoir releases

The goals are to eliminate the low inter-substrate DO concentrations that affect salmon spawning and rearing habitat, and to establish full salmon spawning and rearing activity.

Existing Activities

The Tuolumne River Technical Advisory Committee currently is funding work, using a field technique that measures inter-substrate permeability. Such measurements would be useful in the assessment of the ecological health of stream beds.

2.8 Suisun Marsh Wetlands

2.8.1 Problem Description

The CWA Section 303(d) list includes Suisun Marsh as an impaired water body due to flow regulation and modification, and urban and stormwater sewer runoff. In fall 1994, DO concentrations reached as low as 1 mg/l and were frequently 4 mg/l in Goodyear, Cordelia, and Frank Horan Sloughs after the islands in the marsh were flooded for duck club management. The islands are flooded with channel water that becomes nearly anaerobic while on the islands. This island water then flows into the main channel on ebb tide and can cause low DO concentrations in the channel. Low DO concentrations were measured during the Suisun Marsh Salinity Control Test in 1994; but the severity, extent, and frequency of the problem are unknown. DO concentrations also decrease to 1 mg/l in summer and fall in the slough that receives effluent from the Fairfield-Suisun Treatment Facility. The relative contribution of urban and sewer discharge to this oxygen depletion is unknown.

The islands are flooded with channel water that becomes nearly anaerobic while on the islands. This island water then flows into the main channel on ebb tide and can cause low DO concentrations in the channel.

2.8.2 Approach to Solution

Priority Actions

1. Assess the level and ecological importance of the addition of oxygen-depleted water to the main channel.

The Suisun Marsh Preservation Agreement negotiations and Suisun Marsh Ecological Work Group need to assess the level and ecological importance of the addition of oxygen-depleted water to the main channel and develop MPs as appropriate.

The goals are to maintain DO concentrations above the 5-mg/l standard and attain natural ecosystem process and function in the marsh.

The goals are to maintain DO concentrations above the 5-mg/l standard and attain natural ecosystem process and function in the marsh.

Information Needed

A new field technique is needed to measure inter-substrate permeability. The new technique can be used to monitor inter-substrate DO concentrations and to develop an index of spawning habitat quality for each river, based on inter-substrate permeability and DO concentrations. (Biological indices and other ecological assessments would be performed through the Ecosystem Restoration Program, in coordination with the Water Quality Program.)

Monitoring programs and special studies are needed to assess the frequency, distribution, severity, and causes of DO concentrations below 5 mg/l in Suisun Marsh; and their potential effects on ecosystem process and function

Existing Activities

The Suisun Marsh Ecological Work Group has been assembled to address problems such as low DO in the Suisun Marsh area.

3. DRINKING WATER

3. DRINKING WATER

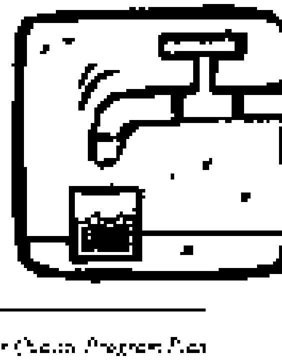
The CALFED drinking water objective is to continuously improve source water quality that allows for municipal water suppliers to deliver safe, reliable, and affordable drinking water that meets and, where feasible, is better than applicable drinking water standards. This section of the Water Quality Program Plan identifies drinking water quality concerns that result from using Delta waters as a source of drinking water supply and identifies proposed Water Quality Program actions that can be taken in the nearer term that may improve source water quality. Bromide, organic carbon, and salts are constituents of major concern for drinking water; salts are of importance to agricultural uses of Delta waters. Concentrations and loadings of these constituents will be affected by actions in the Water Quality Program and by the choice of storage and conveyance options. Section 3.7 presents an analysis of the capacity of Water Quality Program actions to affect concentrations of bromide and organic carbon in drinking water supplies taken from the Delta. Since bromide is a constituent of the total salt load, the analysis in Section 3.7 also can serve as a preliminary model for the effects of the Water Quality Program on total salt in the system.

Bromide, organic carbon, and salts are constituents of major concern for drinking water; salts are of importance to agricultural uses of Delta waters.

3.1 SUMMARY

As part of its commitment to continual improvement of water quality, CALFED is developing an overall Drinking Water Quality Improvement Strategy to guide its activities. The Strategy is composed of a combination of actions and studies that will be conducted under the scrutiny of the Delta Drinking Water Council. Actions and studies include source protection and control, conveyance improvements, storage and operations improvements, monitoring and assessment, treatment studies and facilities, health effects studies, capturing more drinking water during periods of high Delta water quality, and improving the opportunities for voluntary exchanges or purchases of high-quality source waters. This Strategy is critically needed because about two-thirds of Californians drink water that comes from the Delta, and their health can be affected by the quality of that water. Safe drinking water is not a fixed target. Its definition changes continually as new scientific information becomes available, as understanding of water quality and human health impacts improves, and as regulatory developments reflect new scientific findings. The CALFED Drinking Water Quality Improvement Strategy must, therefore, be a continually evolving process to achieve the vision not only of providing drinking water that meets standards for public health protection but also of continually striving toward excellence in drinking water

About two-thirds of Californians drink water that comes from the Delta, and their health can be affected by the quality of that water.



quality. This section identifies the initial features of this Strategy, with the understanding that this constitutes only the beginning of a continuing process. Evolution of the Strategy will be through the full involvement of CALFED agencies, stakeholders, and the public.

Several source water constituents create difficulties for the production of a safe drinking water supply from Delta sources. These include bromide, natural organic matter, microbial pathogens, nutrients, salinity, and turbidity. All are naturally occurring, to one degree or another, and some are magnified by anthropogenic actions. Changes in treating drinking water and reducing sources of contaminants can improve the quality and safety of drinking water from the Delta. Future drinking water regulations may, however, require improvements beyond those that can be gained through the actions specified in this section. (See Section 3.7.) The priority actions listed in the following pages are those that can be implemented in the nearer term with the potential to improve water quality. The degree to which taking these actions may correct the problems is not addressed.

Pollutants in Delta waters come from tidal interaction with the ocean and from point and non-point sources located throughout the Delta and tributary watersheds.

Pollutants in Delta waters come from tidal interaction with the ocean and from point and non-point sources located throughout the Delta and tributary watersheds. Other pollutants can enter the aqueducts and reservoirs of the drinking water supply system. Pathogens largely come from urban stormwater runoff; livestock operations; recreational users of the Delta; storage reservoirs; and, potentially, inadequately treated discharges of wastewater. Sources of organic matter, primarily organic carbon (usually expressed as total organic carbon [TOC]), include runoff from the following sources: soils, agricultural drainage, urban stormwater tidal wetlands as a result of natural plant decay, algae, and wastewater treatment plant discharges. The most important source of bromide is sea-water intrusion, which also is reflected in agricultural drainage from areas irrigated with Delta water. Other sources of bromide may include geological formations, groundwater influenced by ancient sea salts, and use of bromine-containing chemicals in the watersheds of the Delta. Salinity, as reflected in total dissolved solids (TDS), comes from sea-water intrusion and, to a lesser extent, from natural leaching of soils, agricultural drainage, wastewater treatment plants, and stormwater runoff. Turbidity results from storm events, all types of runoff, resuspended sediments, and phytoplankton populations. Nutrients largely result from erosion, agricultural runoff, including livestock operations; urban stormwater runoff; and wastewater treatment plant discharges. Mass loading analyses have not been conducted to establish the relative amounts of pollutants from each of these sources.

TOC and bromide react with disinfectants during the treatment process to form disinfection by-products (DBPs) that are a public health concern and will be more stringently regulated in the near future.

Pathogens are a direct health concern. A primary purpose of drinking water treatment is to remove or inactivate pathogens. TOC and bromide react with disinfectants during the treatment process to form disinfection by-products (DBPs) that are a public health concern and will be more stringently regulated in the near future. Nutrients contribute to excess growth of algae in storage reservoirs and in aqueducts, which can result in treatment difficulties and production of unpleasant flavors and odors.

High levels of TDS, salinity, and turbidity adversely affect consumer acceptance and treatment plant operations. High TDS reduces the ability to implement local water management programs, such as water recycling and groundwater replenishment, results in direct economic impacts on residential and industrial water users, and reduces options for blending with other supplies.

3.2 Drinking Water Focus of the Water Quality Program

The Water Quality Program addresses water quality problems exclusive of those that would be addressed by the Storage and Conveyance elements of the CALFED Program. Several drinking water regulations that pose treatment challenges will be implemented and will need to be complied with prior to implementation of storage and conveyance alternatives. Therefore, the primary focus is on water quality improvements in the nearer term, although the Water Quality Program also will be an important aspect of long-term solutions.

Several drinking water regulations that pose treatment challenges will be implemented and will need to be complied with prior to implementation of storage and conveyance alternatives.

CALFED will pursue aggressively a mix of strategies to improve in-Delta water quality. Program actions to address the drinking water concerns of the more than 22 million Californians who rely on Delta water fall into four broad categories. These actions will:

- Enable users to capture more drinking water during periods of high Delta water quality.
- Reduce contaminants and salinity that impair Delta water quality.
- Evaluate alternative approaches to drinking water treatment, to address growing concerns over DBPs and salinity.
- Enable voluntary exchanges or purchases of high-quality source waters for drinking water uses.

None of these actions, by itself, can assure adequate supplies of good-quality drinking water that meet current and future state and federal regulations. All the actions must be pursued in conjunction with other CALFED actions, such as conveyance and storage improvements, to generate significant improvements in drinking water at the tap.

Both specific and regionwide approaches to drinking water quality improvements address the following locations: the Bay-Delta Region, Sacramento and American Rivers, North Bay Aqueduct, South Bay Aqueduct, Clifton Court Forebay and Bethany Reservoir, Contra Costa Water District intakes, Delta-Mendota Canal (DMC) at the City of Tracy intake, San Joaquin River, California Aqueduct, south of O'Neill Forebay and Check 13, and Castaic Lake and Lake Silverwood.

Priority actions and information needed are identified to ensure that Water Quality Program objectives are achieved in each geographic area.

3.3 Problem Statement

Source water from the Bay-Delta poses treatment challenges and public health concerns for the 22 million Californians who drink the water. Low water quality reduces options for recycling the water and blending with other sources, and increases utility costs of treating the water to meet drinking water regulations and protect public health.

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3.4 Objective

The CALFED drinking water quality objective is to continuously improve source water quality that allows for municipal water suppliers to deliver safe, reliable, and affordable drinking water that meets and, where feasible, is better than applicable drinking water standards. This objective promotes improved water management through source control and prevention projects, exchanges, blending, purchases of high-quality water, wastewater recycling, groundwater use, and alternative approaches to drinking water treatment. Of primary importance is the reduction and maintenance of pathogen loadings in source waters to required levels, and the reduction of TOC and bromide levels to avoid production of harmful levels of DBPs. Reduction of TDS will facilitate improved water management.

Of primary importance is the reduction and maintenance of pathogen loadings in source waters to required levels, and the reduction of TOC and bromide levels to avoid production of harmful levels of DBPs.

3.5 PROBLEM DESCRIPTION

Delta waters are used to produce drinking water for approximately 22 million people in California. Utilities divert source water at several points in the Delta, each with distinct water quality characteristics. These waters are subsequently treated by a variety of means to control pathogens and other contaminants of concern, and to meet federal and state drinking water regulatory requirements. Depending on the specific source water at the intakes, existing treatment plant configurations, attendant operational constraints, and regulatory requirements, utilities may have difficulty in simultaneously providing adequate supplies of drinking water while complying with drinking water regulations and meeting customer requirements for palatability. Therefore, two inter-related concerns arise from source water quality: (1) the treated water may not meet all applicable drinking water standards, and (2) the treated water may not be aesthetically acceptable to the consumers. Because treated water quality is a product of source water quality and treatment methods, treatment options can be significantly narrowed based on source water quality and drinking water regulations.

Utilities may have difficulty in simultaneously providing adequate supplies of drinking water while complying with drinking water regulations and meeting customer requirements for palatability.

The process of treating surface waters generally involves mixing coagulant chemicals with the source water. This process causes the removal of some dissolved organic material and most of the particulates to aggregate and to settle out. The settled water is then filtered, usually through beds of special sand and anthracite mixtures, removing many more microbial contaminants. At one or more points in the process, oxidative disinfectant chemicals are applied for specified contact times. Water that flows from the treatment facility into the pipes that distribute the water to homes and businesses must additionally contain a sufficient disinfectant residual (usually chlorine or chloramine) to prevent regrowth of harmful bacteria or other organisms in the distribution system, up to the taps of customers.

The constituents in Delta waters identified of most concern with respect to production of drinking water include microbial pathogens, bromide, natural organic matter, dissolved solids, salinity, turbidity, and nutrients. Some other contaminants of Delta waters, including pesticides, metals, and methyl tert-butyl ether (MTBE), were evaluated and considered to be of limited significance to drinking water at this time because of their relatively low concentrations in Delta waters.

The constituents in Delta waters identified of most concern with respect to production of drinking water include microbial pathogens, bromide, natural organic matter, dissolved solids, salinity, turbidity, and nutrients.

3.5.1 Pathogens

Microbial pathogens are a direct threat to public health. The primary purpose of drinking water treatment is to remove or kill pathogens. Under the 1989 Surface Water Treatment Rule (SWTR), surface water must be treated by filtration or disinfection to minimize disease risks from microbes. In addition, turbidity, which can compromise disinfection, must be removed. Emphasis in this rule was on reducing risks from *Giardia*, *Legionella*, and viruses. The Interim Enhanced Surface Water Treatment Rule was promulgated in December 1998 and adopted more stringent turbidity removal requirements. The Long-Term 2 Enhanced Surface Water Treatment Rule (to be promulgated by May 2002) is expected to include requirements for the control of *Cryptosporidium*.

The primary purpose of drinking water treatment is to remove or kill pathogens.

Filtration and disinfection are required for drinking water from Delta sources. Levels of microbial pathogens in Delta waters do not specifically influence the degree of these treatments, since current regulations are based on uniform treatment requirements. However, future regulations may require treatment that is proportional to pathogen levels in source waters. Pathogen levels in Delta waters are largely unknown at this time. Primary disinfection by utilities using Delta water sources usually is accomplished by physical removal and oxidation with chlorine. An increasing number of utilities are using ozone or a combination of disinfectants.

Chlorine has been used as a primary disinfectant for drinking water for decades. It is effective for bacteria, viruses, and *Giardia* at reasonably feasible concentrations and contact times. It is well understood, relatively simple, and inexpensive. However, it is not able to inactivate *Cryptosporidium*. If future regulations required disinfection of *Cryptosporidium*, alternative disinfectants would be needed.

Chlorine has been used as a primary disinfectant for drinking water for decades.

Some utilities have adopted ozone treatment in addition to other conventional treatment measures. Ozone is a strong oxidant that is effective for inactivation of most pathogenic microorganisms, including *Cryptosporidium*. However, in the presence of bromide such as found in Delta waters, bromate is formed. Bromate is a health concern and is the subject of new drinking water regulations and ongoing health effects research. Optimized conventional filtration is not completely effective to remove all *Cryptosporidium* from drinking water, and chlorinated disinfectants are relatively ineffective in killing or inactivating it. However, membrane filtration, including low-pressure ultrafiltration membranes, does effectively remove *Cryptosporidium* and *Giardia*, and may provide an alternative to additional ozone disinfection. Membrane filtration has been used successfully in small systems, but it is not known whether the technology is adaptable to large systems such as generally are used to treat Delta waters. For this and other reasons, more California water systems are considering converting

Optimized conventional filtration is not completely effective to remove all Cryptosporidium from drinking water, and chlorinated disinfectants are relatively ineffective in killing or inactivating it.

to ozone for their primary disinfection. Ozone treatment is also very effective in controlling adverse tastes and odors that are frequently associated with algae in source waters. Other emerging treatment technologies include ultraviolet and chlorine dioxide disinfection, but their potential to produce unwanted chemical byproducts and their economic feasibility are as yet unproven.

3.5.2 *Disinfection By-Products*

An unfortunate side effect of oxidative disinfection is the formation of unwanted chemical by-products, some of which result in adverse health impacts. Additionally, the objectionable taste and odor (T&O) characteristics of some DBPs affect consumer acceptance. Different oxidants and different sources of water yield different types and concentrations of by-products.

> An unfortunate side effect of oxidative disinfection is the formation of unwanted chemical by-products, some of which result in adverse health impacts.

The Safe Drinking Water Act Amendments of 1996 directed EPA to set regulations that protect against microbial pathogens while simultaneously decreasing the occurrence of DBPs. EPA promulgated the first stage of rules (Stage 1 Disinfectants/Disinfection By-Product Rule (D/DBP) and Interim Enhanced Surface Water Treatment Rule) in December 1998. These rules will be effective in December 2001. The Stage 1 D/DBP Rule lowers the maximum contaminant level (MCL) for total trihalomethanes (TTHMs) to 80 ug/l, and sets MCLs for haloacetic acids (60 ug/l) and bromate (10 ug/l). EPA is required to promulgate the Stage 2 D/DBP Rule and Long-Term 2 Enhanced Surface Water Treatment Rule by 2002. These rules currently are being negotiated.

Ozone does not produce halogenated by-products such as chloroform and the other chloro-bromo-THMs, although it produces bromoform and bromate in the presence of organic carbon and bromide. Therefore, ozone use combined with chloramine enables utilities to more easily meet lower TTHM standards. However, ozonation is more complex and expensive than chlorination. Ozonation of natural organic matter generates higher levels of assimilable organic carbon that can support bacterial regrowth in drinking water distribution systems. Because ozonation does not produce a persistent disinfection residual, other disinfectants (generally chloramines) must be used to protect distribution systems from bacterial regrowth and to minimize TTHM formation in the distribution system. Perhaps more importantly, ozone produces chemical by-products of its own. In the presence of bromide, ozone produces bromate, which appears to have the highest cancer-causing potential of the DBPs measured to date. Apart from bromate, ozone has the capacity to produce a number of other oxidized organic by-products, the potentially harmful effects of which are unknown. However, these by-products may be reduced through biological filtration.

> Ozonation of natural organic matter generates higher levels of assimilable organic carbon that can support bacterial regrowth in drinking water distribution systems.

Bromide is present in Delta water supplies because of sea-water intrusion into the Delta and agricultural return flows into the San Joaquin River from Delta water. (Bromide in agricultural return flows is primarily due to recycling ocean-derived bromide from areas irrigated with Delta water.) TOC from natural and human sources, and bromide react with disinfectant chemicals to produce a broad range of chemical DBPs with different effects, depending on the disinfectant employed. The presence of bromide in source waters shifts the proportion of bromine-containing DBPs to higher levels. Because of the higher molecular weight of brominated versus chlorinated by-products, it is more difficult for utilities to meet MCLs that are based on weight/volume. Moreover, recent health effects studies suggest that brominated by-products may cause more serious health problems than chloroform, including the possibility of causing miscarriages in pregnant women. In addition, nutrients affect disinfection treatment indirectly by supporting the growth of algae and other organisms, which subsequently adds to the TOC concentrations of the water.

Bromide is present in Delta water supplies because of sea-water intrusion into the Delta and agricultural return flows into the San Joaquin River from Delta water.

3.5.3 *Treatment Control of Disinfection By-Products*

Currently, most water treatment plants use chlorine as the primary disinfectant within the treatment plant. Many facilities also use chlorine to maintain a disinfectant residual as the water travels through the distribution system. This practice ensures the safety of the treated water as it travels to the consumer but forms elevated levels of chlorinated DBPs.

Chloramines (the combination of chlorine and ammonia) can be used as an alternative to chlorine, to provide a safe disinfectant residual within the distribution system. Chloramines form lower levels of DBPs, replacing the long reaction times between chlorine and DBP precursors in the distribution system. Consequently, this process reduces DBP levels that reach the consumer.

Water utilities also may use "enhanced" coagulation to minimize DBP formation. Enhanced coagulation refers to the practice of using elevated coagulant doses to remove DBP precursors prior to their reaction with chlorine. Under optimal conditions, enhanced coagulation can remove from 30 to 50% of the organic DBP precursors and result in significant DBP reductions. However, the effectiveness of this treatment process is variable and highly depends on raw water quality. In addition, enhanced coagulation does not reduce bromide, which is an inorganic DBP precursor.

Enhanced coagulation refers to the practice of using elevated coagulant doses to remove DBP precursors prior to their reaction with chlorine.

One alternative to the use of chlorine for disinfection is ozone. Ozone is a strong disinfectant capable of inactivating most pathogens within short contact times. The use of ozone also can improve the aesthetic qualities of water, including clarity, taste, and odors. Ozone (in place of chlorine) results in the minimal formation of chlorinated DBPs. Because ozone does not provide a lasting disinfectant residual, subsequent chlorination (or chloramination) is required which forms some DBPs. One drawback to the use of ozone is that it reacts with bromide to form bromate. New bromate regulations will take effect in 2001. Previous studies have shown that bromate formation during ozonation may be controlled through chemical addition of acid or ammonia. These bromate control strategies can significantly increase the overall cost of ozonation.

GAC can be used to remove both DBPs and DBP precursors. GAC acts as an adsorbent, removing many organic compounds. Once the GAC adsorption capacity is exhausted, it must be regenerated within a furnace. Typically, GAC must be shipped to an off-site regeneration facility. Consequently, GAC has relatively high capital and operating costs.

GAC has relatively high capital and operating costs.

Recent developments suggest that the use of membrane processes, such as reverse osmosis or nanofiltration, may provide a viable method for controlling DBP precursors. Membranes can remove both organic precursors and the bromide ion, which both contribute to DBP formation. Additionally, these membranes provide excellent pathogen removal. Drawbacks associated with the use of membranes include the need for extensive pre-treatment to minimize membrane fouling and the difficulty in disposing of the brine waste stream (which results from separating the dissolved material from solution). These concerns result in the relatively high current costs for membrane treatment. Other membrane processes such as microfiltration and ultrafiltration provide excellent pathogen removal but do not reduce DBP precursors to a substantial degree. However, as the processes provide increased pathogen removal, they may contribute to decreased disinfection requirements — resulting in less DBP formation.

Recent developments suggest that the use of membrane processes, such as reverse osmosis or nanofiltration, may provide a viable method for controlling DBP precursors.

Recent private-sector efforts have generated substantial advances in treatment technologies. CALFED will encourage these technologies by funding a demonstration project to design and operate an ultra-violet (UV) disinfection plant. CALFED also will fund demonstration projects to design and operate desalination facilities for agricultural drainage, using membrane treatment technology and focusing on management of brines and on-site waste stream management, and other promising treatment technologies that arise during the Program. Specific treatment goals are to:

- Initiate a UV disinfection plant demonstration project by the end of 2002.
- Initiate a regional desalination demonstration project by the end of 2002.
- Evaluate the practicability of and determine time lines for full-scale implementation by the beginning of 2007.

3.5.4 Source Control of Disinfection By-Products

Research is underway to evaluate the impacts of agricultural practices on the quality and quantity of TOC releases to the Delta. The contribution of natural wetlands to TOC concentrations found in Delta waters at drinking water intakes is not understood. The proposed restoration of wetlands through the CALFED Ecosystem Restoration Program may increase the total amount of TOC at drinking water intakes, increasing the potential to form DBPs. Changing channel flows and increasing the amount of tidal waters exchanged with the estuary (by increasing the tidal wetland volume) may increase the amount of bromide in Delta waters, significantly increasing DBP formation.

Research is underway to evaluate the impacts of agricultural practices on the quality and quantity of TOC releases to the Delta.

3.5.5 Total Dissolved Solids, Salinity, Turbidity, and Nutrients

A major problem during periods of low Delta outflow is tidal mixing of salt into the Delta channels. Salts are also present in fresh-water inflows to the Delta due to municipal and agricultural discharges. The most heavily concentrated source of agricultural discharges to the Delta is the San Joaquin River. The addition of a proposed activity may change contributions of salt to the Delta. The creation of wetlands as a part of the CALFED Ecosystem Restoration Program could contribute organic carbon to drinking water intakes and may change salinity outflow characteristics. In changing salinity outflow characteristics, the restoration projects also may contribute higher levels of bromide to drinking water intakes. The restored wetlands also may use more water, thereby reducing the fresh water available to repel salinity.

A major problem during periods of low Delta outflow is tidal mixing of salt into the Delta channels.

High salt levels in municipal water supplies can result in the following impacts: (1) reduced opportunities for water recycling and groundwater replenishment programs that depend on good source water quality to meet local resource program salinity objectives, (2) economic impacts on industrial and residential water users due to corrosion of appliances, plumbing, and industrial facilities, and (3) aesthetic impacts (salty taste) for drinking water consumers.

Consumer acceptance of drinking water is of major concern. Consumers want water that is both safe and pleasant to drink. Adverse taste, odor, and appearance problems originate from source water and the effects of treatment.

Consumer acceptance of drinking water is of major concern. Consumers want water that is both safe and pleasant to drink. Adverse taste, odor, and appearance problems originate from source water and the effects of treatment.

Elevated TDS levels can adversely affect consumer acceptance and local water management and water use efficiency programs. Waters with naturally high TDS or salinity taste salty or may be unacceptably hard if calcium and magnesium levels are high. Consumers may resort to the use of ion-exchange systems (water softeners) to produce softer water. Ion-exchange systems are regenerated using highly saline water, which is then flushed into the wastewater system. Dissolved solids in supply water and salt added during use result in higher TDS effluent from wastewater treatment plants. High TDS and salt make the water unacceptable for many wastewater reclamation applications. Multiple (more than once) reclamation cycles are increasingly difficult with higher TDS source water, and water management flexibility is reduced due to lack of ability to blend supplies from different sources. In addition, high TDS levels can cause direct economic impacts on industrial and residential water users, due to more rapid corrosion of infrastructure and appliances.

Turbidity and natural organic matter from stormwater runoff, wetlands, and agricultural activities provide a disinfectant demand that can require higher applied disinfectant doses or longer contact times. These materials also can harbor pathogens and protect them from disinfection. The major factors affecting physical removal processes for Delta waters in warm months are the presence and types of algae, water temperature, and pH.

The presence of nutrients (such as nitrate and phosphate), higher light levels, and warmer waters can enhance algal growth. Algal blooms are common in the Delta, in the aqueducts, and especially in storage reservoirs. Algae may cause physical clogging of filters and air binding, decreased filter runs, increased filter backwashing and decreased overall plant performance, and increased operating costs. The majority of algae are nontoxic; a few species are toxic or produce algal toxins. The presence of algae in the source water can cause large pH swings that can adversely affect coagulation, flocculation, and sedimentation. While algae are effectively removed by treatment, growth of some species of algae in raw waters produces objectionable odors and flavors in finished water, such as geosmin or methylisoborneol (MIB), that are not removed by conventional treatment. Warm and diurnally varying water temperatures can cause temperature inversions in upflow clarifiers that can result in large daily swings in settled water turbidities.

The presence of nutrients, such as nitrate and phosphate, higher light levels, and warmer waters can enhance algal growth.

During winter, high turbidities from storm-related events may necessitate reducing filtration rates to prevent filter breakthrough. Fluctuations in source water turbidity and in the specific components of turbidity over time require close attention to coagulant doses and proper filter operation. In addition, colder water temperatures reduce coagulation effectiveness, and the ability to achieve a filterable floc is made more difficult.

TOC, in and of itself, does not affect the physical removal process; but TOC levels affect the degree of coagulation, flocculation, and sedimentation required. For example, increases in TOC also increase the coagulant demand of the water, thus requiring more coagulant in order to effectively remove the turbidity. Enhanced coagulation for TOC removal is then required. Organic carbon affects treatment in two additional ways: pathogens may adhere to particulate organic carbon and be shielded from disinfection, and oxidative disinfectants do not

TOC, in and of itself, does not affect the physical removal process; but TOC levels affect the degree of coagulation, flocculation, and sedimentation required.

preferentially attack pathogenic organisms. Consequently, the more organic material in the water, the more disinfectant is spent oxidizing the organic matter.

3.6 APPROACH TO SOLUTION

The reader is reminded that Water Quality Program actions are intended to be implemented irrespective of the storage and conveyance alternative selected. Actions focus on source control and prevention, as well as a mix of other approaches that should be undertaken in addition to any water quality improvements that may result from selection of storage and conveyance options. Priorities for action were identified based on the apparent potential of an action to improve water quality and its capability for nearer term implementation. Assignment of priorities does not necessarily reflect the degree to which taking these actions is likely to correct the problems. Please refer to Section 3.7 for a discussion of the capabilities and limitations of planned CALFED water quality actions to address critical drinking water problems.

Priorities for action were identified based on the apparent potential of an action to improve water quality and its capability for nearer term implementation.

The perception is growing that CALFED alternatives should be decided on in a phased approach over several years. Near-term drinking water regulations that pose problems for treatment will be promulgated prior to implementation of storage and conveyance options and realization of associated water quality benefits (Stage 1 of the D/DBP Rule was promulgated in December 1998, and Stage 2 of the regulation is targeted for May 2002). However, the effective date for Stage 2 may be up to 5 years if significant construction of treatment modifications is required. Moreover, a potential Stage 3 regulation, which may require even more stringent standards, should be developed in the next century. Accordingly, this section of the Water Quality Program Plan emphasizes activities likely to result in mitigation of adverse effects in the next several years. Proposals for research, demonstration, pilot, and longer term projects were discussed and developed.

The general approach to shorter term drinking water quality improvement was to reduce loadings of constituents of concern, reduce variability of source water quality, and enhance treatment flexibility, rather than rely on source replacement with higher quality waters or relocation of intakes to attain higher quality source waters. However, these latter options were discussed and developed as appropriate.

To begin to address the concerns as currently understood, the Drinking Water Work Group developed the following list of potential action items that can be implemented in the near future. This is a general list and not all items will apply to each withdrawal point or to each delivery system using Delta source waters.

Potential Action Items That Can Be Implemented in the Near Future

Agricultural drains	Treat drainage, relocate discharge points, release drainage during ebb tidal flows, implement BMPs, and modify land management practices to reduce loadings of TDS, nutrients, TOC, salinity, and selenium. Support land retirement programs for drainage impaired lands with local sponsorship.
Animal enclosures	Implement BMPs to reduce entry of fecal matter and associated TOC, nutrients, and pathogens into Delta drinking water sources.
Treated wastewater effluents	Improve treatment, relocate outfalls, encourage a watershed-based approach to permitting that evaluates cumulative impacts by using methods such as total maximum daily loads (TMDLs) of pollutants that affect drinking water quality.
Urban runoff	Treat drainage, relocate outfalls, encourage a watershed-based approach to permitting that evaluates cumulative impacts by using methods such as TMDL of pollutants that affect drinking water quality.
Algae control	Treat water to kill or remove algae, reduce nutrient sources, and evaluate operational measures.
Boating control	Develop and implement education, and support enforcement programs to reduce discharges of fecal matter and other wastes.
Local watershed management	Support community-based watershed efforts to reduce non-point sources of contaminants.
Blending exchange	Develop a Bay Area blending exchange project that enables Bay Area water districts to work cooperatively in order to address water quality and supply reliability concerns on a cooperative basis. Facilitate water quality exchanges and similar programs to make high-quality Sierra water in the eastern San Joaquin Valley available to urban southern California interests.
Treatment	Invest in treatment technology demonstration.
Delta Drinking Water Council and Work Groups	Support the ongoing efforts of the Delta Drinking Water Council and its technical work group to develop necessary technical information on Delta water quality, identify appropriate treatment options, pursue source water exchange opportunities, and make other evaluations necessary to meet CALFED's goal of continuous improvement in Delta water quality for all uses.

Water Quality Program actions probably will minimally affect the levels of bromide, particularly for State Water Project (SWP) users. Bromide largely derives from sea-water intrusion. Diverting or repelling sea water or substituting cleaner source waters would require substantial reconfiguration of general Delta flows. Similarly, TDS and salinity from sea-water intrusion could not be effectively controlled by Water Quality Program actions.

Water Quality Program actions probably will minimally affect the levels of bromide, particularly for SWP users. Bromide largely derives from sea-water intrusion.

Some actions in this section could adversely affect parties who discharge wastes in the Delta and its tributaries. Prior to imposing these impacts, full project-specific environmental documents must be prepared to assess the complete range of proposed impacts, and mitigation measures must be proposed according to applicable laws.

CALFED is committed to continued stakeholder involvement in developing plans to address the water quality problems of the Bay-Delta estuary. Of particular importance is prioritizing actions for implementation. Stage 1A and Stage 1 actions have been identified in a preliminary fashion, but considerable evolution of these plans remains to be accomplished. The work in progress represented by Stage 1A and Stage 1 plans is subject to change, consistent with the CALFED adaptive management philosophy and in conjunction with ongoing stakeholder support and involvement. As a programmatic document, the CALFED Programmatic EIS/EIR is intended to establish the basic framework supporting detailed plans that will evolve with appropriate stakeholder input. Accordingly, currently identified Stage 1A and Stage 1 actions reflect progress made to date and are incomplete. Linkages of priority actions described in the Water Quality Program Plan and plans for Stage 1A and Stage 1 are not yet fully formed, nor is the exact sequence of water quality actions defined. Therefore, the information does not currently exist to enable the Water Quality Program Plan to be amended to include this detail.

CALFED is committed to continued stakeholder involvement in developing plans to address the water quality problems of the Bay-Delta estuary.

The following discussion addresses specific and regionwide approaches to decrease levels of nutrients, pesticides, pathogens, non-sea-water TDS, and TOC. In all cases, the approaches focus on means to reduce the impacts of constituents of concern irrespective of the storage and conveyance alternatives, consistent with the scope of the Water Quality Program component.

3.6.1 Bay-Delta Region

Priority Actions

1. Refine and expand the comprehensive CALFED Drinking Water Quality Improvement Strategy to identify and control drinking water parameters of concern.

The comprehensive strategy includes monitoring drinking water parameters of concern, conducting research, collecting information, and developing methods to reduce point and non-point wastewater sources. A strategy for implementing these measures will be further developed and refined based on the type of industry, state of technology, current regulations, cost, and other relevant considerations. This process will occur throughout the 30-year CALFED implementation period and will fully involve stakeholders.

2. Manage restoration projects to minimize adverse impacts and maximize benefits for drinking water quality.

   CALFED ecosystem restoration and other habitat restoration projects may cause adverse impacts on drinking water quality, particularly with regard to additional production of TOC from natural and created wetlands. CALFED should locate habitat restoration projects to avoid and reduce TOC pollution at intakes. Further research is warranted on this issue. Substantial uncertainty exists concerning TOC production and possible loadings from wetlands restoration, particularly with respect to production of more reactive TOC fractions. Proposals to evaluate these impacts have been developed by the U.S. Geological Survey (USGS) and DWR. CALFED should promote or implement these proposals.

Substantial uncertainty exists concerning TOC production and possible loadings from wetlands restoration, particularly with respect to production of more reactive TOC fractions.

3. Conduct a pilot study on agricultural drainage control actions.

   Conduct a comprehensive pilot study of potential methods to reduce organic carbon loadings to the central Delta from agricultural drains. The goal is to identify and evaluate actions to reduce the quantity or improve the quality of drainage discharged to the central Delta. Actions should be economically feasible and result in improved water quality at the south Delta pumping plants. Potential actions to be investigated in the pilot study include:

   a. The feasibility of removing TOC in agricultural drainage. The initial focus could be on Twitchell Island and central Delta islands. Investigate various treatment technologies at a pilot-scale in field experiments.

   b. Relocating agricultural drains to discharge locations that are remote from the pumping plants. Investigate the economic feasibility of a central Delta drain that would discharge to the Sacramento River.

   c. Storing summer and, where feasible, winter drainage on individual islands in the central Delta and releasing the drainage downstream of urban intakes on the ebb tide.

d. Implementing land management projects, including conversion to early season crops, no tillage farming practices, reduced frequency of winter leaching, conversion to wetlands, land retirement, and less water-intensive irrigation systems

4. Implement full-scale agricultural drainage control actions.

Implement cost-effective, full-scale treatment or management actions that would reduce agricultural drainage in order to reduce the contribution of agricultural drainage to TOC concentrations at drinking water supply pumps. Actions include, but are not limited to, relocation of drains, treatment of drain water, management of drain water, and land management.

5. Minimize pathogens from recreational boating

Wastewater dumped from houseboats, recreational boaters, and other recreation activities results in pathogen pollution of the watershed. Educational solutions could include programs such as developing partnerships with recreational interests, distributing materials at marinas, parks, and recreational supply stores, posting signs at recreational areas; and participating in community events.

Wastewater dumped from houseboats, recreational boaters, and other recreation activities results in pathogen pollution of the watershed.

A stakeholder process is proposed to evaluate additional educational and regulatory needs. Discussions would include the California Department of Boating and Waterways; San Francisco Bay Estuary Project, boating and marina interests, other recreational interests; park departments; and enforcement agencies such as the U.S. Coast Guard, RWQCB, and county sheriff departments. CALFED funding could be used to support identified solutions through educational programs, bans on waste discharges, and facility improvements, such as improved or additional pumpout and restroom facilities. Educational programs such as those in the California Department of Boating of Waterways, the Sacramento River Watershed Program, and local and other efforts will be considered for expansion.

6. Reduce wastewater and stormwater sources of drinking water constituents of concern

Urbanization of the Bay-Delta, as described in the sections to follow, may result in substantial degradation of Bay-Delta waters. It is recognized that wastewater and stormwater discharges may result in undesirable loadings of pathogens, nutrients, TOC, and TDS; and that the development of NPDES permits provides opportunities to address impacts on drinking water. Expansion of the wastewater facilities and urbanization of land in the Delta area are identified as potential sources of increased pollutant loadings. CALFED and stakeholders, including the SWRCB, DWR, California

Expansion of the wastewater facilities and urbanization of land in the Delta area are identified as potential sources of increased pollutant loadings.

Department of Health Services (DHS), drinking water and wastewater utilities, and county planning departments, should participate in the development of a comprehensive watershed protection program to minimize impacts of increasing wastewater discharges into the waters of the Sacramento-San Joaquin Delta estuary and its tributaries.

Currently identified Stage 1 and Stage 1A actions are incomplete and can be augmented through ongoing stakeholder involvement to include such elements as TMDL development and investigating the sources of pathogens in the system. Such actions may be included in the Stage 1 and/or Stage 1A lists.

7. Evaluate treatment plant operational and technological needs.

Evaluate treatment plant operational and technological needs to reduce brominated and chlorinated DBP formation. Also evaluate whether common treatment system technology, coupled with operational changes, are sufficient to meet existing and proposed drinking water standards. Support development of new advance treatment technologies such as ultraviolet and chlorine dioxide disinfection and membrane filtration.

8. Identify problems and solutions to urban runoff.

Current and future urban runoff from Delta and tributary urban areas are potential sources of pathogens and other contaminants. The Sacramento Stormwater Management Program, one of several local stormwater programs, currently is conducting literature reviews and preparing an issue paper to assess this potential problem. CALFED should continue efforts to better identify problems and solutions, through such activities as literature reviews, research, and public education activities. CALFED also should participate in implementing solutions. (This action will be coordinated with the action listed action above to reduce wastewater and stormwater sources of drinking water constituents of concern.)

> Current and future urban runoff from Delta and tributary urban areas are potential sources of pathogens and other contaminants.

9. Reduce the loading of TDS to the Sacramento and San Joaquin Rivers and to the Delta.

The salinity and selenium sections of this Water Quality Program Plan identify a number of approaches to address TDS loading in the Sacramento and San Joaquin Rivers and the Delta. These approaches could reduce TDS levels at drinking water intakes.

10. Conduct additional studies concerning algae and macrophyte growth.

> The excessive growth of algae and macrophytes in water conveyance and storage facilities is a concern for drinking water suppliers.

The excessive growth of algae and macrophytes in water conveyance and storage facilities is a concern for drinking water suppliers. The presence of nitrogen and phosphorus nutrient compounds in Delta water supplies, at levels that readily support the growth of algae, contributes to the excessive growth of algae and macrophytes in water supply facilities. Additional studies are needed to more fully understand the sources and loadings of nutrients in the watershed. Also needed is increased understanding of the relationship between nutrient concentrations and loads in the Delta watershed, and the occurrence of excessive algae and macrophyte growth in water conveyance and storage facilities containing Delta water supplies. (See also information needed to address low DO and oxygen-depleting substances.) In addition, the role of other factors affecting algae growth, such as the operation and maintenance of water conveyance and storage facilities, warrants further assessment. Operational controls are discussed further in individual sections.

11. Implement source controls in the Delta and its tributaries.

CALFED, with CalEPA – specifically the SWRCB and the CVRWQCB, DHS, and DWR, with assistance from EPA – will coordinate a comprehensive source water protection program. This program will include identification and implementation of appropriate pollutant source control measures, focused regulatory and/or incentive programs targeting priority pollutants, development of monitoring and assessment programs, and infrastructure improvements to separate drinking water intakes from irremediable sources of pollutants. The following actions are planned:

The source water protection program will include identification and implementation of appropriate pollutant source control measures, focused regulatory and/or incentive programs targeting priority pollutants, development of monitoring and assessment programs, and infrastructure improvements to separate drinking water intakes from irremediable sources of pollutants.

- The CVRWQCB, with support from CALFED and DHS, will establish a comprehensive state drinking water policy for Delta and upstream tributaries by the end of 2004.

- As part of the CALFED Science Program, develop comprehensive monitoring and assessment program by the beginning of 2003.

- Evaluate and determine whether additional protective measures (regulatory and/or incentive-based) are necessary to protect beneficial uses by the end of 2004.

Consistent with the above policy, the CVRWQCB— with support from DWR and DHS — will begin implementation of appropriate source control measures (for example, advanced wastewater treatment and local drainage management practices) by the end of 2006.

12. Develop a Bay Area blending/exchange project that enables Bay Area water districts to work cooperatively in order to address water quality and supply reliability concerns on a consensual basis.

This is an "umbrella" project that will evaluate a range of potential changes to existing infrastructure and institutional arrangements in order to encourage a regional approach to water supply operations. Specific actions include:

- Identify potential local partners and develop agreements as needed for necessary studies by July 2001.
- Secure authorization and funding for feasibility studies by July 2001.
- Begin feasibility study and environmental review July 2001; complete feasibility study by July 2002.
- Complete environmental review, documentation, and preliminary design on selected alternative by the end of 2003.
- Finalize agreements with project participants by mid-2004.
- Obtain necessary authorizations and funding (including any required local voter approval) by the end of 2004 and begin construction by the end of 2005.

Information Needed

1. Refined measurements of sources and loadings of drinking water quality parameters of concern.

   The sources and loadings of parameters of concern that affect drinking water quality in the Delta, at drinking water intake points and in storage reservoirs, should be identified and measured. The current understanding of pollutant loadings from non-point sources, stormwater drains, and agricultural drains is limited. Improved characterization of drinking water contaminant loadings will facilitate identification and implementation of cost-effective pollutant reduction actions as a part of the Water Quality Program. CALFED should institute a comprehensive study of the magnitude, extent, and origin of these pollutants (TOC, TDS, and pathogens). The resulting report should address a strategy to reduce pollutant loading from permitted discharges and non-point sources.

   The current understanding of pollutant loadings from non-point sources, stormwater drains, and agricultural drains is limited.

2. Evaluation of drinking water treatment options

   Because utilities will need to comply with upcoming and planned drinking water regulations before changes in storage and conveyance could provide significantly improved water quality, most utilities have begun planning and initiating their approaches to compliance. CALFED plans to develop a close working relationship with utilities producing drinking water from the Delta in order to coordinate planning efforts and take maximum advantage of the opportunity to combine source water improvements with improved treatment plant operations. A greater understanding of these plans would allow prioritization of CALFED Water Quality Program actions and perhaps development of other helpful actions. Information gathering should continue during refinement of the proposed actions and as part of the CALFED Phase III implementation.

3. Evaluation of approaches to reduce organic carbon loadings to the Delta from agriculture.

An existing drainage management program for Byron Tract appears promising and is supported by CALFED.

A number of potential methods can reduce organic carbon loading to Delta waterways. These methods have been discussed, and some have received preliminary evaluation. However, no method has been adequately studied to assess the actual reduction in loading, the feasibility, or the costs. Pilot studies at Rock Slough and Old River should be undertaken to determine the water quality efficacy of relocating agricultural drains from Veale Tract away from the Rock Slough intake. An existing drainage management program for Byron Tract appears promising and is supported by CALFED. In addition, development and use of Delta flow models to specifically assist with this evaluation is recommended. Contra Costa Water District (CCWD) has been involved in ongoing efforts to model water quality at intakes. Continuing efforts of The Metropolitan Water District of Southern California (MWD), California Urban Water Agencies (CUWA), DWR, and USGS to use models in order to estimate water quality at the intakes should be supported and extended by CALFED.

4. Augmentation of existing monitoring activities as needed to determine drainage volumes and quality in Delta channels.

Currently, data on drainage volume discharges to Delta channels are based on older studies and limited recent data. Additional measurements of irrigation return flow and irrigation return quality are needed.

5. Assistance in identifying and developing improved analytical techniques for *Cryptosporidium* and *Giardia*.

Significant limitations in current measuring techniques create uncertainty in the use of the data.

6. Evaluation of algae and macrophyte growth constituents

   Algae and macrophyte growth constituents and their origins should be evaluated, and methods should be devised to reduce algae and macrophyte production in conveyance and storage facilities of drinking water diversions from the Bay-Delta. CALFED should support research actions addressing: (1) the relationship between nutrient levels and excessive algae and macrophyte growth problems in water supply facilities, and (2) the role and importance of other factors, such as water facility operation, in producing algae blooms. This research activity should be coordinated with DWR, the U.S. Bureau of Reclamation (Reclamation), and water supply agencies involved in the operation and maintenance of water supply facilities containing Delta water supplies. Such research would provide: (1) information that is necessary for the identification of feasible source control actions, and (2) MPs to address the problem of excessive algae and macrophyte growth in water supply facilities.

Existing Activities

The State Water Contractor's Sanitary Survey Action Committee (SSAC) meets regularly in an ongoing effort to investigate and correct water quality problems identified by the two previous sanitary surveys of the SWP that were published in 1990 and 1996. Sanitary surveys are repeated every 5 years, and efforts to protect the quality of SWP waters are ongoing.

In addition to DWR's Municipal Water Quality Investigation (MWQI) Program, other agencies are undertaking studies to evaluate some of the measures being considered by CALFED. CALFED should help support these studies to the extent warranted.

In addition to DWR's Municipal Water Quality Investigation Program, other agencies are undertaking studies to evaluate some of the measures being considered by CALFED.

Treating Agricultural Drainage

The MWQI Program commissioned a preliminary study to assess the feasibility of treating agricultural drainage in order to improve organic carbon concentrations in Delta waterways. The study found that up to a 60% reduction in TOC concentrations could be achieved with conventional ferric chloride coagulation flocculation. Whether drainage treatment can be cost effective and feasible has not been determined. The following activities should be included in a comprehensive study of agricultural drainage management.

Managing Frequency of Leaching

Most Delta islands with peat soils are leached every 3 years. If the islands were leached only during years when Sacramento River and San Joaquin River flows were high, the high flows potentially could flush the leachate out of the system. By not leaching in low-flow years, organic carbon concentrations potentially could be reduced in the south Delta. However, the implications of not leaching could affect the productivity of Delta islands. A stakeholder process should be initiated with Delta agricultural interests to determine the need for, and to direct, additional studies. From such a process, a BMP approach might be developed and implemented.

Rerouting Agricultural Drainage

Rerouting several key agricultural drains potentially could improve export water quality. For example, CALFED and other stakeholders believe that rerouting or otherwise managing agricultural drainage on Veale Tract and Byron Tract away from Rock Slough could provide lower TOC concentrations at the CCWD pumping plant on Rock Slough. Brown and Caldwell evaluated the feasibility of collecting Delta agricultural drainage and discharging it past Chipps Island. That study indicated that over 700,000 acre-feet of drainage, with a peak flow of 1,600 cfs, discharges annually from various locations in the Delta. Pilot studies at Rock Slough and Old River should be undertaken to determine the water quality efficacy of relocating drains. In addition, the development and use of Delta flow models are recommended to specifically assist with this effort. Ongoing efforts of MWD, CUWA, DWR, and USGS to use models in order to estimate water quality at the intakes should be supported and extended by CALFED.

Rerouting several key agricultural drains potentially could improve export water quality.

Storage in Detention Ponds with Release during High Flows

Potentially, agricultural drainage could be stored in detention ponds and released during periods of high flow when it would have less impact on Delta water quality. Reducing agricultural drainage at times when pumping rates are high also could improve export water quality. While such operations could improve the quality of diverted drinking water sources, it would not improve south Delta water quality. Real-time monitoring of various water quality parameters, including organic carbon, could be used to determine optimum times for release of stored drainage water. However, there are concerns that storing water in detention ponds may actually increase the organic carbon concentra-tion of the drainage, and drainage detention ponds would certainly occupy valuable acreage. Further study is warranted.

Reducing agricultural drainage at times when pumping rates are high also could improve export water quality.

Converting to Low-Tillage Cropping and Other Options

Some water quality scientists believe that converting from agricultural crops that require extensive tillage and irrigation to low-tillage cropping and other options, such as permanent pasture and grazing, could reduce soil oxidation and the loading of organic carbon discharged from Delta islands. The efficacy of these MPs on drinking water source impacts needs to be further studied.

Converting to Flooded Wetlands

In addition to the benefits described above for changing land use practices on agricultural lands with peat soils, maintaining saturated soil conditions may further reduce oxidation and therefore organic carbon loading. Pilot studies on flooded lands need to be conducted to determine whether flooding offers useful land management options and whether such activities would result in adverse water quality consequences.

Pilot studies on flooded lands need to be conducted to determine whether flooding offers useful land management options and whether such activities would result in adverse water quality consequences.

Implementing Irrigation Efficiency Measures

Flooding to leach salt and some irrigation methods (e.g., spud ditch irrigation) are extremely inefficient with respect to irrigation and salt management, and produce large volumes of drainage water and large loads of TOC. Implementation of water-conserving irrigation and salt management methods may offer significantly decreased drainage water volumes and TOC loads. Studies need to be conducted in order to evaluate the potential of irrigation efficiency measures to reduce TOC and salt loads in drinking water sources.

3.6.2 Sacramento and American Rivers

Priority Actions

1. Evaluate the effects of increased urbanization and recommend control strategies.

   It is generally recognized that water quality is currently higher in the Sacramento and American Rivers than in the Delta proper. However, long-term urban development is expected along these rivers that could potentially degrade their quality. CALFED recommends study of the potential impacts of increased urbanization over the next 30 or more years on wastewater and stormwater loadings to the Sacramento and American Rivers. Where appropriate, mitigation measures would be developed and implemented.

It is generally recognized that water quality is currently higher in the Sacramento and American Rivers than in the Delta proper. However, long-term urban development is expected along these rivers that could potentially degrade their quality.

2. Control algal blooms in upstream reservoirs and aquatic weed growth in the lower American River.

   This is a water treatment issue for the City of Sacramento's Fairbairn Water Treatment Plant to reduce nutrient loadings that support algal and aquatic weed growth. Impacts on the water supply from aquatic plant growth include T&O, as well as clogging of fish screens. Additional studies are required specific to this source to determine why this problem occurs and potential solutions.

3. Reduce impacts from livestock grazing along the Sacramento River by the use of BMPs.

Livestock grazing, dairy operations, and other confined animal feeding operations are potential sources of pathogens, TOC, nutrients, and TDS in the Sacramento River watershed. The City of Sacramento, Department of Utilities has been tracking research concerning grazing animals and their potential contribution of pathogens to the Sacramento River system, as well as the implementation of grazing BMPs in the Sacramento River watershed. The University of California, Davis, (UC Davis) Extension Program has conducted extensive research on various grazing animals, with the cooperation of the grazing industry. The Cattlemen's Association has been supporting research on BMPs for grazing lands, as well as promoting these practices in its educational outreach programs. The UC Davis Extension Program provides educational resources and rangeland water quality short courses for the grazing industry. CALFED should assess the findings of these independent programs and support stakeholder involvement and implementation of livestock management BMPs. Efforts would be generally useful to several watersheds that affect drinking water intakes in the Delta. Implementation of prevention measures, such as buffer strips along stream channels, offer the prospect of ecosystem enhancement opportunities and should be coordinated to achieve maximum benefits. CALFED should support BMP development and enforcement by the RWQCBs of pollution prevention measures.

Livestock grazing, dairy operations, and other confined animal feeding operations are potential sources of pathogens, TOC, nutrients, and TDS in the Sacramento River watershed.

4. Reduce impacts for dairies and other confined animal feeding operations.

Confined animal feeding operations may contribute pollution to the Delta through poor management of animal wastes. The CVRWQCB has identified more than 1,600 dairies in the region, and spot inspections have indicated that many of the facilities are following practices that may adversely affect water quality.

Information Needed

1. Determine the impacts from the Natomas East Main Drain.

DWR has collected data at this location, but it was noted that a data gap remains with respect to understanding loadings and impacts from the Natomas East Main Drain. Because of interest in relocating agricultural drains and relocating drinking water intakes in the northern parts of the Delta, it would be useful to determine the water quality effects of this drain.

2. Determine the sources of contaminants of concern in the watershed.

Previous studies have shown that information on the sources of organic carbon in the Sacramento River watershed is incomplete. The Sacramento River Watershed Program (SRWP) will collect some data on organic carbon concentrations at a number of locations along the Sacramento River and its major tributaries. Data are needed on the concentrations and loads of organic carbon in urban runoff, wastewater discharges, and agricultural drainage. CALFED should support and augment the SRWP effort as needed.

Previous studies have shown that information on the sources of organic carbon in the Sacramento River watershed is incomplete.

Information also is needed on the key sources of TDS in the Sacramento River watershed. As the population of the watershed grows, potential mitigation measures may be needed for increased wastewater and urban runoff discharges with high TDS. DWR authored a paper about TDS impacts resulting from anticipated population growth in the watershed. The CMARP should consider expanding on the study to evaluate key point sources of TDS in the watershed.

Information also is needed on the key sources of TDS in the Sacramento River watershed.

3. Estimate the likely future impacts from increased urbanization.

As noted above, future development may adversely affect water quality in the Sacramento and American River watersheds. An estimate of adverse impacts is recommended.

Existing Activities

Wild animals may be a source of pathogens to the Sacramento and American Rivers and to the Delta in general. UC Davis is planning to conduct research on this potential source of pathogens. Of particular interest is information on loading of protozoan pathogens such as *Giardia* and *Cryptosporidium*. CALFED should support these activities.

Wild animals may be a source of pathogens to the Sacramento and American Rivers and to the Delta in general.

3.6.3 North Bay Aqueduct

Priority Actions

1. Implement the Barker Slough Watershed Management Program.

Solano County Water Agency (SCWA) and the other North Bay Aqueduct (NBA) water users are in the process of developing a management program to control drinking water contaminants in the Barker Slough watershed. The tasks include identifying areas with the greatest impact on source water quality and designing BMPs with the potential to improve the quality of

SCWA and the other NBA water users are in the process of developing a management program to control drinking water contaminants in the Barker Slough watershed.

runoff water and the quality of water in Barker Slough at the pumping plant. The most suitable BMPs, including structural and non-structural, will be implemented by property owners on a voluntary basis. Water quality monitoring will ascertain the effectiveness of the BMPs. A watershed stakeholders group has been formed to advise the NBA contractors on all aspects of the program.

SCWA has received a $580,000 Delta Tributary Watershed Program grant to evaluate BMPs and develop the watershed management plan. Additional funding will be needed to fully implement the plan. CALFED will support implementation of a watershed management plan and will provide funding to implement BMPs that will improve watershed runoff water quality and to provide water quality monitoring in the Barker Slough watershed.

2. Study the feasibility of relocating the NBA intake.

The water quality in the NBA is considered some of the poorest in the Delta for drinking water (with respect to TOC and turbidity, but not with regard to bromide), resulting largely from water quality degradation in the watershed. Future changes in the northwest Delta may degrade the water quality at Lindsey Slough, which appears to provide an element of dilution to the degradation from the upper watershed. Large CALFED environmental restoration projects near the mouth of Lindsey Slough may cause an increase in organic carbon levels and potentially an increase in pathogen levels. In addition, the goal of these restoration projects is to increase populations of the fish species of concern. Increases in these fish populations may lead to restrictions in pumping at the Barker Slough Pumping Plant.

> The water quality in the NBA is considered some of the poorest in the Delta for drinking water (with respect to TOC and turbidity, but not with regard to bromide), resulting largely from water quality degradation in the watershed.

An alternative under consideration is construction of an alternate point of intake either on the Tehama-Colusa Canal or on Miner Slough. These alternate intakes would provide the option to use source water containing a larger proportion of Sacramento River water, which is often of considerably higher quality in terms of organic carbon and turbidity, compared to Barker Slough. An in-depth analysis of the need for, and feasibility of, constructing an alternate intake is recommended. Potential water quality impacts of the ecosystem restoration activities, specifically at Lindsey Slough, need to be studied to determine whether the activities will increase concentrations of organic carbon or other drinking water contaminants at the NBA intake. Determining that these activities cause negative water quality impacts would provide further impetus for constructing an alternate point of intake for the NBA.

> Potential water quality impacts of the ecosystem restoration activities, specifically at Lindsey Slough, need to be studied to determine whether the activities will increase concentrations of organic carbon or other drinking water contaminants at the NBA intake.

Information Needed

1. Conduct studies to further delineate the dry season organic carbon contributions and possible means to reduce loads.

   Laboratory and field studies are needed to determine sources of organic carbon and other drinking water contaminants at the Barker Slough Pumping Plant. Studies should address the in-channel contribution of algae and other aquatic plants, and the sources of organic carbon in the watershed.

2. Collect water quality data for alternative intake locations.

   Water quality data are needed at potential alternative intake locations (currently, the Tehama-Colusa Canal and Miner Slough).

3. Study the water quality impacts of CALFED ecosystem restoration activities on Barker Slough Pumping Plant diversions.

   Study the water quality impacts of CALFED ecosystem restoration activities on Barker Slough Pumping Plant diversions and identify mitigation strategies, as needed.

Existing Activities

1. Development of the Barker Slough Watershed Management Plan.

   CALFED will support the development of the Barker Slough Watershed Management Plan by the NBA contractors with partial funding by the Delta Tributary Watershed Program.

3.6.4 South Bay Aqueduct

Priority Actions

1. Implement a watershed management program within the South Bay Aqueduct (SBA) proper.

   The SBA is open from Bethany Reservoir to near Lake Del Valle. Although the size of the contributing watershed is small, sanitary surveys have identified specific problems resulting from ranching and other watershed activities that could allow agricultural and stormwater runoff into the SBA and contribute to algal growth. A study should be conducted to determine the areal extent of watershed that contributes to the SBA and identify the sources of loadings. As BMPs to reduce loading of contaminants are developed for the activities that contribute to SBA loadings, the BMPs also should be applied in the SBA watershed.

2. Develop and implement management programs for Lake Del Valle, including possible control of swimming and boating.

   Increasing concerns have been raised regarding microbial pollution of source waters from recreational swimmers. It is recognized that, from a source water protection standpoint, the most desirable situation is to ban all whole-body contact in these source waters. Because SWP reservoirs are required to be multi-use facilities, it is not possible to ban swimming. Source water protection may be achieved by restricting swimming to areas bermed off from the main water body. For Lake Del Valle, a feasibility study is recommended to determine the need for, costs of, and institutional feasibility of creating and maintaining a bermed-off swimming area. If this is feasible, CALFED funding for implementation may be appropriate.

   Increasing concerns have been raised regarding microbial pollution of source waters from recreational swimmers.

   Additional microbial contaminant sources for Lake Del Valle include boating, other whole-body-contact activities, and sanitary waste handling facilities. Control of these sources may include education and limiting the locations of facilities and activities.

3. Develop and implement management programs for the upper Lake Del Valle watershed.

   Ranching operations in the Arroyo Valle watershed above Lake Del Valle appear to contribute nutrients that promote algal growth; livestock operations also may contribute pathogens to Lake Del Valle. A watershed management program, patterned after that initiated by the San Francisco Public Utility Commission for the Alameda Creek watershed above Calaveras Reservoir, is recommended. BMPs could be implemented as they are developed elsewhere.

Information Needed

1. Research and develop control strategies for algae in the SBA and Clifton Court Forebay.

   Algae can cause problems during drinking water treatment and can elicit T&O complaints from consumers. Copper sulfate and Komeen (a copper-based algicide) currently are being used to control the growth of algae in the SBA and Clifton Court Forebay. Although the use of copper products does not pose a public health threat, some municipalities are having difficulty meeting

   Algae can cause problems during drinking water treatment and can elicit T&O complaints from consumers.

Control of these sources may include education and limiting the locations of facilities and activities.

3. Develop and implement management programs for the upper Lake Del Valle watershed.

   Ranching operations in the Arroyo Valle watershed above Lake Del Valle appear to contribute nutrients that promote algal growth; livestock operations also may contribute pathogens to Lake Del Valle. A watershed management program, patterned after that initiated by the San Francisco Public Utility Commission for the Alameda Creek watershed above Calaveras Reservoir, is recommended. BMPs could be implemented as they are developed elsewhere.

Information Needed

1. Research and develop control strategies for algae in the SBA and Clifton Court Forebay.

   Algae can cause problems during drinking water treatment and can elicit T&O complaints from consumers. Copper sulfate and Komeen (a copper-based algicide) currently are being used to control the growth of algae in the SBA and Clifton Court Forebay. Although the use of copper products does not pose a public health threat, some municipalities are having difficulty meeting wastewater effluent limits for copper. Therefore, the use of copper sulfate is not an optimal solution. The following issues may lead to reduced effectiveness or restricted use of copper sulfate in the future: (1) copper selects for the growth of algae that are tolerant to this chemical, (2) copper may be toxic to other aquatic organisms (e.g., invertebrates and fish), (3) there are drinking water limits on copper (although copper limits have not been approached), (4) new restrictions may be placed on copper sulfate usage in surface waters as a result of the proposed California Toxics Rule, (5) copper accumulated in water treatment plant sludge can greatly increase disposal costs, and (6) nutrients from dead algae can be dissolved into the water column and may promote algae growth later. Several other approaches to control algae in the SBA and Clifton Court Forebay have been suggested and, in some cases, tried. These options, including physical removal using chains and screens, and control of floating algae by using attached algae as nutrient scrubbers, require further evaluation. Additional research on algal control in the SBA is warranted.

   Algae can cause problems during drinking water treatment and can elicit T&O complaints from consumers.

3.6.5 Clifton Court Forebay and Bethany Reservoir

Priority Actions

1. Develop and implement watershed management programs for Clifton Court Forebay and Bethany Reservoir to address nutrients and pathogens.

   Much of the land surrounding Clifton Court Forebay and Bethany Reservoir is used for agriculture and livestock grazing. While there is no watershed around Clifton Court Forebay, some agricultural drains directly discharge to Clifton Court. Additionally, pollution from stormwater runoff can occur. Although these watersheds cannot contribute large amounts of pollutants, every pound of the pollutants is carried off with the diverted water. A watershed management program, similar to that initiated by NBA users at Barker Slough, is recommended to address nutrient and microbial pathogen pollution from agricultural activities, particularly livestock operations. As BMPs are developed for these activities, they could be implemented in these small watersheds. Stakeholders should be included in further delineation of potential sources of contaminants and in implementation of BMPs to reduce loading of contaminants.

   While there is no watershed around Clifton Court Forebay, some agricultural drains directly discharge to Clifton Court.

2. Evaluate impacts of new wastewater discharges to the Delta.

   Population expansion into the Delta area is resulting in plans to increase wastewater discharges to the Delta. For example, the wastewater treatment plant for Discovery Bay discharges near Clifton Court Forebay and the CCWD Old River intake. The current plan for expansion is a 50% increase in capacity at the Discovery Bay wastewater facility. Another example is the new Mountain House community located east of the Tracy Pumping Plant that may, ultimately, need to discharge wastewater to Delta channels. Increased loadings and impacts of such discharges need to be evaluated and addressed as part of the comprehensive CALFED Drinking Water Quality Improvement Strategy.

   The current plan for expansion is a 50% increase in capacity at the Discovery Bay wastewater facility.

3. Control algae in Clifton Court Forebay.

   The control of algae in Clifton Court Forebay is addressed earlier in Section 3.6.4, "South Bay Aqueduct."

Information Needed

1. Identify and mitigate high-impact agricultural drains near Clifton Court.

   Discharges nearest to drinking water intakes can substantially degrade water quality at the intakes. For example, Byron Tract was noted as having drainage substantially poorer in quality than water found in Delta channels. The impacts of these sources need to be better characterized. Detailed studies should be conducted on the drains in the immediate area of Clifton Court, including modeling of loads. Depending on the results of these studies, this action could be followed by BMPs.

Discharges nearest to drinking water intakes can substantially degrade water quality at the intakes.

2. Determine algae mitigation in Clifton Court Forebay.

   Studies are needed to determine the best methods of algae removal or avoidance for the Clifton Court Forebay area.

Existing Activities

1. Control of flows and water levels by barriers and operational changes.

   The use of barriers and operational changes to improve south Delta water levels and redirect San Joaquin River flows to protect fish may affect water quality at Clifton Court. This is an ongoing activity that is being considered by DWR with the CALFED storage and Delta conveyance actions (under projects of the Interim South Delta Program [ISDP]). Continuing studies should include evaluations of water quality impacts and modification of plans, as needed, to avoid negative water quality impacts.

The use of barriers and operational changes to improve south Delta water levels and redirect San Joaquin River flows to protect fish may affect water quality at Clifton Court.

3.6.6 Contra Costa Water District Intakes

CCWD intakes include Mallard Slough, Rock Slough, and Old River.

Priority Actions

1. Relocate, reduce, or eliminate agricultural drainage into Rock Slough.

   Current studies indicate that relocation or treatment of agricultural drainage from Veale Tract may be the most effective means to reduce impacts on the Rock Slough intake; however, other forms of source reduction, control, and management can be investigated within the scope of the CALFED Program. CCWD has developed a proposal for a feasibility study of mitigation measures

Current studies indicate that relocation or treatment of agricultural drainage from Veale Tract may be the most effective means to reduce impacts on the Rock Slough intake.

for drainage into Rock Slough. One possibility would be to relocate the discharge to Sand Mound Slough downstream of the one-way gates.

Drainage from Byron Tract also has the potential to affect CCWD's drinking water intake on Old River near Highway 4. Relocation of discharges and other forms of management to reduce these impacts should implemented with CALFED support.

As part of the approach to solving problems of discharges near drinking water intakes, a watershed management strategy will be used to identify stakeholders, develop a consensus approach, and monitor water quality. Studies by CCWD are ongoing to further determine impacts from Veale Tract discharges. CALFED funding for this pilot project and for CCWD's Byron Tract program is recommended.

Information Needed

1. Determine impacts from the Veale Tract drain and the Discovery Bay discharge point.

   Studies by CCWD are ongoing to further determine impacts from the Veale Tract drain and the Discovery Bay discharge point. Funding for these studies is recommended.

2. Study the control of agricultural drainage near intakes.

   CCWD considers management and control of local drainage to be among the most cost-efficient means of improving source water quality impacts at urban intakes in the Delta. Drainage control programs may be effective near the Old River intake. Actions could include treatment, volume reduction through BMPs, consolidation of discharges, or relocation of the point of discharge. Studies by CCWD are underway to evaluate these possibilities. Development and implementation of BMPs through a watershed stakeholder process should be supported by CALFED.

CCWD considers management and control of local drainage to be among the most cost-efficient means of improving source water quality impacts at urban intakes in the Delta.

Existing Activities

1. Study concerning relocation of Veale Tract agricultural drain

   CCWD has already spent considerable time on the study to relocate the Veale Tract agricultural drain. Continuance of the study is recommended.

3.6.7 *Delta-Mendota Canal at the City of Tracy Intake*

Priority Actions

1. Evaluate the water quality impacts associated with discharging the City of Tracy wastewater treatment plant effluent near the City's drinking water intake, and the impacts of potential discharges from the new Mountain House community under development east of the Central Valley Project (CVP) Tracy Pumping Plant.

   The City of Tracy drinking water intake is in the DMC. The DHS believes that drinking water quality might be adversely affected by discharges from the City's wastewater treatment facility into Old River. These discharges are expected to increase over time as the population of Tracy expands. The City of Tracy is considering moving its intake to the SWP. CALFED should support further evaluation of this action to protect the City of Tracy's drinking water quality.

> The City of Tracy drinking water intake is in the DMC. The DHS believes that drinking water quality might be adversely influenced by discharges from the City's wastewater treatment facility into Old River.

Information Needed

1. Identify and characterize drains near the City of Tracy intake.

   Discharges nearest to drinking water intakes may pose the greatest risks for adverse impacts on water quality. For Tracy, these drains have not been identified and characterized adequately. Focused studies on several drains in the vicinity of the Tracy intake is recommended.

3.6.8 *San Joaquin River*

Priority Actions

1. Establish a watershed management program for the San Joaquin River.

   A San Joaquin River Watershed Program should be established that is similar in scope to the Sacramento River Watershed Program. Such a program could address both drinking water and ecosystem concerns in the San Joaquin River watershed.

> A San Joaquin River Watershed Program should be established that is similar in scope to the Sacramento River Watershed Program.

2. Address drainage problems in the San Joaquin Valley to improve downstream water quality

   This action will include implementing recommendations from the San Joaquin Valley Drainage Implementation Program; identifying and supporting innovative drainage management programs; and supporting voluntary land retirement programs for drainage-impaired lands, with local sponsorship. This action includes CALFED actions, which target approximately 35,000 acres of land retirement and complementary land retirement actions under other programs. These actions include:

   - Finalize the State Basin Plan Amendment and TMDL for salinity in the lower San Joaquin River by the end of 2001.

   - Begin implementation of appropriate source control measures (for example, on-farm and district actions, development of treatment technology, real-time management, and reuse projects such as agroforestry) by the end of 2003.

Information Needed

1. Determination of the concentrations, loads, and sources of organic carbon, TDS, bromide, nutrients, and pathogens in the San Joaquin River watershed

   The CMARP should include monitoring of the San Joaquin River for key drinking water parameters, such as organic carbon and pathogens. Where permitted discharges may affect drinking water quality, key drinking water parameters should be included in NPDES permits.

> The CMARP should include monitoring of the San Joaquin River for key drinking water parameters, such as organic carbon and pathogens.

Existing Activities

1. Testing of San Joaquin River.

   DWR, USGS, and the CVRWQCB have performed extensive testing on the San Joaquin River. The City of Stockton has run models on DO levels in the vicinity of the City of Stockton. Additional studies are proposed.

3.6.9 California Aqueduct

Priority actions involve the portion of the California Aqueduct south of O'Neill Forebay and Check 13.

Priority Actions

Much of the land surrounding the southern portions of the California Aqueduct is used for agriculture and grazing. A number of agricultural drains directly affect the Aqueduct, and large stretches of the Aqueduct are not adequately protected from stormwater runoff that is impacted by soil erosion or agricultural and livestock runoff. Other major drinking water conveyance channels have similar runoff problems. CALFED agencies will implement appropriate physical modification and watershed management programs to correct this problem. Specific actions include:

1. Control drainage of stormwaters into the aqueduct by physical modification of facilities.

   The introduction of stormwater runoff that might be affected by agricultural and livestock operations and by soil erosion is a primary problem identified for the San Luis Canal section of the California Aqueduct (which runs from near Los Banos to near Kettleman City). Sediment, TDS, pathogens, and nutrients that stimulate algal growth may enter the system in this way. In addition, this reach of aqueduct is not well protected from stormwater runoff. The SSAC has instituted actions to control entry of stormwater. CALFED will initiate a comprehensive evaluation of necessary physical modifications (for example, modifications to berms, bypasses, and stormdrains to divert storm-water away from, and prevent its discharge into, the Aqueduct and similar conveyance channels) by the end of 2001. CALFED then will identify and begin implementation of necessary physical improvements by the end of 2003.

The introduction of stormwater runoff that might be affected by agricultural and livestock operations and by soil erosion is a primary problem identified for the San Luis Canal section of the California Aqueduct.

2. Develop and implement a watershed management program to minimize drainage impacts on the aqueduct.

   Much of the land surrounding the southern reaches of the California Aqueduct is used for agriculture and livestock grazing. A number of agricultural drains directly affect the aqueduct. Pump-in from groundwater programs during drought emergencies also can degrade water quality. A watershed management program, including projects for Arroyo Pasajero, has been developed to address nutrient, sediment, and pathogen pollution from these activities. Implementation of the watershed program would include forming a stakeholder group of landowners, urban water managers, DWR, SSAC, and others, to identify BMPs in order to reduce loading of contaminants and to

Much of the land surrounding the southern reaches of the California Aqueduct is used for agriculture and livestock grazing.

initiate corrective actions. CALFED then will develop and implement watershed management programs adjacent to appropriate conveyance channels by the beginning of 2004.

Existing Activities

The SSAC is considering design and implementation of appropriate modifications, including berms, bypasses, and storm drains, to divert stormwater away from and prevent its discharge into the aqueduct. Such activities could be made eligible for CALFED funding.

3.6.10 Southern California

Priority Actions

1. Facilitate water quality exchanges and similar programs to make high-quality Sierra water in the eastern San Joaquin Valley available to urban southern California interests.

   For example, MWD and the Friant Water Users Authority and its member agencies have commenced preliminary discussions to accomplish these objectives and to improve water supply reliability for the agricultural districts. CALFED will work to assure that these efforts and others are consistent with overall programs to restore the upper San Joaquin River. Specific actions include:

   - Initiate evaluations and studies of potential infrastructure improvements by December 2000.
   - Complete feasibility studies and implement selected demonstration projects by the end of 2001.
   - Complete environmental review and begin implementation of a long-term program, including necessary infrastructure, by the end of 2004.

2. Develop and implement a watershed management program to control nutrients, turbidity, and pathogens.

   Local drainage and runoff in the Castaic Lake and Lake Silverwood watersheds may contribute pathogens, nutrients, and turbidity to the SWP reservoirs. Sources of contaminants in these watersheds include recreational use in the watersheds, highway and road runoff, wastewater treatment system spills or failures, and livestock grazing. Livestock grazing operations in the

Local drainage and runoff in the Castaic Lake and Lake Silverwood watersheds may contribute pathogens, nutrients, and turbidity to the SWP reservoirs.

watersheds around the reservoirs may result in increases in nutrient and pathogen loadings. Presently, sheep grazing occurs in the Castaic Lake watershed on a seasonal basis on lands owned by DWR and the BLM; however, no grazing occurs in the Lake Silverwood watershed. Development of a watershed management plan to control local sources of drinking water contaminants to the reservoirs is desirable.

The watershed management plan should address land development and land use in the watersheds of SWP reservoirs, including activities on state and federal lands. Fire management plans also should be developed as a component of watershed management plans. Development of a watershed management plan would involve forming a stakeholder group of landowners, the SSAC, BLM, U.S. Forest Service (USFS) and others. The group would identify sources of contaminants and feasible source control measures to reduce contaminant loadings to the reservoirs. Source control measures could include creation of buffer zones for animal grazing activities, and construction of flow-through wetlands and stormwater detention basins to improve storm runoff water quality before it reaches the reservoirs (i.e., similar to the Drainage Water Quality Management Plan for the Lake Mathews watershed).

3. Control body-contact recreational use to minimize microbial pathogens from humans.

There is a need to ensure that pathogens, specifically *Cryptosporidium*, *Giardia*, and potentially viruses, do not occur in the SWP aqueduct and reservoirs. Future drinking water regulations may include more stringent disinfection requirements to control these pathogens. Modeling studies for Eastside Reservoir clearly show increasing microbial pathogen loads in storage reservoirs as a result of body-contact recreation. It is recognized that, from a source water protection standpoint, elimination of all body contact in reservoirs that are used to store drinking water sources would be desirable. Since these reservoirs are SWP reservoirs and are designated as multi-use waters, full restriction is likely not to be possible. Therefore, restriction of swimming to physically separate swimming lagoons may help to minimize pathogen loading and maintain the multi-purpose concept of the facilities. CALFED should support evaluation of methods to manage body-contact recreation in order to minimize pathogen loading from such activities without causing unacceptable restrictions to recreational use.

Future drinking water regulations may include more stringent disinfection requirements to control pathogens.

4. Evaluate structural alternatives at Castaic Lake and Elderberry Forebay to control algae.

On the West Branch of the SWP, water enters Castaic Lake from Elderberry Forebay. After major T&O-producing algae blooms at Castaic Lake in 1993 and 1994, MWD and DWR conducted a study to evaluate the relationship between releases from Elderberry Forebay and T&O problems in Castaic Lake. They evaluated mixing and water transport mechanisms associated with T&O events, and identified operational and engineering strategies to manage T&O events in Castaic Lake. The engineering strategies involve modifications to the outlet at Elderberry Forebay in order to reduce mixing and transport of malodorous compounds from the surface where they are produced to the deepest reaches of the lake. The engineering strategies require further feasibility studies before implementation. CALFED should support such feasibility studies.

5. Provide secondary containment for all sanitary facilities at SWP terminal reservoirs.

   Spills from wastewater collection, transport, and treatment systems and sanitary facilities (including chemical toilets and floating toilets) at SWP reservoirs can contribute pathogens and other pollutants to the reservoirs. To reduce the risk of pollution from spills or failures of sanitary facilities, it is recommended that all sanitary facilities at SWP reservoirs be equipped with secondary containment structures. CALFED should support the implementation of this action and coordinate this effort with DWR, Department of Parks and Recreation, SWP contractors, and local sanitary districts.

Spills from waste-water collection, transport, and treatment systems and sanitary facilities (including chemical toilets and floating toilets) at SWP reservoirs can contribute pathogens and other pollutants to the reservoirs.

6. Control recreational boating use to minimize pollution from MTBE.

   Two-cycle engines are considered major contributors of MTBE and other fuel contaminants in source waters, particularly in storage reservoirs. Some utilities already have banned the use of two-cycle engines on some reservoirs. The most recent information on MTBE indicates that it does not pose a human health risk in reservoirs, as once thought. CALFED should continue to monitor technical developments regarding human health risk and MTBE. Should a significant risk be identified, CALFED should institute water quality actions to eliminate the risk.

Information Needed

1. Conduct studies to determine impacts of recreational activities.

   Aside from the studies to determine methods of reducing the impacts of body-contact recreation and recreational boating in terminal reservoirs, no other studies are proposed.

Existing Activities

1. Program to detect algae blooms

   Since 1973, DWR has maintained a biological surveillance program to detect algal blooms in the reservoirs of the Southern Field Division of the SWP and to provide early warning to urban water contractors. The MWD has begun algae studies in the terminal reservoirs to determine mechanisms for reducing algal production.

   MWD also is conducting studies to evaluate local drainage and stormwater runoff to Castaic Lake and Lake Silverwood as potential sources of pathogens.

3.7 CAPACITY FOR REDUCING BROMIDE AND ORGANIC CARBON THROUGH WATER QUALITY PROGRAM ACTIONS

The importance of bromide to the CALFED Program resulted in the formation of a panel of independent experts to evaluate the significance of bromide to the CALFED selection of a Preferred Program Alternative.

The CALFED Phase II Report identifies bromide as a critical constituent with respect to selection of a Preferred Program Alternative. Bromide is critical because the selection of storage and conveyance options has the potential to profoundly affect bromide concentrations in municipal water supplies diverted from the Delta. Figures 4 and 5 illustrate this potential. The importance of bromide to the CALFED Program resulted in the formation of a panel of independent experts to evaluate the significance of bromide to the CALFED selection of a Preferred Program Alternative. The panel report is attached in its entirety as Appendix E.

Bromide is present in sea water. Bromide enters into Delta drinking water supplies primarily through mixing with waters of San Francisco Bay and the Pacific Ocean.

Bromide is present in sea water. Bromide enters into Delta drinking water supplies primarily through mixing with waters of San Francisco Bay and the Pacific Ocean. This section will demonstrate that the ocean is, in fact, the source of most of the bromide in the Bay-Delta estuary system. Other sources of bromide may exist, however, and CALFED needs to evaluate these sources and to institute corrective actions where feasible in order to reduce their contributions. Organic carbon can be reduced through treatment, either at the source or at drinking water treatment facilities. Because of the importance of organic carbon as a reactant chemical in the formation of DBPs, it is desirable to control sources of organic carbon through specific water quality actions in addition to whatever improvements would be provided through changed storage or conveyance mechanisms.

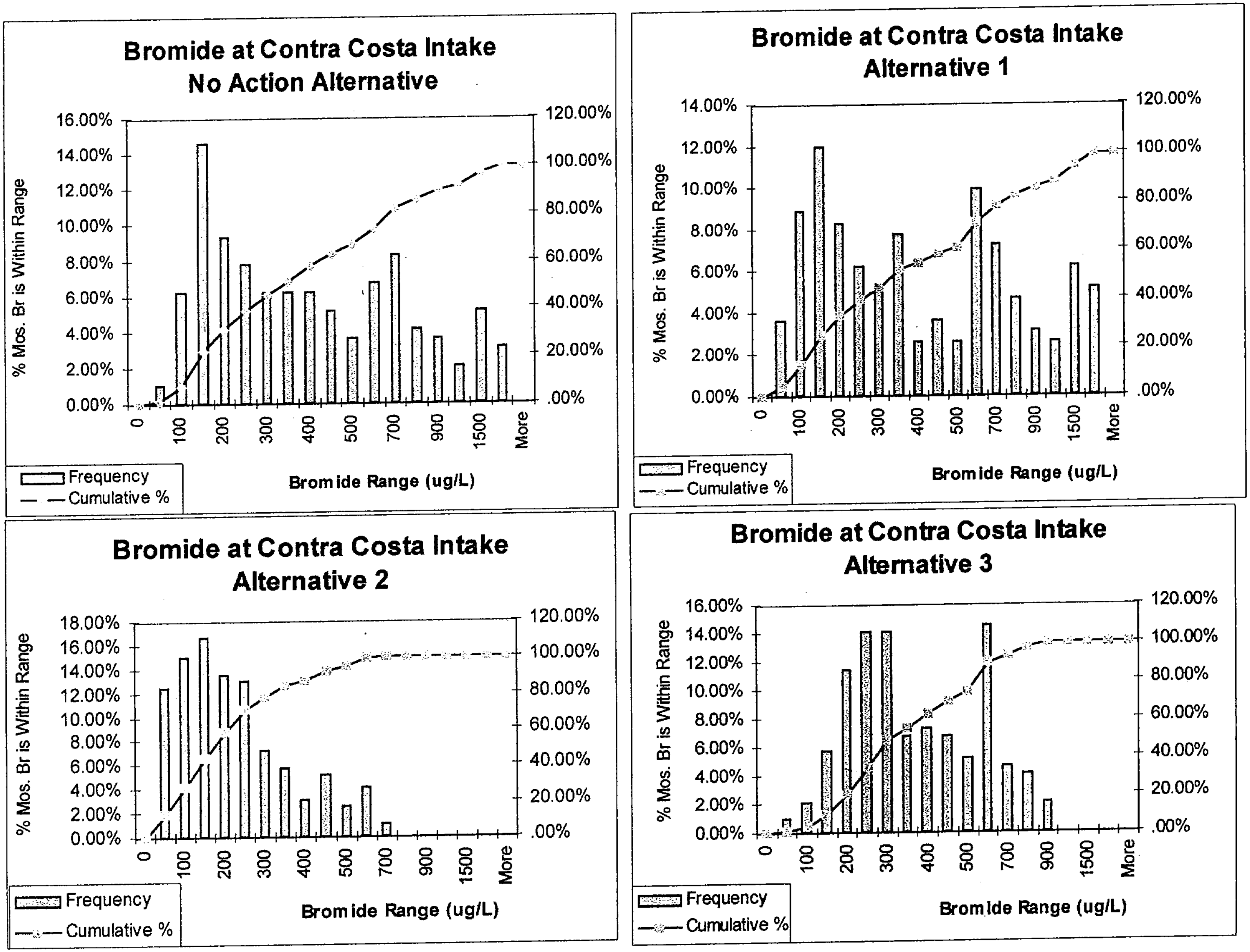


Figure 4. Bromide at Contra Costa Canal Intake

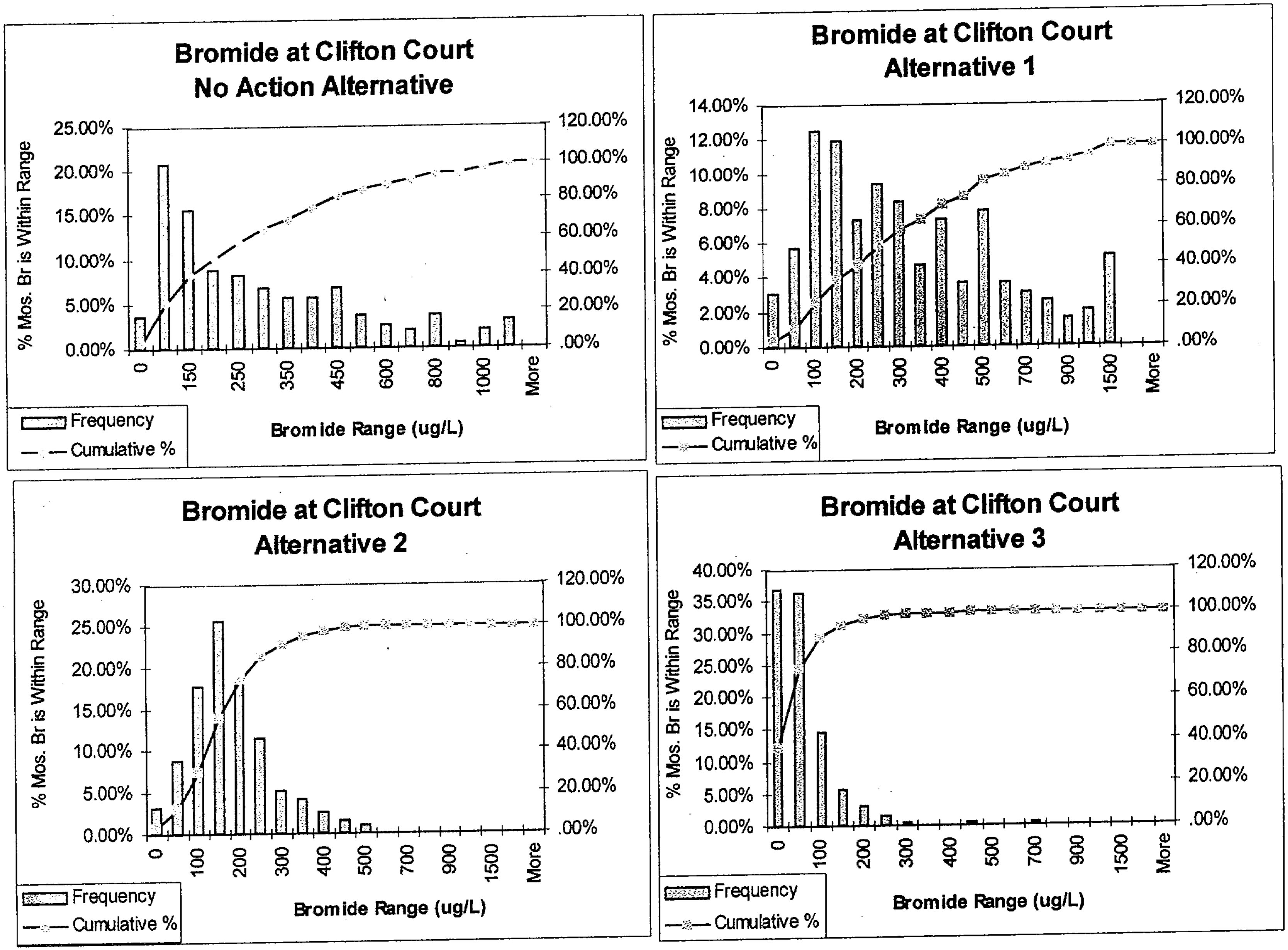


Figure 5. Bromide at Clifton Court Forebay

This section is a preliminary evaluation of the importance of non-ocean sources of bromide in the Delta system, of the potential of Water Quality Program actions to reduce bromide, and of the potential to control organic carbon in Delta drinking water supplies through water quality actions.

These analyses are intended to identify priority actions for the first stage of program implementation.

3.7.1 Bromide

In addition to saline water entering the Delta from the Bay-ocean, water flows into the Delta through the Sacramento River, the San Joaquin River, and east side streams (the Cosumnes, Mokelumne, and Calaveras Rivers) and from the Bay estuary. About 70% of the fresh-water inflow is through the Sacramento River, with the San Joaquin River making up the bulk of the remainder. The east side streams collectively contribute less than 5% of Delta fresh-water inflow. From January 1990 to March 1998, the average concentration of bromide in Sacramento River water was 18 µg/L with a standard deviation of 40 µg/L. By contrast, San Joaquin River water averaged 310 µg/L with a standard deviation of 150 µg/L during the same period. Therefore, although bromide concentrations in the Sacramento River are variable, this river does not appear to be an important source of bromide. It should be noted that bromide samples are collected at a sampling station on the Sacramento River about 8 miles downstream of the Sacramento Regional County Sanitation District wastewater treatment plant outfall. Therefore, the indication is that the loading of bromide from sources in the Sacramento River watershed do not play a significant role in the overall loading of bromide in the water diverted from the Delta. Similarly, the east side streams are low in dissolved minerals and are not important bromide contributors.

About 70% of the fresh-water inflow to the Delta is through the Sacramento River, with the San Joaquin River making up the bulk of the remainder.

Based on available information, it appears that the San Joaquin River is the most important source of bromide to the Delta system, exclusive of the Bay-ocean. Figure 6 depicts the south Delta. Water in the San Joaquin River normally flows into the Delta from the south, where it divides—some heading through Old River and some continuing in the river channel north to Stockton, then west toward the Bay. Pumping by the SWP, and particularly by the Tracy Pumping Plant in the south Delta, causes more San Joaquin River water to be diverted from its channel than would be diverted without pumping. Some of this water leaves the San Joaquin River to flow into Old River. Also, San Joaquin River water tends to be drawn southward to the pumps through Turner Cut and Middle River. During periods of lower San Joaquin River flow, essentially the entire river volume can be drawn into the pumps. The CVP Tracy Pumping Plant receives the highest percentage of San Joaquin River water because the plant operates continuously. The Harvey O. Banks Pumping Plant of the SWP pumps from Clifton Court.

Based on available information, it appears that the San Joaquin River is the most important source of bromide to the Delta system, exclusive of the Bay-ocean.

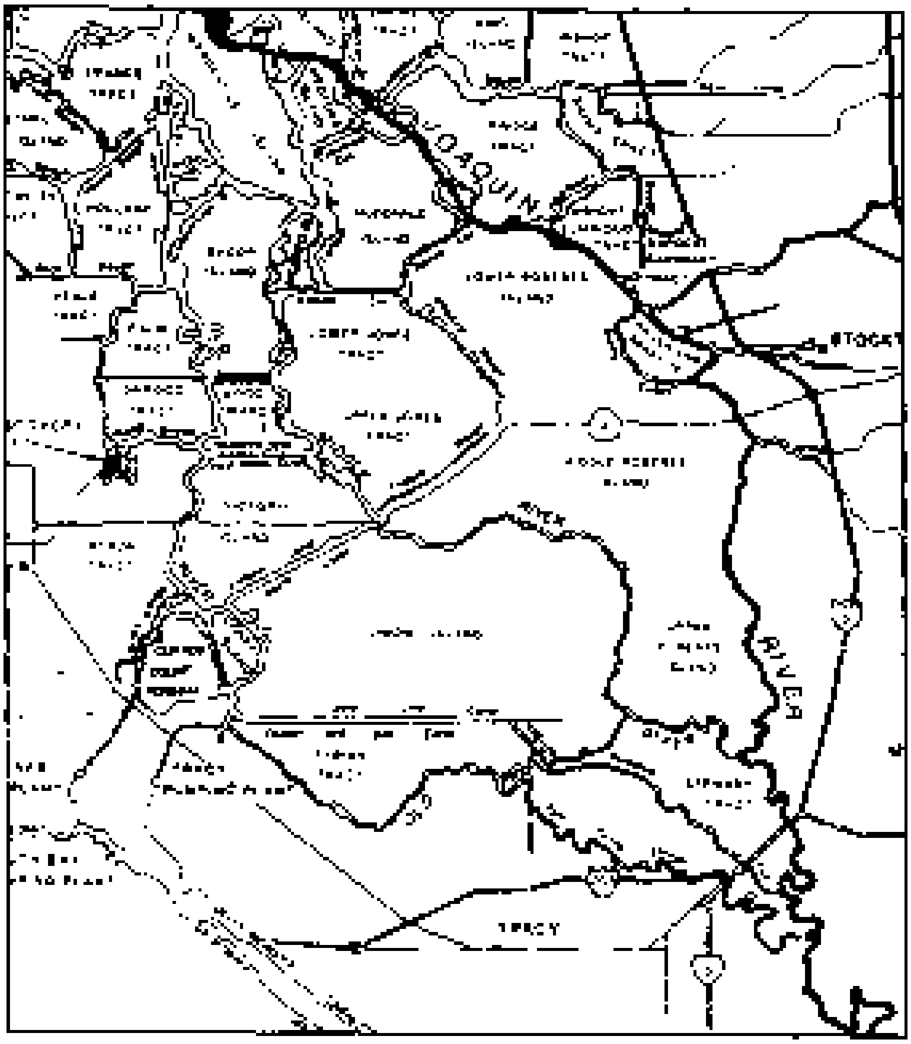


Figure 6. Vicinity Map of the South Delta

which is filled on a tidal basis. Tidal operation of Clifton Court tends to maximize the influence of the Sacramento River and thus provides somewhat better mineral quality by limiting the influence of the San Joaquin River.

Most of the water diverted through the CVP in the Delta is used for irrigation in the San Joaquin River watershed. Farmers must manage salt to avoid a buildup in the soil sufficient to cause plant toxicity. It is therefore necessary to leach salt from the soils, and this activity results in saline agricultural drainage. Drainage is discharged to the San Joaquin River, which is currently the conduit for removal of salt from the San Joaquin River watershed.

Diversion of San Joaquin River water into CVP pumps and return of agricultural drainage through the San Joaquin River creates a cycle by which salts are moved from the Delta into the San Joaquin Valley, back to the Delta, and back to the valley again. Therefore, some of the salt and bromide load leaving the valley through the San Joaquin River was introduced to the valley from the Delta as a result of sea water intrusion. This component of the bromide load would be significantly affected by the choice of storage and conveyance alternatives.

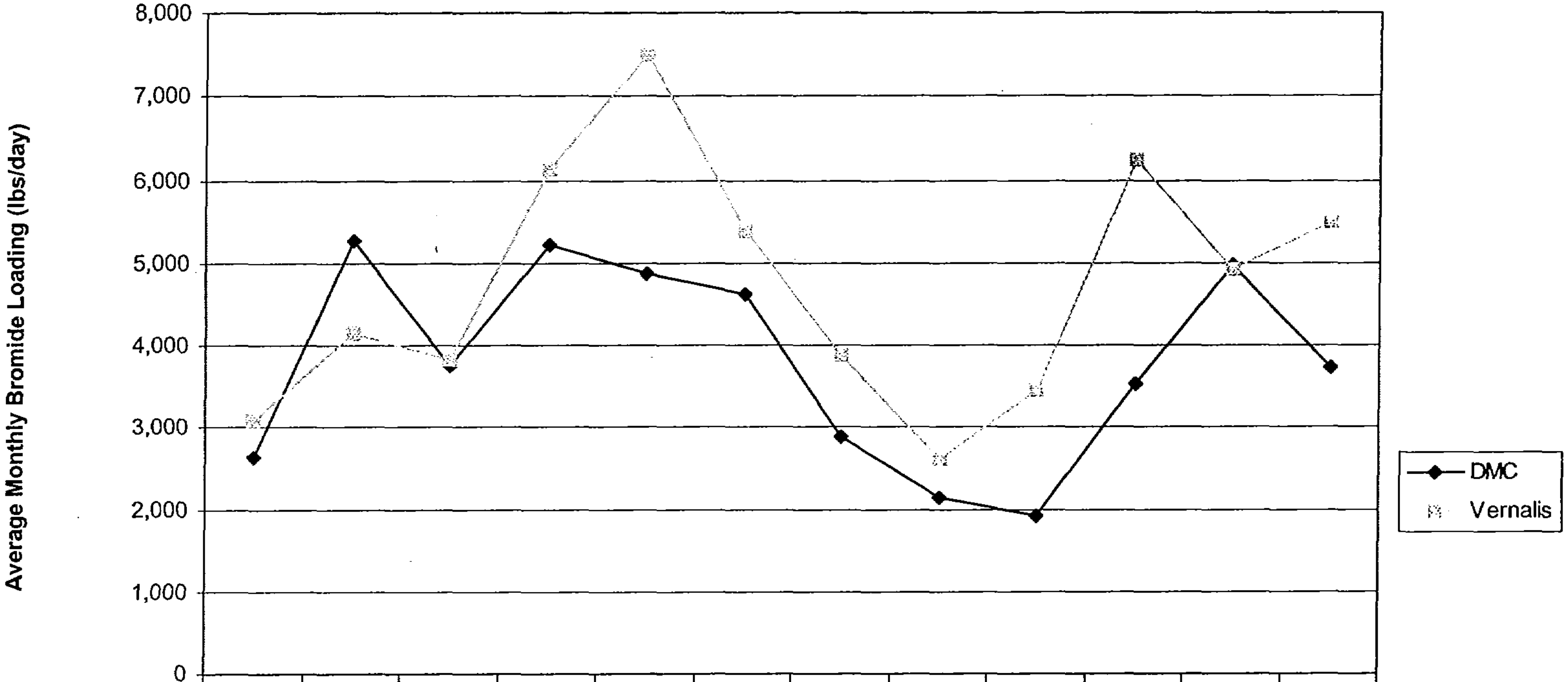
Diversion of San Joaquin River water into CVP pumps and return of agricultural drainage through the San Joaquin River creates a cycle by which salts are moved from the Delta into the San Joaquin Valley, back to the Delta, and back to the valley again.

A question of great importance to the CALFED Water Quality Program is how much of the bromide load in the San Joaquin River is not of Delta or ocean origin. A preliminary answer to this question can provide a basis for realistic expectations as to what amount of benefit can be achieved through actions along the San Joaquin River, and can help to identify priorities for water quality actions to be taken during the first stage of program implementation.

Using flow data from the USGS and bromide data from DWR's MWQI Program, daily bromide loads were computed for the DMC at the Tracy Pumping Plant and for the San Joaquin River near Vernalis (near the point where the river flows into the Delta). Daily loads were averaged by month and are depicted in Figure 7.

Overall, the bromide load entering the San Joaquin Valley through the DMC was computed to be about 80% of the loading appearing in the San Joaquin River near Vernalis. The period of record for this analysis is January 1990 to September 1996. Loading calculations were made using the average daily flows on the days samples were taken.

The ratio of bromide to chloride in sea water has been found to be constant at 0.0034. A useful way of evaluating bromide sources in the Delta is to examine the association with chloride. Based on data collected through DWR's MWQI Program, the bromide to chloride ratio in the DMC and San Joaquin River are 0.0032 and 0.0031, respectively. These data indicate strong sea-water influence.



Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
DMC	2,623	5,260	3,758	5,205	4,878	4,612	2,875	2,133	1,907	3,540	4,957	3,737
Vernalis	3,089	4,138	3,817	6,125	7,501	5,403	3,870	2,607	3,450	6,236	4,912	5,492

Month

Figure 7. Bromide Loadings at the Delta-Mendota Canal and the San Joaquin River at Vernalis

Taken together, the relative loads of bromide in the system and the ionic ratios clearly indicate that most of the bromide load appearing in the San Joaquin River is from sea-water intrusion.

Taken together, the relative loads of bromide in the system and the ionic ratios clearly indicate that most of the bromide load appearing in the San Joaquin River is from sea-water intrusion.

While it may be true that most of the bromide coming from the San Joaquin Valley is a result of sea-water intrusion, it has also been suggested that additional bromide loading in the San Joaquin River watershed may be a factor. The use of bromide in agriculture has been hypothesized to be a significant source. Methyl bromide is used in the San Joaquin Valley as a soil fumigant. Based on usage data derived from the California Department of Pesticide Regulation (DPR), an average of about 400,000 pounds of active ingredient were used on soils annually in Madera, Mariposa, Merced, San Joaquin, and Stanislaus Counties from 1992 to 1995. Some proportion of this poundage could presumably have been converted to bromide and migrated to the San Joaquin River.

The lack of an evident ratio shift indicates that bromide from methyl bromide use is not an important source of bromide loading in the system.

Based on 135 bromide samples collected between 1990 and 1998 and subjected to quality control-quality assurance procedures by DWR, the ratio of bromide to chloride has not varied significantly from the sea-water ratio. If methyl bromide were a significant contributor of bromide to the river system, the bromide to chloride ratio should be higher, as bromide from this source would not be accompanied with additions of chloride. The lack of an evident ratio shift indicates that bromide from methyl bromide use is not an important source of bromide loading in the system. Use of methyl bromide for soil fumigation is expected to end in 2005 by decree of the EPA. San Luis Reservoir is another hypothesized source of bromide in water supplies delivered to the South Bay and Southern California. According to this hypothesis, geological strata in the reservoir or in its watershed may be a source of bromide that is leached into the water, then transported to South Bay and Southern California municipalities.

Figure 8 depicts the vicinity of San Luis Reservoir. San Luis Reservoir is a shared facility, 60% of which belongs to the CVP and the remainder to the SWP. Water enters the reservoir from O'Neill Forebay. Water flows out of the reservoir through the Santa Clara Valley Water District (SCVWD) intake facility on the west side of the reservoir. The San Luis Pumping/Generating Plant, located between O'Neill Forebay and San Luis Reservoir, permits bidirectional flow. Therefore, the reservoir also releases to O'Neill Forebay. Water enters O'Neill Forebay from Check 12 of the California Aqueduct, located on the north side of the forebay. CVP water enters the forebay through O'Neill Pumping Plant, which connects the DMC to O'Neill Forebay and is located on the northeast side of the forebay. Water leaves O'Neill Forebay either to San Luis Reservoir or to the San Luis Canal through Check 13, located on the southeast of the forebay. Both federal and state water flows out through Check 13.

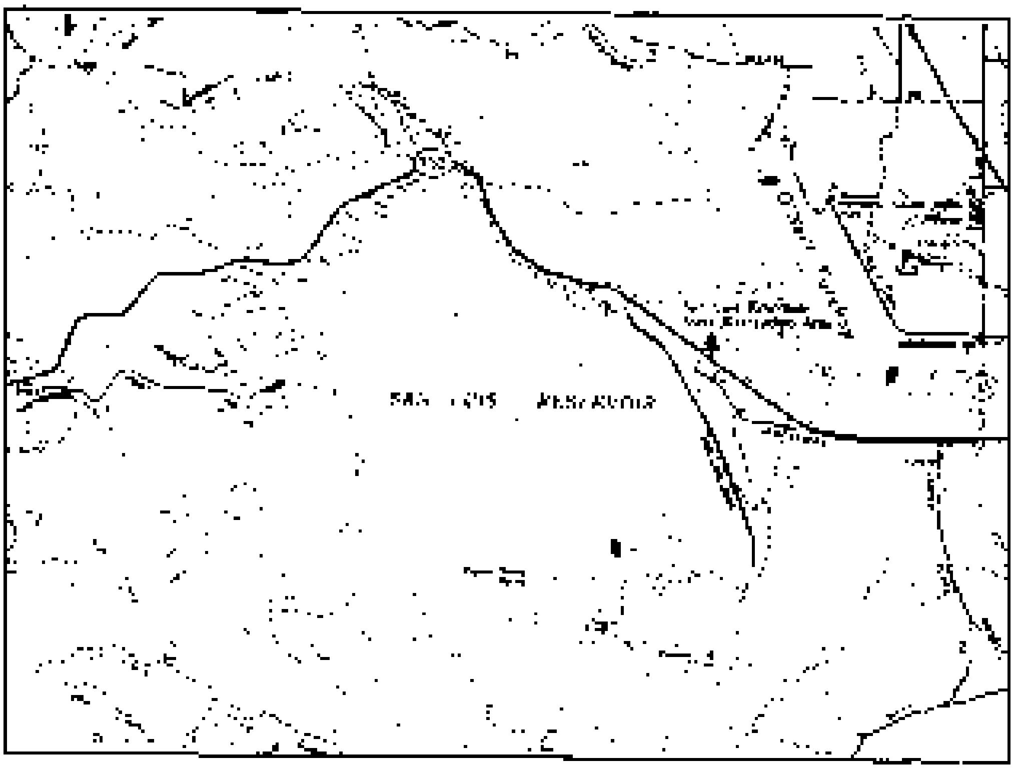


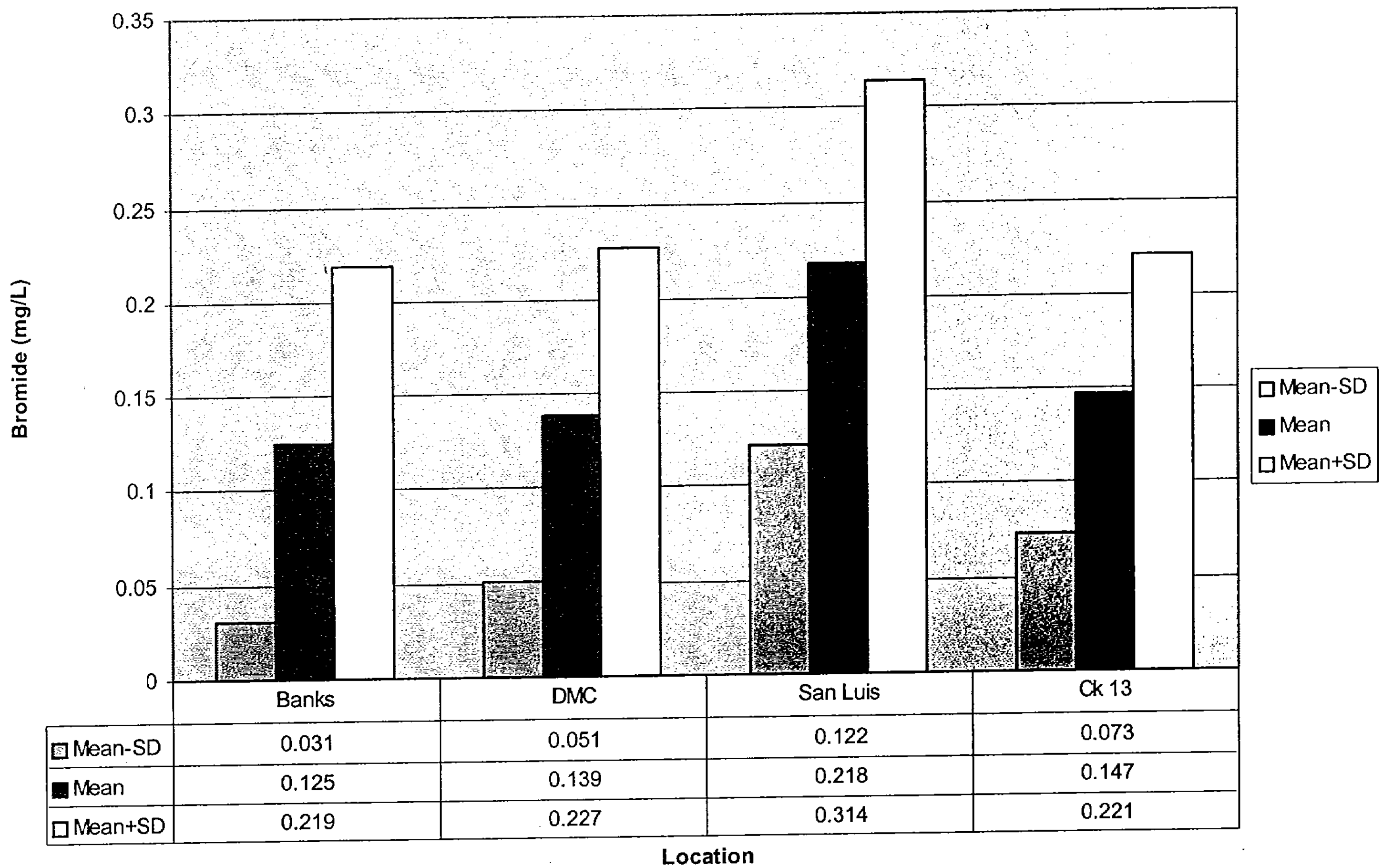
Figure 8. Vicinity Map of the San Luis Reservoir

Figure 9 depicts bromide concentrations measured at various points in the San Luis Reservoir vicinity from 1994 to January 1995. The Harvey O. Banks Pumping Plant location represents bromide in SWP water entering the forebay, DMC represents bromide entering O'Neill Forebay through the DMC, San Luis reflects bromide concentrations in San Luis Reservoir water delivered to the SCVWD, and Check 13 represents bromide in water leaving O'Neill Forebay on its way to Southern California. Water flowing through Check 13 contains a mixture of SWP, CVP, and San Luis Reservoir water. Bromide concentrations in San Luis Reservoir were measured as somewhat higher than those found in either the SWP or DMC inflows. This effect appears to be reflected in marginally higher bromide concentrations of water flowing through Check 13. These increases are not pronounced, however, and may be due to the concentrating effect of evaporation in the reservoir and to filling the reservoir with water having elevated bromide concentrations. An additional consideration is that the San Luis Reservoir data were produced by SCVWD, whereas the other data were produced by DWR. Although the data from both sources appear reasonable, further evaluation will be needed to determine whether the data from these sources are strictly comparable. Potential sources of error may include use of different analytical instruments and different sampling dates.

Empire Tract in the Delta is known to contain bromide in groundwater that is thought to be of connate (ancient sea water) origin. Drainage from Empire Tract has been measured to contain bromide ranging from 0.40 to 2.5 mg/l, as compared to nearby King Island where bromide ranged from 0.09 to 0.11 mg/l. According to data from a 1990 DWR report that were analyzed by MWD, drainage from Empire Tract accounts for less than 3% of the total drainage volume from Delta lowlands, and the contribution of bromide from this source is minimal in comparison to other sources. Figure 10 summarizes the results of this analysis.

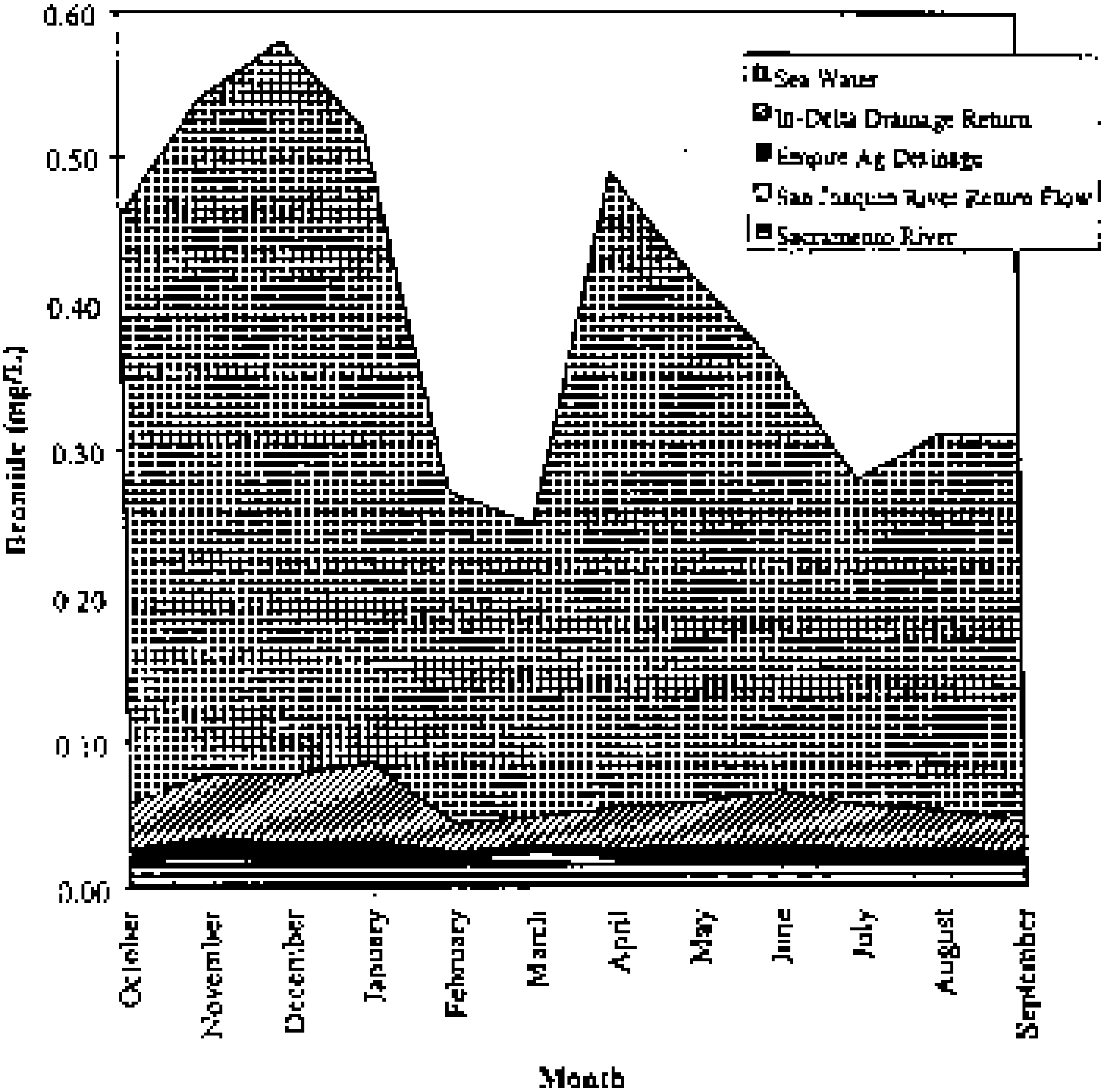
3.7.2 *Organic Carbon*

Figure 11 depicts organic carbon concentrations at selected Delta locations, as measured by DWR's MWQI Program. The presence of organic carbon in waters diverted through the NBA is a particular cause of concern and is discussed specifically in Section 3.6.3 of this report. The discussion centers on developing a reasonable expectation of what might be done to control organic carbon concentrations in waters diverted from the south Delta, exclusive of the storage and conveyance options chosen for the CALFED Program. MWD estimates that the CALFED alternatives could result in the following organic carbon concentrations in water exported from the Delta through the Harvey O. Banks Pumping Plant.



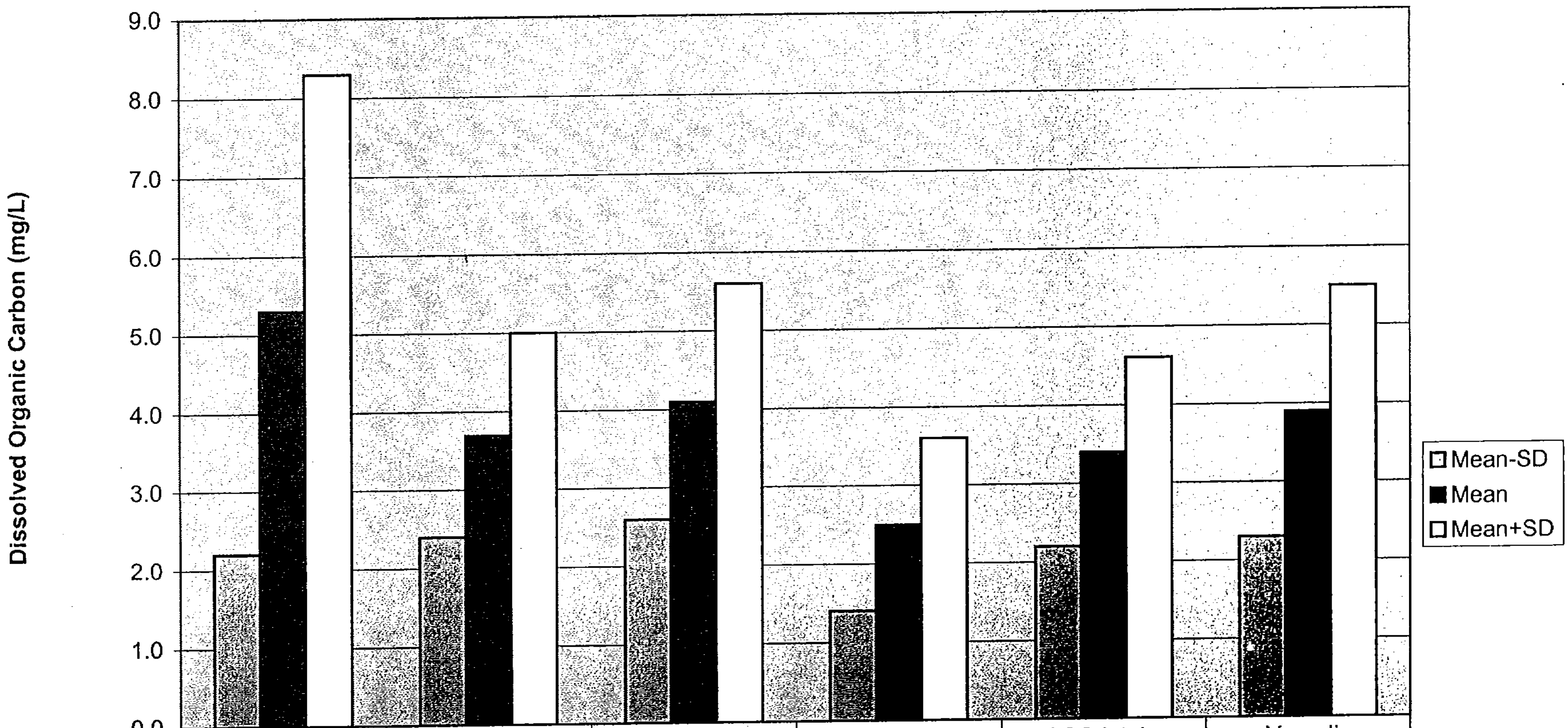
	Banks	DMC	San Luis	Ck 13
Mean-SD	0.031	0.051	0.122	0.073
Mean	0.125	0.139	0.218	0.147
Mean+SD	0.219	0.227	0.314	0.221

Figure 9. Bromide in the San Luis Reservoir Area



Source: Metropolitan Water District of Southern California. Based on bromide samples collected in calendar year 1990.

Figure 10. Possible Contribution of Bromide at Banks Pumping Plant from Several Sources



	North Bay PP	Banks	DMC	Greenes	CCC Intake	Vernalis
Mean-SD	2.2	2.4	2.6	1.4	2.2	2.3
Mean	5.3	3.7	4.1	2.5	3.4	3.9
Mean+SD	8.3	5.0	5.6	3.6	4.6	5.5

Location

Figure 11. Organic Carbon at Selected Delta Locations

Estimated Organic Carbon Concentrations in Water Exported from the Delta through Banks Pumping Plant Associated with the CALFED Program Alternatives

Alternative	Median Organic Carbon (mg/l)	90th Percentile Organic Carbon (mg/l)
No Action	3.2	3.8
1	3.1	3.4
2	3.1	3.7
3	2.5	2.9

Notes: The median organic concentrations can be achieved half of the time, while the 90th percentile numbers represent the organic carbon concentrations that would be achieved 90% of the time.

DWR estimated that drainage from Delta islands during April through August contributed 40–45% of the organic carbon fraction with the capacity to form DBPs in Delta source waters. The estimate for the November through February drainage period was 38–52%. (The estimate was based on water year 1988.) While this estimate can be in error to some degree, it indicates that drainage from Delta islands may be responsible for most of the increase that is seen as water flows through the Delta. Control of organic carbon at the source would, therefore, seem to offer the theoretical prospect of producing results similar to construction of a new canal, with respect to organic carbon.

Control of organic carbon at the source would seem to offer the theoretical prospect of producing results similar to construction of a new canal, with respect to organic carbon.

DWR has undertaken a preliminary evaluation of the feasibility of treating Delta island drainage for organic carbon removal. This evaluation indicates that removal of about 60% of the organic carbon in island drainage through conventional processes may be technically feasible. Although fairly costly, such treatment could perhaps prove to be economically feasible, depending on the comparative cost of addressing the problem in other ways.

In its recent report, CUWA concluded that attaining a 3.0 mg/l or better organic carbon concentration in source waters from the Delta is a desirable objective for enabling current and prospective drinking water standards to be met, assuming that a bromide goal of 50 µg/l also could be met. Although it is probably not practical to treat all Delta drainage for organic carbon removal, it appears theoretically possible to use island drainage treatment to a degree sufficient to meet the CUWA objective independent of the selection of storage and conveyance alternatives. Because the results of the preliminary treatment study have not been verified with pilot-scale testing and feasibility and because adequate cost analyses have not been completed, it would be premature to conclude that this option is workable. Also, treatment to remove organic carbon would not affect bromide.

This approach may not be practical if CALFED actions to restore the aquatic ecosystem result in new inputs of organic carbon to the system. Treatment options and the TOC consequences of ecosystem restoration actions are topics for further study.

3.7.3 Conclusions

Based on this preliminary analysis, it appears unlikely that Water Quality Program actions, short of drainage treatment, can be expected to greatly reduce bromide or organic carbon concentrations in drinking water supplies from the Delta. Both organic carbon and bromide might be subject to control by drainage treatment if the technology can be proven and if it can be made economically feasible. These conclusions must, however, be proven through further detailed analysis.

> Based on this preliminary analysis, it appears unlikely that Water Quality Program actions, short of drainage treatment, can be expected to greatly reduce bromide or organic carbon concentrations in drinking water supplies from the Delta.

3.7.4 Recommendations

The above analyses of bromide and organic carbon sources suggest the following recommendations for further study and action in the first stage of program implementation:

1. Perform a more thorough evaluation of sources of bromide in the San Joaquin River, including:

   (a) "Fingerprinting" sources, using water quality characteristics such as ionic and isotopic ratios.

   (b) Determining the fate and transport of methyl bromide in the San Joaquin Valley as related to conversion to bromide and mobility into the San Joaquin River system.

2. Further evaluate the causes of increased bromide in San Luis Reservoir by quantifying the effects of evaporation and timing of reservoir filling. Also, determine whether a significant unidentified source of bromide exists.

3. Quantify the importance of connate groundwater on Empire Tract and adjacent islands. Additional sampling and analysis may be required.

4. Conduct inter laboratory comparative studies to demonstrate that DWR, SCVWD, MWD, Lawrence Berkeley Laboratory, and other laboratories performing bromide analyses of Delta water are able to produce comparable data.

5. Perform further feasibility evaluations for treating Delta island drainage to remove TOC and, if favorable, initiate a pilot-scale field evaluation of treatment feasibility. (Refer to earlier discussion on page 3-14.)

6. Perform pilot studies to determine the feasibility of managing or relocating island drains to reduce TOC and the pathogen impacts on drinking water intakes. (Refer to earlier discussions on page 3-14.)

7. Track public health effects studies to more specifically identify the potential health effects of bromide-related DBPs.

8. Investigate alternative sources of high-quality water supply for urban users of Delta water. Capture more drinking water during periods of high Delta water quality.

9. Evaluate alternative approaches to drinking water treatment, to address growing concerns over DBPs and salinity. Approaches to include technologies for the removal of pathogens from urban water supplies.

10. Investigate combinations of new supplies, operational changes, and technological changes that can minimize salt content of urban drinking water supplies and provide continuously greater public health protection.

11. Convene an expert panel in a public forum to make recommendations to the governing entity regarding solutions to identified public health issues for urban users of Delta water.

12. Develop a plan sufficient to meet forthcoming EPA and DHS standards for brominated and chlorinated DBPs.

13. Support the ongoing efforts of the Delta Drinking Water Council and its technical work groups. Specific actions include:

    - The Council will complete its initial assessment of progress toward meeting CALFED water quality targets and alternative treatment technologies by the end of 2003.

    - The Council will complete its final assessment and submit final recommendations on progress toward meeting CALFED water quality targets and alternative treatment technologies by the end of 2007.

14. Reduce contaminants and salinity that impair Delta water quality.

15. Enable voluntary exchanges or purchases of high-quality source waters for drinking water uses.

Undertaking these actions in the first stage of CALFED Program implementation will develop the information necessary to institute prevention and control activities but will not result in immediate water quality improvement.

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4. MERCURY

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4.1 SUMMARY

Mercury levels of certain species of fish in the Delta and San Francisco Bay are at sufficient concentrations to warrant fish advisories for human consumption. The mercury that has accumulated in the Delta and Bay, and continues to accumulate, may also be adversely affecting wildlife, both aquatic and terrestrial.

Mercury levels of certain species of fish in the Delta and San Francisco Bay are at sufficient concentrations to warrant fish advisories for human consumption.

Information should be developed to document current mercury levels in water, sediment, and fish throughout the Bay, Delta, San Joaquin and Sacramento Rivers, Cache Creek, and other tributaries. This information can be used to assess mercury bioaccumulation in wildlife (especially sport fish), human exposure, and the ecologic and human impacts of mercury bioaccumulation. Documentation also could identify mercury sources and their remediation potential. Documentation would require a comprehensive monitoring program that should address the loadings and sources of total and methyl mercury, the amounts of sediment-carried mercury transported throughout the system, the forms and bioavailability of this mercury, and the concentrations of mercury in fish or other bioindicator species. This approach is needed to document the current status of mercury contamination in this system, as well as to provide a means to quantify the success of remediation efforts. In addition, a common database of existing mercury data, newly acquired mercury data, geographic spatial information, and accurate fate and mobility models are necessary to store and use the data as a basis for mercury management or other decisions affecting water quality.

The mercury issue is complex. For example, the total load of mercury is only one of several considerations for exposure assessment and cost effective remediation. Studies are needed to address the current status of the processes (e.g., methylation) affecting mercury transformation and bioaccumulation in the Bay-Delta region. These studies need to address the source and forms of mercury currently transported in the Bay-Delta and whether or where they are bioavailable. These studies will provide a basis to prioritize remediation or clean-up of the sources of mercury that are currently leading to excessive bioaccumulation of mercury

4.2 Problem Statement

Water quality problems associated with mercury occur on a global basis. The most serious problems, with respect to human health, occur when mercury accumulates in edible aquatic organisms. Mercury can be transported through the atmosphere from various emissions, such as power plants, or can enter aquatic systems in runoff from mining operations or in runoff from natural geological sources. A number of mercury sources are present in California, including mining, atmospheric, and geological.

Mercury has been found throughout the San Francisco Bay-Delta estuary at elevated concentrations in water, sediment, and organisms. Mercury is of concern from both an environmental and human health perspective. Effects on fish include death, reduced reproductive success, impaired growth and development, and behavior abnormalities. Mercury exposure in birds can cause reproductive effects, and in plants can cause death and sublethal effects. The direct and additive effects of mercury within the estuary on reproduction, development, and juvenile survival of aquatic and aquatic-feeding species are poorly understood.

> Mercury has been found throughout the San Francisco Bay-Delta estuary at elevated concentrations in water, sediment, and organisms.

In general, mercury concentrates through aquatic food chains such that organisms in higher trophic levels accumulate higher mercury concentrations. Fish found at the top of the food web can exhibit mercury tissue concentrations over 1 million times the mercury concentration of the surrounding water. High mercury levels in sport fish have culminated in consumption advisories in which some consumers are advised to not eat these fish. Mercury (in the form of methyl mercury) poses a serious concern to human health as it accumulates in tissue, bioaccumulates within the food web, and is a potent neurotoxin in humans. Mercury can cause nervous system damage in developing fetuses, as well as in children and adults.

4.3 Objective

The objective is to reduce mercury in water and sediment to levels that do not adversely affect aquatic organisms, wildlife, and human health.

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4.4 PROBLEM DESCRIPTION

In 1971, DHS issued a health advisory recommending that pregnant women and children should not consume striped bass taken from the Bay-Delta estuary due to high mercury levels.

A 1994 fish tissue contamination study in the Bay revealed mercury concentrations in fish tissue in species other than striped bass that were of concern to human health. Based on evaluation of the results of this study (including levels of other contaminants of concern), in December 1994, the California Office of Environmental Health Hazard Assessment (OEHHA) issued advisories concerning consumption of fish caught from the Bay. Specifically, adults were advised to limit consumption of sport fish from the Bay to two times a month, and pregnant or nursing women and children 6 or under were advised to limit consumption to one time a month. Further, the advisory recommended that large shark and striped bass from the Bay should not be consumed at all.

The SWRCB's biennial water quality assessment lists 48,000 acres of Delta waterways as impaired because of fish consumption advisories for mercury. Water bodies (or segments) included on the CWA Section 303(d) impaired water bodies list due to mercury levels include: (1) in Delta waterways, Marsh Creek; (2) in the Sacramento River watershed, the lower American River, Cache Creek, the lower Feather River, Harley Gulch, Humbug Creek, the Sacramento River (from Red Bluff downstream to the Delta), Sacramento Slough, and Sulfur Creek; and (3) in the San Joaquin watershed, Panoche Creek, Salt Slough, and San Carlos Creek.

> The SWRCB's biennial water quality assessment lists 48,000 acres of Delta waterways as impaired because of fish consumption advisories for mercury.

In general, large-scale, systematic sampling of a variety of fish species has not been conducted in the Bay, the Delta, or in the Sacramento and San Joaquin River Basins. Proper protection of the public from mercury contamination requires comprehensive studies of sport fish species that are commonly caught and consumed in the Delta estuary. These studies should include monitoring the levels of mercury contamination in different species through several flow cycles at multiple sites in these waterways. The studies can be used to evaluate the public health risks of consuming different species at different sites throughout the region and to prioritize cleanup and remediation options. Comprehensive studies that can be used in a health evaluation also have not been conducted.

Elevated mercury levels also may have lasting effects on habitat and ecology in these waterways. In 1986, the CVRWQCB surveyed mercury contamination in fish and sediment in the Sacramento River watershed. The survey detected elevated mercury levels in sediment in the Yuba and Bear Rivers and in Cache, Putah, and Stony Creeks. Ongoing research by UC Davis has confirmed these streams as among those with the highest levels of bioavailable mercury, as measured with in-stream bioindicator organisms. Recent sampling by the USGS National Water Quality Assessment (NAWQA) Program has confirmed that elevated concentrations are still present in the sediments of the Yuba and Bear Rivers and in Cache Creek, as well as in the sediments of other streams and rivers in the Sacramento River Basin. Fish captured in certain tributaries contained mercury levels that exceeded the 1973 National Academy of Sciences guidelines to protect aquatic resources and their predators. The CVRWQCB also has determined that mercury has caused the impairment of aquatic habitat beneficial use of the Sacramento River between the Colusa Basin Drain and the Delta.

A 1997 report containing survey results of bioavailable mercury throughout the northwestern Sierra Nevada (the Feather River south to the Cosumnes River) found the most highly elevated mercury levels in the aquatic food webs of the South and Middle Forks of the Yuba River, the North Fork of the Cosumnes River, tributaries throughout the Bear River drainage, the mid-section of the Middle Fork of the Feather River, and Deer Creek. Similar surveys of mercury levels in sediment and their bioavailability to aquatic bioindicator organisms and wildlife should be extended throughout the Delta estuary. Such surveys will enable a full assessment of ecologic risks and facilitate prioritizing cleanup and remediation options.

4.4.1 Sources and Transport of Mercury

Natural sources of mercury include volcanic releases, forest fires, and oceanic releases into the atmosphere. Little is known about the relative contribution from natural sources of mercury to the estuary.

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There is a wide assortment of anthropogenic sources of mercury. Mercury has been used globally in many industrial, agricultural, and domestic applications. For example, mercury is used in such products and processes as barometers, thermometers, mercury arc lamps, switches, fluorescent lamps, sensors, catalysts for oxidizing organic compounds, gold and silver extraction from ores, rectifiers, and cathodes in electrolysis/electroanalysis; in the generation of chlorine and caustic paper processing, batteries, and dental amalgams, as laboratory reagents, lubricants, caulks, and coatings; in pharmaceuticals as a slimicide; and in dyes, wood preservatives, floor wax, furniture polish, fabric softeners, and chlorine bleach. Human-related sources of mercury include fossil fuel combustion, production of chlorine and caustic soda at chlor-alkali plants, waste incineration, cremation, industrial discharges flowing through sewage treatment plants, mines and mining activities, smelters, and mercury spills from naval vessels.

Mining-related activities are known to be a significant anthropogenic source of mercury within the estuary. The California Coast Ranges, on the west side of the Sacramento Valley, contain a large deposit of cinnabar; mines in this area supplied the majority of mined mercury in the United States. During the late 1800s and early 1900s, mercury was intensively mined from the Coast Ranges and subsequently transported across the Central Valley to the Sierra Nevada for use in placer gold mining operations. The majority of Coast Ranges mercury mines are now abandoned and remain unreclaimed. Some of the best known mercury mines are found in the Cache Creek and Lake Berryessa drainages in the Sacramento River watershed, in the San Joaquin River watershed, in the Marsh Creek watershed in the Delta (Mount Diablo Mine), in the South Bay watershed (New Almaden mining district), and in Panoche Creek (draining to the San Joaquin River from the New Idria mercury mining district). In addition to the active and abandoned mercury mines, many unmined mercury deposits (in the form of cinnabar or HgS) are found throughout the Coast Ranges. Natural springs occurring in the Coast Ranges also discharge mercury that has been mobilized by geothermal processes.

Mining-related activities are known to be a significant anthropogenic source of mercury within the estuary.

The mercury used in gold mining in the Sierra Nevada was refined liquid quicksilver or elemental mercury. Virtually all of the mercury brought to the Sierra Nevada for gold mining was ultimately lost into Sierran watersheds; once back in the environment, this elemental mercury likely underwent various transformations into different forms. The CVRWQCB has estimated that approximately 7,600 tons of refined quicksilver were deposited in the Mother Lode region alone during the Gold Rush mining era. Mercury also was used in the northwestern and central Sierra Nevada for gold mining.

Much of the mercury used in gold mining could have been incorporated into the 13 billion cubic meters of sediments extracted by mining activities and released to the rivers of the Bay-Delta watershed. Studies by UC Davis and, more recently, by USGS show that the sediments mobilized by hydraulic mining ultimately were transported to the Bay-Delta, where they formed marshes and islands, or were deposited in shallow-water sediments. Some of these potentially mercury-contaminated areas now are being considered for habitat restoration through CALFED's Ecosystem Restoration Program. USGS studies show that mercury concentrations in Bay sediments containing hydraulic mining debris range from 0.3 to 1 μg/g. More importantly, these sediments contain mercury in its most reactive forms, including methyl mercury.

Recent studies suggest that the Coast Ranges may be a more significant contributor of mercury loadings to Central Valley rivers and the estuary than the Sierra Nevada. However, the relative contribution of these loads (dominated by cinnabar minerals) to mercury bioaccumulation, compared to the possibly more reactive mercury from the Sierra side of the valley (dominated by elemental mercury from placer gold mining) is unknown. Additional mercury may be introduced by industrial processes or runoff in urban centers.

Monitoring indicates that significant loading of metals to the estuary occurs during high-flow conditions. Sampling in the Sacramento River performed by the CVRWQCB in January 1995 during a peak storm period detected high mercury concentrations in the Yolo Bypass. (Water from the Sacramento Valley entered the estuary via both the Sacramento River and the Yolo Bypass during this storm period.) Further investigation determined that Cache Creek (which drains Clear Lake, an area with several mercury mines) appears to be a significant source of mercury discharging into the Yolo Bypass (and ultimately into the Delta) during heavy runoff events. Cache Creek was estimated to have exported approximately 1,000 kilograms (kg) of mercury to the estuary in 1995. Long-term, quantitative studies by UC Davis of just one tributary of Cache Creek (Davis Creek) have found annual loadings of 180-250 kg per year of newly deposited mercury. High mercury levels also were found in the Sacramento River upstream of the confluence with the Feather River. In addition, recent work by consultants to the Sacramento County Sanitation District, and confirmed by subsequent sampling by the USGS, has shown that an unknown source of mercury is present somewhere between Red Bluff and Colusa, and that the loading from this source following stormwater runoff is significant. The source and form of this mercury is unknown. Sampling by the USGS NAWQA program at the Yolo Bypass during the 1997 flood showed that the loading of mercury to estuary was approximately 32 kg per day at peak discharge. In contrast, mercury loadings to the Bay from the Sacramento River during the dry season are approximately 0.2 kg per day.

Monitoring indicates that significant loading of metals to the estuary occurs during high-flow conditions.

Marsh Creek is another watershed in Contra Costa County with high mercury levels. Studies conducted in 1995 through 1997 determined that this relatively small watershed exported 10-20 grams of mercury per day, with greater amounts during storm events. These studies also found that approximately 95% of the mercury load of the entire extended watershed originated from the Mount Diablo Mine area, with 89% coming from a highly localized area of exposed mine tailings. Although considerably less than the Cache Creek loads, virtually all of the mercury load derived from the Mount Diablo mercury mine was found to originate in dissolved form, presumably highly available for microbial methylation, and ultimate movement and bioconcentration into the food web. Also notable was the finding that, although geologically naturally enriched in mercury, the natural watershed did not contribute significantly to the mobilized, annual storm-associated loadings of mercury. Mine wastes were found to greatly dominate the overall loading.

Mercury transported from these watersheds is deposited in the Bay-Delta. Depositional areas ranging from the Yolo Bypass to Suisun Marsh have the potential to be important sources of mercury methylation. These areas may be a more significant source of the methyl mercury found in fish than the new mercury coming from the mines. Mercury in sediment may be resuspended through bioturbation, wave action, dredging activities and disposal, and flooding of lands. The chemical form of mercury in the sediment and environmental conditions at the time of release will affect the bioavailability of the reintroduced mercury.

Bulk mercury contamination is extensive on both sides of the Central Valley, primarily widely scattered hydraulic mining debris on the east side, and active and abandoned mines and associated debris piles on the west side. Cumulatively, these activities have resulted in the ongoing deposition of significant amounts of mercury in sediments of the Bay-Delta system.

In summary, bulk mercury contamination is extensive on both sides of the Central Valley, primarily widely scattered hydraulic mining debris on the east side, and active and abandoned mines and associated debris piles on the west side. Cumulatively, these activities have resulted in the ongoing deposition of significant amounts of mercury in sediments of the Bay-Delta system.

Bulk mercury contamination is extensive on both sides of the Central Valley, primarily widely scattered hydraulic mining debris on the east side, and active and abandoned mines and associated debris piles on the west side. Cumulatively, these activities have resulted in the on-going deposition of significant amounts of mercury in sediments of the Bay-Delta system.

Determining the relative contributions of the various sources (mercury mines, hydraulic mining debris, and recycling from depositional areas) to the primary problem (methyl mercury in fish) is essential before cost-effective solutions to the region's mercury problems can be developed.

4.4.2 Transformation and Bioavailability of Mercury

Mercury occurs naturally within the environment in a variety of forms, including elemental mercury ($Hg(0)$ or quicksilver); dissolved in rainwater (Hg^{2+}); as the ore, cinnabar (HgS); and as methyl mercury ($HgCH_3$), an organo-metal. Mercury can undergo biological and chemical reactions that cause it to change form and alter its solubility, toxicity, and bioavailability. Toxicity depends primarily on the particular form of mercury. Methyl mercury is the most toxic form of mercury to animals and humans, and is created in the environment by microbes under appropriate conditions.

Methylation of mercury is a key step enabling the entrance of mercury into food chains. Nearly 100% of the mercury that bioaccumulates in fish tissue is in the form of methyl mercury. The biotransformation of inorganic mercury into methylated organic mercury in water bodies occurs in both the sediment and the water column. Many factors affect the formation of methylated mercury, including pH, temperature, oxygen redox level, salinity, toxicity, rate of sediment deposition, rate of pore water diffusion (or the rate at which methyl mercury diffuses out of the sediment and into the water), rate of mercury deposition, species of mercury deposited, and the rate of methyl mercury removal by bioaccumulation and other biological processes including de-methylation

As stated above, the predominant form of mercury varies within the Delta estuary. Elemental mercury from gold mining activities is prevalent in drainage from the Sierra side of the valley, while cinnabar predominates in loadings from the Coast Ranges side of the valley. Determining the relative transformation and bioavailability of these different forms throughout the watershed, in addition to their sources and loadings, will be important for prioritizing remediation options. For example, recent water quality data indicate that a significant amount of mercury from the gold mining era still exists in the sediment of the Upper Yuba River watershed, which is then transported downstream into Englebright Reservoir, where it is largely contained. Bioavailability studies by UC Davis reveal that the reservoir intercepts both inorganic, sediment-based mercury as well as bioavailable methyl mercury. While elevated mercury levels have been found upstream and in the reservoir, aquatic organisms taken from below the dam consistently demonstrate lower levels of mercury than those organisms in the reservoir or upstream. This finding suggests that the reservoir serves as an interceptor of bioavailable mercury, preventing it from being transported downstream to the estuary. This finding also may indicate that much of the mercury in the Sierra Nevada remaining from gold mining activities, at least that originating upstream in dammed tributaries, may be trapped in foothill reservoirs and prevented from reaching the estuary. However, mercury bioaccumulation in these reservoirs may still pose localized health risks that should be evaluated.

Studies of mercury transformation, methylation, and bioavailability must be extended throughout the watershed and include the Bay-Delta. Research is needed to determine the methylation capability of Bay-Delta sediments, particularly those sediments that originated from hydraulic mining activities. Flooding or disturbing such sediments could inadvertently increase the amount of methyl mercury in the Bay ecosystem (i.e., uninformed restoration activities could augment the mercury contamination of Bay fish). Numerous instances of accelerated methylation have occurred when sediments were flooded for reservoirs elsewhere, even in the absence of the type of mercury contamination found in hydraulic mining debris.

Research is needed to determine the methylation capability of Bay-Delta sediments, particularly those sediments that originated from hydraulic mining activities.

4.5 APPROACH TO SOLUTION

4.5.1 *Priority Actions*

Since it is well documented that mercury is an important contaminant in the Bay-Delta estuary that can affect humans and wildlife, it is appropriate that a coordinated and well-planned effort be implemented to determine the extent of the problem and cost-effective solutions for remediation. This effort requires a broad step-wise approach. Initially, a thorough risk appraisal should be conducted for the Delta estuary, including the major rivers and their tributaries, to determine the extent of the problem and risks to humans and wildlife. A related assessment should be conducted to determine the major sources of mercury and to follow its transport and transformation to biologically available forms. The information gathered in these steps would be used to formulate a variety of remediation and risk management strategies and to increase public awareness and education. The next step would be to implement remediation strategies expected to result in the greatest short-term effect and follow these with longer term strategies. A final component of this approach would be to demonstrate the effect of the remediation strategies by showing a reduction in mercury loading, transport, transformation, bioavailability, and bioaccumulation. **No remedial activities on abandoned mine sites should be conducted without federal environmental "Good Samaritan" protection. Without this protection, acting CALFED agencies may become responsible parties for the abandoned sites.**

Initially, a thorough risk appraisal should be conducted for the Delta estuary, including the major rivers and their tributaries, to determine the extent of the problem and risks to humans and wildlife.

It is envisioned that this approach would involve three stages, as outlined below.

Stage I - Data Collection, Evaluation, Planning, and Remediation Demonstration (probably a 5-year approach)

Fish tissue monitoring for impacts on human health and wildlife

Evaluate existing fish tissue data for mercury, with a focus on the risks to humans and wildlife.

Identify data gaps and needs (e.g., multi-site, multi-species, and multi-year data) for fish tissue and wildlife monitoring.

Plan and undertake monitoring to fill data gaps.

Investigate fish consumption patterns (e.g., species) in the watershed to better characterize human exposure due to fish consumption.

Using new and existing data, evaluate human risks throughout the Delta estuary due to consumption of fish contaminated with mercury. Identify local versus widespread risks. Consider whether risks require local or widespread remediation efforts. Include evaluation of acceptable levels of mercury in sediment and water.

Using new and existing data, evaluate wildlife risks throughout the Delta estuary due to mercury contamination. Identify local versus widespread risks. Consider whether risks require local or widespread remediation efforts. Include evaluation of acceptable levels of mercury in sediment and water.

Source, transport, mine site inventory, and geological site inventory

Determine the loads and forms of mercury from an investigation of existing data and from new data collection activities.

Map locations of mercury mines and mercury prospects.

Map locations of geological sources of mercury, such as springs.

Identify urban inputs of mercury.

Categorize sources based on size, mercury loading, and clean up potential.

Transformation and bioavailability studies

Develop and undertake a set of studies of bioavailability and methylation to understand the specific geochemical and hydrological factors that contribute to the production of biologically available forms of mercury.

Develop and undertake a set of studies to understand the specific geochemical and hydrologic factors that contribute to demethylation or detoxification of mercury in the watershed.

Identify locations in the watershed with low and high bioavailability.

Develop a general or specific model of mercury transformation and bioavailability in the watershed.

Studies to determine relationship between mercury loads and mercury bioaccumulation

Develop and undertake a study of mercury bioaccumulation. This will require sampling multiple species and trophic levels in aquatic food webs. Identify potential indicator species that show major steps in the entry or accumulation of methyl mercury in food webs. These species may serve as target indicators to follow the effects of remediation.

Develop a general or specific model of bioaccumulation for sport fish species and wildlife.

Link models of mercury transformation and bioavailability to those of bioaccumulation in order to model the relationship between observed mercury loads and observed fish contamination for as much of the watershed as possible.

Refine new data collection activities to fill gaps in models. Test relationships between observed data and models.

Remediation demonstration

Develop a variety of remediation options and projects that are based on changing mercury loading, transport, transformation, or bioavailability for different sections of the watershed.

Use valid models to test the effects and time frame for various remediation options.

Evaluate and prioritize remediation options, based on feasibility, cost, expected results, and time frame.

Select and implement a remediation project(s) with a short term time frame for expected results.

Information management

All of the above activities will require the development of a centrally located database or the development of common standards for a database so that data from a variety of agencies can be merged for interpretation and used by all researchers and water quality managers.

A Geographic Information System (GIS) using readily available information software, such as Arcview, should be developed so that chemical and spatial information related to mercury management can be stored, retrieved, and used by researchers and water quality managers.

Public outreach

Continue and expand on stakeholder groups. Distribute information on new studies, health evaluations, and remediation efforts to local stakeholders and other interested parties.

Stage II - Expanded Remediation and Monitoring of Remediated Areas (a 3- to 5-year approach)

Remediation actions

Select and implement new remediation projects with expected results of intermediate or long term time frames.

Evaluate demonstration remediation actions for success.

Refine or verify models for mercury load and fish tissue concentrations using monitoring data generated below.

Update prioritization of remediation options based on monitoring results.

Fish tissue monitoring for impacts on human health and wildlife

Continue monitoring at fishing sites and especially above and below sites during and after remediation. This effort will be ongoing to determine mercury levels during remediation and post-remediation activities in order to evaluate the level of success of those activities.

Re-evaluate human health risks and wildlife impacts at remediated sites.

Monitoring major sources and transport of mercury

Continue monitoring sources and loads of mercury, including mercury in water and sediment. Include monitoring at sites during and after remediation, as well as at sites not yet being remediated. This monitoring is needed to evaluate the short- and long-term success of remediation actions.

Monitoring transformation, bioavailability, and bioaccumulation

At focused sites (such as source and sink areas) and at sites during and after remediation, monitor mercury transformation (e.g., methylation and demethylation), conditions affecting transformations, and bioavailability.

Monitor the mercury content of indicator species at the same sites as above.

Information management and public outreach

Continue the development and implementation of an information management, GIS, and public outreach database and activity programs.

Stage III - Long-Term Remediation and Monitoring of Remediated Areas
(a 3- to 5-year approach)

Fish tissue monitoring for impacts on human health and wildlife

Continue fish tissue monitoring with the ultimate goal of lifting advisories and preventing the implementation of new ones.

Monitor loads and forms of mercury in water and sediment with the expectation that concentrations, loads, and toxic forms will decrease due to remediation efforts.

Evaluate the success of all remedial activities.

Continue to maintain the information database and public outreach activities.

Remediation actions

Select and implement new remediation projects with expected results of longer term time frames.

Evaluate intermediate-term remediation actions for success.

Refine or verify models for mercury load and fish tissue concentrations using the monitoring data generated below.

Update prioritization of remediation options based on monitoring results. Prioritize newly discovered sources.

Fish tissue monitoring for human health and wildlife impacts

Continue monitoring at fishing sites and especially above and below sites during and after remediation. This effort will be ongoing to determine mercury levels during remediation and post-remediation activities in order to evaluate the level of success of these activities.

Reevaluate human health risks and wildlife impacts at remediated sites. Update public outreach and communication efforts to reflect changes in risk and impact.

Monitoring major sources and transport of mercury

Continue monitoring sources and loads of mercury, including mercury in water and sediment. Include monitoring at sites during and after remediation, as well as at sites not yet being remediated. This monitoring is needed to evaluate the short- and long-term success of remediation actions.

Monitoring transformation, bioavailability, and bioaccumulation

At focused sites (such as source and sink areas) and at sites during and after remediation, monitor mercury transformation (e.g., methylation and de-methylation), conditions affecting transformations, and bioavailability.

Monitor mercury content of indicator species at the same sites as above.

Refine models linking mercury loading and concentrations in fish and wildlife based on ongoing monitoring data.

Information management and public outreach

Maintain the information management system, GIS, and public outreach database.

Update the public outreach activities and program.

4.5.2 Information Needed

1. Identification of sources of mercury in the Cache Creek watershed and its potential to result in methylation, bioavailability, and ultimately bioaccumulation.

Cache Creek has been identified as a major source of total mercury to the Yolo Bypass and the Bay-Delta estuary. In 1995, for example, 1,000 kg of mercury was exported from the creek. Approximately 50% of this mercury was deposited in the Cache Creek Settling Basin, but the remainder was exported to the Yolo Bypass. However, less is known about specific sources of mercury within the Cache Creek watershed or the forms of that mercury and its potential to result in methylation, bioavailability, and ultimately bioaccumulation.

Cache Creek has been identified as a major source of total mercury to the Yolo Bypass and the Bay-Delta estuary.

Studies completed by UC Davis and a proposal submitted by the USGS have addressed or will address some of the issues concerning the bioavailability and bioaccumulation, and the sources and speciation of mercury in the Cache Creek watershed. However, these studies will not identify all sources and will not address all questions regarding the bioavailability of the mercury from those sources, or characterize the extent of mercury accumulation within aquatic organisms in the affected streams and downstream areas. Therefore, a logical sequence of steps designed to obtain the necessary information on the sources and biological effects of mercury is needed to provide water quality managers with sufficient information to plan effective remediation. These steps should include (1) studies of mercury occurrence and bioaccumulation in and downstream of the Cache Creek watershed; and (2) a monitoring program that will document the current status of mercury concentrations, the effects of any remediation activities, and the trends in mercury loadings over longer periods.

An initial mercury study should include an investigation of mercury concentrations and loads along the main stem of Cache Creek, during dry weather and during stormwater runoff conditions, followed by similar studies on specific creeks identified as possible sources of that mercury. The success of this approach will necessitate completion of concurrent studies on mercury speciation and methylation, and actual measurements of mercury in aquatic organisms along these spatial gradients. New gauging stations will need to be installed, and existing gauging stations will need to be maintained in order to accurately record discharges for calculating mercury loadings from these streams. Speciation studies include the fractionation of mercury collected from environmental samples, such as water, suspended sediment, and bed sediment according to size (dissolved, colloidal, or bulk sediment) and studies to show the mineralogical residence of the mercury. The mineralogical residence may be as cinnabar (mercury sulfide [HgS]); as mercury adsorbed to oxides of iron, manganese, or aluminum, adsorbed onto organic matter, as elemental mercury; or in other solid phases. It is expected that bioavailability is different for each of these types of mercury and may be different even for different size fractions. Therefore, bioavailability studies need to be completed on the various size fractions and mineralogical types.

Data indicating the concentrations and forms of mercury in water and sediments are useful to quantify loadings and to model or predict mercury bioavailability. However, direct measurements of mercury bioaccumulations (e.g., fish or invertebrate tissue residues) are necessary to complement these models and to validate predictions of bioavailability.

> Data indicating the concentrations and forms of mercury in water and sediments are useful to quantify loadings and to model or predict mercury bioavailability.

Because aquatic insects remain in limited geographic areas, data indicating their whole-body mercury residues may be used to locate and confirm sources of contamination in the watershed. These data also indicate year-to-year variations, which would make them useful for evaluating the effectiveness of future remedies undertaken in the watershed (e.g., reclamations of abandoned mercury mines).

Continued studies of mercury accumulations in fish also are needed in the Cache Creek watershed. Methyl mercury is known to biomagnify through aquatic food webs and become concentrated in fish. Recreationally sought-after species (e.g., catfish and bass) should be collected from areas heavily used by

> Continued studies of mercury accumulations in fish also are needed in the Cache Creek watershed.

the public (e.g., campgrounds and parks), and their muscle tissues should be analyzed for mercury. These data can be used in human health risk assessments.

Native fish, such as California roach, Sacramento sucker, and Sacramento pikeminnow (squawfish), should be collected throughout the watershed for determination of their whole-body residues of mercury. California roach are widely distributed because they tolerate the warmer temperatures and lower summer low flows that occur in upstream, unregulated tributaries. Sacramento pikeminnow (squawfish) are less widely distributed, and their abundance in Cache Creek may be reduced because of introduced fish such as carp and bass; but they are permanent residents of many stream segments. Pikeminnow are piscivorous (fish-eating) and prey on California roach; therefore, their body burdens are useful indicators of mercury biomagnification. Sacramento suckers are not piscivorous but are widely distributed, long-lived fish. These fish tissue residue data can be applied in an ecological risk assessment that estimates consumption-related hazards to fish-eating birds or mammals inhabiting the Cache Creek watershed.

Another priority is investigating the downstream impacts of mercury transported from the Cache Creek watershed, especially impacts in the Yolo Bypass region and the Yolo Wetlands, and in areas further downstream in the Delta and Bay. A number of issues are worthy of detailed study, including further investigation of the forms of mercury and its potential to be methylated. A recent composite bottom sediment sample collected by the USGS NAWQA Program in the Yolo Bypass between Woodland and Interstate 80 showed elevated concentrations of mercury (0.34 nanogram per gram [ng/g]). That level is similar to concentrations measured in sediments collected from Cache Creek near Rumsey. Since the Yolo Bypass and Bay-Delta region are different environments with different water chemistries relative to the Cache Creek Basin, the methylation processes and rates of methylation may be vastly different. Therefore, studies on mercury methylation and bioaccumulation completed within the Cache Creek watershed may not necessarily apply to the Yolo Bypass, Delta, or Bay because of the different chemical and hydrological environment.

Another priority is investigating the downstream impacts of mercury transported from the Cache Creek watershed, especially impacts in the Yolo Bypass region and the Yolo Wetlands, and in areas further downstream in the Delta and Bay.

It has been shown, for example, that mercury methylation rates in the Florida Everglades depend on salinity gradients and the amount of sulfate in the water. Mercury transported to the Yolo Bypass includes that originating from the Cache Creek watershed and that transported from the Sacramento and Feather Rivers, including sources in the Sierra Nevada. Therefore, detailed investigations along a salinity gradient will need to be completed. These studies also should include investigations of mercury accumulation in various aquatic and terrestrial organisms along this spatial gradient, and should include an assessment of the land uses and its effects on mercury methylation, bioavailability, and bioaccumulation. The studies also should test the effects of planned or anticipated changes in land use that may affect mercury chemistry — for example, the permanent flooding of areas for wildlife habitat that may contain elevated levels of mercury in bottom sediment. One recently funded CALFED project is examining such a scenario in part of the Yolo Bypass. That study focuses on aquatic invertebrates.

In addition to mercury methylation studies, it is critical to understand what processes affect mercury demethylation or de-toxification and to measure in-situ microbial-mediated mercury methylation and methyl mercury degradation rates. Studies showing actual rates of these processes within the entire system will greatly benefit the planning of remediation activities and cost-effective management in these critical areas.

A chemical and biological monitoring program will be required to run parallel to the studies on mercury methylation and bioaccumulation. The purpose of the monitoring program will be to document trends in mercury and methyl mercury concentrations and loads, and trends in concentrations of mercury in biological tissue. This documentation will help to clearly identify beneficial results derived from remediation activities. The monitoring program will be designed to characterize loads of mercury and methyl mercury, which will require installing new gauging stations and continuing to maintain existing ones. Biological monitoring will include measuring the amount of mercury in various organisms comprising the trophic levels of the aquatic community in the selected streams or waterways. The biological monitoring also should include a component to identify sections of streams that are used for sport fishing. The species of fish typically caught and the levels of mercury in that fish will be analyzed for mercury to better document human exposure levels. The entire monitoring program should continue for such time as necessary to establish trends in the mercury occurrence and chemistry before, during, and after remediation.

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A GIS database will need to be developed to store the chemical, biological, and spatial information so that current and future water quality managers can document trends in mercury concentrations in sediment, water, and tissue of aquatic organisms. The GIS system should include new and retrospective data for Cache Creek and other sources of mercury to the Delta.

Sacramento River and Tributaries

Recent monitoring activities have documented that a significant source of mercury to the Sacramento River is present somewhere between north of Red Bluff and the park at Woodson Bridge. Significant increases of the mercury load in the Sacramento River have been documented in this reach of river during stormwater runoff periods. Synoptic (with the flow) studies for that reach of river could determine the actual source of this mercury. In addition to characterizing such

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local sources of mercury to the Sacramento River, it is also critical to understand where, when, and how methylation and demethylation of mercury occur in this portion of the Delta estuary.

The USGS NAWQA Program has completed recent monitoring for methyl mercury at six locations in the Sacramento River watershed. Those sites included three locations on the main stem of the Sacramento River, at Colusa, Verona, and Freeport, and two agricultural drains, at Colusa Basin Drain near Knights Landing and at Sacramento Slough near Knights Landing. Results of that work showed that, on a yearly basis, the median concentrations of methyl mercury at those sites are statistically similar. Mercury levels approach concentrations that would be cause for concern, but larger and more significant concentrations occur following stormwater runoff. At present, little is known about the transport of methyl mercury from sites downstream of large placer-type gold mining operations, such as in the Yuba, Bear, and Cosumnes Rivers.

Dredge tailings that line several large Sacramento River tributaries should be investigated as potential sources of mercury loading. The investigation should address the Yuba, Cosumnes, and Bear Rivers. Suitable sampling sites include the Sacramento River at Bend Bridge, at Colusa, at Verona, and at Freeport; the Feather River near Nicolaus, the Yuba River near Marysville and an additional site on the Yuba River near dredge tailings; two similarly chosen sites on the Bear River, and two similarly chosen sites on the Cosumnes River. Some sampling currently is being conducted by the Sacramento Coordinated Monitoring Program and the SRWP. These monitoring efforts should be augmented and continued through the CMARP. Monthly sampling of total and filtered water samples for mercury and methyl mercury should be completed for a period of 2 years. In addition, a detailed geochemical characterization of the mercury should be completed on samples collected across a range of flow or hydrologic conditions. Some possibilities for geochemical characterization include the determination of mercury and methyl mercury in various size fractions of suspended sediment, including colloidal material; the bioavailability of that material; and the methylation or demethylation rates that may occur in changing hydrologic and chemical environments, such as the gradient between river and estuary.

Dredge tailings that line several large Sacramento River tributaries should be investigated as potential sources of mercury loading.

4.5.3 Existing Activities

Statewide, 33 waters were listed on the 1998 CWA Section 303(d) list due to mercury impairment. Of these, 18 were located in the CVRWQCB's jurisdiction and six in the SFBRWQCB's area. Most listings are associated with mining and resource extraction.

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The CVRWQCB regulates active and inactive mines on an individual basis under its Waste Discharge Program, the NPDES permit program, and the stormwater NPDES program. Operators of active mines, and some inactive mines with a responsible party, are required to obtain permits for any discharges in order to limit releases of inert or non-hazardous wastes.

The Sacramento Coordinated Monitoring Program has been sampling and analyzing for total and dissolved mercury since December 1992. The SRWP has been monitoring for mercury and conducting studies of fish tissue concentrations of mercury.

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The Sulphur Bank Mercury Mine, located near Clear Lake in the Cache Creek watershed, is a federal Superfund site. UC Davis researchers have been investigating mercury methylation, transformation, transport, and bioaccumulation extensively throughout this system since 1992.

EPA has conducted a Preliminary Assessment and Site Investigation of the New Idria Mine site, as a first step in considering whether to add the New Idria Mine site to the National Priorities List (NPL). Sites identified on the NPL fall under the authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) for remediation.

The California Department of Conservation's Division of Mines and Geology maintains a database on abandoned mines in the state.

The Colorado Center for Environmental Management received a grant from EPA to organize stakeholders in the Cache Creek watershed in order to develop a comprehensive watershed management plan. This is called the Cache Creek Watershed Project.

The Sacramento River Mercury Control Planning Project, funded by EPA, includes a proposed implementation plan for control of mercury from both point and non-point sources in the Sacramento River watershed. The draft plan calls for several source control strategies, including reclaiming mine tailings, removing mine tailings, removing instream mercury-enriched sediments, changing the operation of reservoirs and dredging of mercury-rich sediments in major reservoirs, treating mine drainage, further regulating gold mining operations, and creating a mercury recycling program.

The USGS has developed a method to identify deposits of mercury in hydraulic mining debris and has begun to survey mercury concentrations in that debris. The USGS also has submitted proposals for Category 3 funding to begin studying the methylation processes in different types of habitats in the Bay-Delta, as well as the food web transfer of mercury, in order to identify the species most likely to be contaminated by mercury. The USGS will continue to monitor total mercury and

The USGS has developed a method to identify deposits of mercury in hydraulic mining debris and has begun to survey mercury concentrations in that debris.

methyl mercury at two Sacramento River sites during the low-intensity phase of the NAWQA Program. Those sites are the Sacramento River at Colusa and the Sacramento River at Freeport. The low-intensity phase of the NAWQA Program will continue from the federal fiscal year 1999 through 2003. After that, a new monitoring plan will be formulated for the basin. Total and methyl mercury will be monitored on a monthly basis, and mercury in river sediment and tissue of aquatic organisms will be monitored on a yearly basis.

Research at the UC Davis Department of Environmental Science and Policy addresses ongoing projects at reservoirs and creeks, including Davis Creek Reservoir, Clear Lake, the Marsh Creek watershed, streams throughout the Sierra Nevada gold mining region, and new work throughout the Delta. Researchers from UC Davis have determined that fish tissue concentrations can be predicted from lower trophic-level invertebrate concentrations. They have developed techniques to rank tributaries according to their relative bioavailable mercury levels, to determine key sources of bioavailable mercury, and to determine mass loadings of mercury from individual tributaries and entire watersheds. Research is ongoing concerning the factors influencing mercury methylation, transformations, transport, and movement into and bioconcentration through food webs.

Researchers from UC Davis have determined that fish tissue concentrations can be predicted from lower trophic-level invertebrate concentrations. They have developed techniques to rank tributaries according to their relative bioavailable mercury levels, to determine key sources of bioavailable mercury, and to determine mass loadings of mercury from individual tributaries and entire watersheds.

The CVRWQCB and the SWRCB are developing a pilot mercury recycling program based on existing hazardous waste recycling programs. The program includes a public outreach and education component, fostering a cooperative relationship with the gold mining community (both recreational and commercial), and establishing the infrastructure for collecting and transporting recovered mercury to commercial recyclers.

In December 1997, some CALFED Category 3 restoration funds were directed toward evaluating the effects of wetland restoration on methyl mercury production in the estuary. This 3-year study will quantify changes in methyl mercury production caused by restoration activities and evaluate the availability and impact of mercury on the Bay-Delta ecosystem. The results of this work will be used to direct longer-term ecosystem restoration activities in order to minimize methyl mercury production.

The SWRCB and the California Coastal Commission (CCC) are in the process of adopting statewide management measures for mining. The SWRCB formed a Technical Advisory Committee on mines; this committee issued its recommendations in an October 1994 report. The SWRCB, CCC, and RWQCB currently are preparing an implementation plan as required under the Coastal Zone Act Reauthorization Act.

In 1996, the Save San Francisco Bay Association received an EPA grant for its Seafood Consumption Information Project to conduct direct outreach to fishing communities (primarily Hispanic and Asian) on the health risks associated with eating fish caught in the Bay. Activities included (1) conducting surveys on the frequency of fish consumption and on awareness of OEHHA fish advisories, and (2) offering in-house workshops on how to prepare fish in order to avoid eating the most contaminated portions.

5. PESTICIDES

5. PESTICIDES

5.1 SUMMARY

Pesticides, including diazinon and chlorpyrifos, have been identified by CALFED as contaminants of concern in both the Central Valley and Delta. These pesticides have been shown to exceed known toxic levels to sensitive organisms. Pesticide concentrations may alter the abundance and distribution of aquatic species. Inability to prevent toxicity caused by these pesticides could impair full restoration of the ecological integrity of Central Valley rivers and the estuary.

> Inability to prevent toxicity caused by these pesticides could impair full restoration of the ecological integrity of Central Valley rivers and the estuary.

The proposed approaches to address pesticide problems include conducting toxicity and chemical monitoring, TIEs, hazard assessments, MPs, and effectiveness assessments. Diazinon and chlorpyrifos are not the only pesticides addressed in this section. The purpose of this section is to establish a methodology by which toxicity linked to current pesticide usage can be eliminated. The actions taken and planned for toxicity associated with diazinon and chlorpyrifos usage will act as a general pattern for other pesticide toxicity cases that arise. The Parameter Assessment Team also identified carbofuran as a pesticide that needs to be studied. Section 11 of this report, "Toxicity of Unknown Origin," includes methods for toxic constituents, which could include pesticides.

5.2 PROBLEM STATEMENT

Certain pesticides have been identified in surface waters of the Bay-Delta estuary and its watersheds at levels that are reported to impair aquatic life beneficial uses.

Current scientific knowledge is not adequate to determine the ecological significance or spatial and temporal extent of the impairments.

5.3 Objective

The objective is to manage pesticides through existing regulatory agencies and voluntary cooperation of pesticide users such that the beneficial uses of the waters of the Bay-Delta and its tributaries are not impaired by toxicity originating from pesticide use.

5.4 Problem Description

5.4.1 Diazinon and Chlorpyrifos

Surface waters in the Central Valley and Delta estuary have repeatedly tested toxic in bioassays. In some instances, diazinon and chlorpyrifos have been identified as the principal cause of toxicity. In other cases, the chemical cause of toxicity was not identified.

Toxicity from diazinon and chlorpyrifos has been detected in surface water during winter and early spring from applications on orchards, during summer from irrigation return water, and during both winter and summer in urban runoff samples.

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Orchards

Toxicity testing of the estuary began in the late 1980s. Numerous bioassay and chemical studies have identified the organophosphate insecticide diazinon in surface water samples in the Central Valley during winter at concentrations toxic to sensitive invertebrates. Concern has been expressed that contaminants other than diazinon also might be present in winter storm runoff from the Central Valley and might contribute to invertebrate bioassay mortality. Therefore, TIEs were conducted on samples testing toxic in *Ceriodaphnia* bioassays from the Sacramento and San Joaquin Rivers. The results confirm that diazinon was the primary toxicant.

Irrigation Return Water

Chlorpyrifos toxicity was detected on nine occasions in surface water from four agriculturally dominated backwater sloughs in the Delta estuary. In each instance, the *Ceriodaphnia* bioassay results were accompanied by modified Phase I and II TIEs and chemical analysis that implicated chlorpyrifos. On four additional occasions, Phase III TIEs were conducted. These confirmed that chlorpyrifos was the primary chemical agent responsible for the toxicity in these samples. Analysis of the spatial patterns of toxicity suggests that the impairment largely was confined to backwater sloughs and was diluted away after tidal dispersal into main channels. The precise agricultural crops from which the chemicals originated are not known because chlorpyrifos is an agricultural insecticide that is commonly applied during the irrigation season. However, the widespread nature of chlorpyrifos toxicity, at least in March 1995, coincided with applications on alfalfa and subsequent large rainstorms. Further monitoring is needed to conclusively identify all sources.

Urban Runoff

Ceriodaphnia bioassay mortality has been reported in urban creeks of Sacramento and Stockton, including Morrison Creek, Mosher Slough, 5-Mile Slough, the Calaveras River, and Mormon Slough—all within the legal boundary of the Delta. A TIE conducted on samples from each site revealed diazinon and chlorpyrifos. Chemical analyses demonstrated that diazinon and occasionally chlorpyrifos were present at toxic concentrations. *Ceriodaphnia* bioassay results, coupled with TIEs and chemical analysis from the Bay Area, suggest that diazinon and chlorpyrifos may be a regional urban runoff problem.

5.4.2 Extent of Impairment

Orchards

The highest concentrations of diazinon and longest exposures are typically in small water courses adjacent to high densities of orchards. However, after the large storms of 1990 and 1993, diazinon was measured in the San Joaquin River at the entrance to the Delta at toxic concentrations to the *Ceriodaphnia dubia* in EPA three-species bioassays. Following up on these findings, the USGS and CVRWQCB traced pulses of diazinon from both the Sacramento and San Joaquin Rivers across the estuary in 1993. Toxic concentrations to *Ceriodaphnia* were observed as far west in the estuary as Chipps Island, some 60 miles downstream of the City of Sacramento.

The highest concentrations of diazinon and longest exposures are typically in small water courses adjacent to high densities of orchards.

Diazinon is present in urban dominated creeks around the City of Sacramento and Stockton after winter storms, as is discussed below. However, background concentrations of diazinon in urban stormwater runoff increased after application on orchards in January and February, suggesting that urban use is not the sole source of the chemical at this time. Volatilization following application is known to be a major diazinon dissipation pathway from orchards, and a number of dormant spray insecticides have previously been reported in rain and fog in the Central Valley. Composite rainfall samples collected in south Stockton in 1995 demonstrated that diazinon concentrations in rain varied from below detection to about 4,000 nanograms per liter (ng/l) (10 times the acute *Ceriodaphnia* concentration). The rainfall study was continued through March and April 1995 to coincide with application of chlorpyrifos on alfalfa for weevil control. Chlorpyrifos concentrations in composite rainfall samples increased, ranging from below detection to 650 ng/l (again, 10 times the acute *Ceriodaphnia* concentration). However, unlike diazinon, no study was conducted to ascertain whether chlorpyrifos concentrations in street runoff increased.

Irrigation Return Water

In 1991 and 1992, a bioassay study was conducted in agriculturally dominated waterways in the San Joaquin River Basin to determine the extent of toxicity. Chlorpyrifos was detected on 190 occasions between March and June of both years, 43 times at toxic concentrations to *Ceriodaphnia*. Many of the crops grown in the San Joaquin River Basin also are cultivated on Delta tracts and islands. It was unknown whether these same agricultural practices might also contribute to in-stream toxicity in the Delta. Follow-up studies were conducted as part of the SWRCB Bay Protection Program. Chlorpyrifos was periodically identified at toxic concentrations in backwater sloughs, suggesting that the same impairments occur in the Delta as in the San Joaquin River Basin.

Urban Runoff

Detailed information on urban sources of diazinon and chlorpyrifos is not available for the Central Valley. However, source information has been obtained for the Bay Area. The conclusions also may apply in the Central Valley, with the caveat that the Bay Area does not receive significant amounts of diazinon in rainfall as appears to occur in the Central Valley. Confirmatory studies are needed to verify that the Bay Area conclusions also apply to the Central Valley.

The primary source of diazinon and chlorpyrifos in Bay Area creeks is urban stormwater runoff. Samples from urbanized areas in Alameda County indicated that residential areas were a significant source, but runoff from commercial areas also may be important. It is not known what portion of the diazinon and chlorpyrifos found in creeks is attributable to use in accordance with label directions versus improper disposal or over application. However, a preliminary study of runoff from residential properties suggests that concentrations in some creeks may be attributed to improper use.

Novartis, the Registrant for diazinon, completed a diazinon probabilistic risk assessment for the Central Valley. Little data were available for the Delta, and

Novartis, the Registrant for diazinon, completed a diazinon probabilistic risk assessment for the Central Valley. Little data were available for the Delta, and concerns exist over the peer review the document received prior to release.

concerns exist over the peer review the document received prior to release. The risk assessment suggests that the greatest impacts are likely to occur in water courses adjacent to sources such as orchards. Lower concentrations are predicted in main stem rivers. The report predicts that the Sacramento and San Joaquin Rivers will experience acutely toxic conditions to 10% of the most sensitive species, 0.4 and 11.6% of the time in February, respectively, the period of most intensive diazinon off-site movement. Novartis concludes that the risk of diazinon alone in the Sacramento-San Joaquin River Basin is limited to the most sensitive invertebrates, primarily cladocerans. The report notes that cladocerans reproduce rapidly, and their populations therefore are predicted to recover rapidly. The report also predicts that indirect effects on fish through reductions in their invertebrate prey are unlikely, as the preferred food species are unaffected by the diazinon concentrations observed in the rivers. The study recommends, however, that the population dynamics of susceptible invertebrate species in the basin be evaluated, along with the feeding habits and nutritional requirements of common fish species.

Identification of diazinon and chlorpyrifos in agricultural stormwater and irrigation return water and in urban stormwater runoff has resulted in the CVRWQCB including the Sacramento and San Joaquin Rivers and the Delta estuary on the CWA Section 303(d) list as impaired. The listing commits the CVRWQCB to develop a TMDL for each constituent.

5.4.3 *Predominant Uses of Diazinon and Chlorpyrifos*

Diazinon and chlorpyrifos are predominantly used as orchard dormant sprays, for growing season applications to orchards and other crops, and for urban structures and landscapes.

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- **Orchard dormant sprays.** The application of diazinon during winter as an orchard dormant spray for stone fruits and almonds is widely practiced in the Central Valley (approximately half a million acres) to control many highly destructive insect and mite pests.

- **Growing season applications to orchards and other crops.** Chlorpyrifos is used in insect and mite control during the growing season (March through September), with major uses on cotton, alfalfa, citrus, and walnuts.

- **Urban structures and landscapes.** Diazinon and chlorpyrifos are used by professional pest control personnel and homeowners to control destructive insects, (termites and wood-boring beetles), as well as nuisance pests (ants, fleas, cockroaches, and spiders).

5.5 APPROACH TO SOLUTION

5.5.1 Priority Actions

The CMARP will perform monitoring using both EPA standard bioassays and ecologically important local species to screen for and to determine the temporal and spatial extent of toxicity. This monitoring should be coupled with chemical analysis and the TIE procedure to conclusively identify the chemicals causing toxicity. Once chemicals are identified, follow-up studies should be undertaken to determine their concentration, duration, and frequency in surface water and also to ascertain their sources and fate. This information should be analyzed in a risk assessment fashion to help predict likely ecological significance of exceedances.

> When chemicals are detected in surface water at concentrations that may affect beneficial uses, CALFED can help by facilitating the development of corrective actions.

When chemicals are detected in surface water at concentrations that may affect beneficial uses, CALFED can help by facilitating the development of corrective actions. These actions should include development of water quality targets, development of MPs to control off-site movement, financial support to help implement the most cost-effective methods, and monitoring to evaluate MP effectiveness once implemented.

DPR regulates the sale and use of pesticides but does not regulate cleanup of contaminated sites, which is the jurisdiction of the SWRCB and the RWQCBs. DPR and the Boards coordinate these responsibilities under a management agency agreement (MAA), as described later. The role of CALFED should be to use its combined state and federal authority, expertise, and resources in a coordinated effort with both the regulated and regulatory communities in order to help develop a comprehensive pesticide monitoring program. When chemicals are detected in surface water at concentrations that affect beneficial uses, CALFED should help to develop and fund the scientific studies in order to evaluate ecological significance and the preferred management methods to control off-site movement. Pesticide regulation will remain the responsibility of the agencies with regulatory authority.

> A two-pronged action approach to pesticides is proposed.

A two-pronged action approach to pesticides is proposed. First, a comprehensive bioassay and chemical monitoring program in the Central Valley and estuary should be performed as a part of the CMARP. Second, the analysis for the two insecticides presented in this report (diazinon and chlorpyrifos) should be used as a template for further evaluation of these compounds, as well as for the identification and control of other toxic pesticides.

It is proposed that CALFED support the existing regulatory agencies functions (listed below) to determine and correct toxicity associated with pesticide use:

- Verify initial reports that a pesticide is causing toxicity.

  - Confirm toxicity
  - Verify chemical analysis
  - Evaluate TIEs

- Establish use patterns.

- Implement corrective actions.

  - Establish water quality targets and typical points of compliance
  - Develop MPs and public education and outreach programs
  - Support implementation of MPs
  - Evaluate implementation of MPs
  - Monitor water quality for achieving water quality targets
  - Reevaluate corrective actions as necessary

Proposed corrective actions should be consistent with existing regulations and management agreements. The general actions that are required to begin to resolve this water quality problem include (1) establishment of interim and long-term targets (quantitative response limits and water quality objectives, respectively), (2) development and demonstration of cost-effective MPs that can be implemented to meet the targets, (3) completion of studies to determine potential ecological impacts, (4) monitoring to more fully describe existing conditions and evaluate the effectiveness of MP implementation, and (5) establishment of mechanisms to ensure that MPs are implemented. CALFED staff will monitor progress made in these efforts and will periodically issue progress reports.

Proposed corrective actions should be consistent with existing regulations and management agreements.

Water Quality Criteria

The DFG has developed interim diazinon and chlorpyrifos hazard assessment criteria to protect fresh water aquatic life, using the standard EPA criteria development process. Final hazard assessment criteria were not recommended, as several data gaps were identified in the toxicological literature. Studies should be undertaken to fill these gaps. Once completed, DFG should be requested to use the information and calculate a final diazinon hazard assessment criterion. CALFED has agreed to fund the remaining portion of the study in order to establish a technically justified numerical goal. It is proposed that CALFED should fund work at both DPR and the SWRCB to convert the hazard assessment criteria into quantitative response limits and water quality objectives.

Development of Agricultural Management Practices

Development of agricultural MPs to keep orchard dormant spray insecticides on farm and out of surface water is just beginning. The work of the DPR, UC Integrated Pest Management, the Registrants, and others are described below under "Existing Activities." The work of each group is too preliminary at present to ascertain whether any of these actions might be successfully implemented to reduce diazinon and chlorpyrifos concentrations in surface waters to non-toxic levels. No work has yet begun on evaluating possible irrigation return water pesticide control actions.

Once preferred MP options are identified, funding should be sought for their field evaluation. At a minimum, the field testing should ascertain the amount of pesticide reduction achieved under varying Central Valley orchard conditions, whether the reductions would meet water quality objectives, and the cost per acre to the farmer to implement the practice. CALFED presently is funding research at UC Davis to investigate alternatives to traditional uses of organophosphate insecticides in agricultural pest management systems, which will contribute to development of agricultural MPs. CALFED also is funding the Community Alliance with Family Farmers, Biologically Integrated Orchard Systems (BIOS), which develops methods to maintain pest control with minimal use of pesticides. MPs could be distributed through education and outreach programs.

Future costs of MP development should be shared with other agencies to help maintain cost effectiveness in order to realize mutual and multiple benefits associated with widespread implementation of appropriate MPs. It is proposed that CALFED evaluate the feasibility of supporting pollutant trade-off programs.

CALFED presently is funding research at UC Davis to investigate alternatives to traditional uses of organophosphate insecticides in agricultural pest management systems, which will contribute to development of agricultural MPs.

Development of Urban Management Practices

Finding diazinon and chlorpyrifos in urban runoff prompted the formation of an Urban Pesticide Committee (UPC). The UPC is an *ad hoc* committee formed to address the issue of toxicity in urban runoff and wastewater treatment plant effluent due to organophosphate insecticides, in particular diazinon and chlorpyrifos. The UPC is composed of staff from the EPA, SFRWQCB, CVRWQCB, DPR, Novartis, Dow Agro Sciences, municipal stormwater programs, the Bay Area Stormwater Management Agencies Association, county agricultural commissioners, wastewater treatment plants, UC, and consultants. The members of the UPC are committed to working in partnership with the various stakeholders to develop effective measures in order to reduce the concentrations of organophosphate insecticides in urban runoff and wastewater treatment plant effluent. In addition to monitoring the effectiveness of these actions, a draft strategy for pesticide toxicity reduction includes the following:

Finding diazinon and chlorpyrifos in urban runoff prompted the formation of an Urban Pesticide Committee.

- Education and outreach programs by which MPs could be distributed to pesticide users in the general public.

- Education and certification changes for commercial applicators to ensure that pesticides are applied properly.

- Improving the regulatory tools of state and federal agencies.

- Adherence to prescribed MPs by public right-of-way and municipal facilities.

CALFED has funded several projects to begin development of MPs in order to reduce off-site movement of pesticides in the urban arena via stormwater. On another front in the urban arena, DPR has completed a study that identified potential sources of pesticides in sanitary wastewater. Pesticides in sanitary wastewater are treated only partially before being discharged to surface water. Their presence in wastewater may indicate a shift from citizens' dumping unused pesticides into storm drains to citizens' dumping these pesticides into the sewer system.

Evaluate Implementation of Management Practices

The pesticide effort is still at the early stages of MP development. However, once MPs are developed, it is proposed that CALFED begin discussions with both the regulatory and regulated communities about the most efficient methods of implementing the urban and agricultural MPs. CALFED should consult with DPR and the UPC concerning the results of the MP implementation evaluation to determine whether additional MP efforts are needed.

5.5.2 *Information Needed*

Biological surveys should be undertaken to determine the ecological significance of toxic pulses of diazinon. In-stream monitoring should be conducted to assess the impact of diazinon pulses on local aquatic communities. The Novartis diazinon ecological risk assessment predicts that impacts on sensitive invertebrates will occur but that population recovery will be rapid. No indirect food chain effects on larval and juvenile fish are predicted, as these animals were assumed to be capable of switching to an alternate food source.

In-stream monitoring should be conducted to assess the impact of diazinon pulses on local aquatic communities.

Detailed ecological studies are needed to ascertain whether invertebrate populations levels decrease and how long it takes for recovery to occur. These studies should target those areas of the watershed where monitoring has indicated that the most severe impacts might occur. The studies also should consider the additive ecological effect of multiple pesticide exposures. Studies also are needed to verify that higher trophic levels are not affected by decreased invertebrate production. This work should emphasize potential impacts on threatened and endangered fish species.

The Integration Panel for the CALFED Ecosystem Restoration Program has set aside $1.5 million for follow-up work to determine the ecological significance of the pesticide toxicity events. Furthermore, the Integration Panel asked the Contaminant Effects Interagency Environmental Program Work Team to recommend follow-up studies.

Biological surveys and ecological assessments will be conducted through the CALFED Ecosystem Restoration Program in coordination with the Water Quality Program.

It is proposed that CALFED support the efforts of DPR and the RWQCB to monitor surface water in the Sacramento and San Joaquin River watersheds. Monitoring will help to determine compliance with applicable water quality objectives and establish a database useful in developing TMDLs and other regulatory tools necessary to achieve compliance. This monitoring portion, as well as some studies, may be incorporated into the CMARP.

5.5.3 Existing Activities

Both DPR and the SWRCB/RWQCBs have statutory responsibilities for protecting water quality from the adverse effects of pesticides. In 1997, DPR and the SWRCB signed an MAA, clarifying these responsibilities. In a companion document, "Pesticide Management Plan for Water Quality," a process was outlined for protecting beneficial uses of surface water from the potential adverse effects of pesticides. The process relies on a four-stage approach:

The "Pesticide Management Plan for Water Quality" outlines a process for protecting beneficial uses of surface water from the potential adverse effects of pesticides. The process relies on a four-stage approach.

- Stage 1 relies on education and outreach efforts to communicate pollution prevention strategies.

- Stage 2 efforts involve self-regulating or cooperative efforts to identify and implement the most appropriate site-specific reduced-risk practices.

- Stage 3 achieves mandatory compliance through restricted-use pesticide permit requirements, implementation of regulations, or other DPR regulatory authority.

- Stage 4 achieves mandatory compliance through the WQCPs of the SWRCB and RWQCB or other appropriate regulatory measures consistent with applicable authorities.

Currently, DPR is coordinating a Stage 2 effort to address the effects of dormant sprays on surface water. DPR's stated goal is to eliminate the toxicity associated with dormant spray insecticides (i.e., chlorpyrifos, diazinon, and methidathion) in the Sacramento and San Joaquin River Basins and the Delta. CALFED is granting funds to UC Davis for the development of BMPs for various uses of pesticides. As long as progress continues toward compliance with appropriate water quality objectives, Stage 3 activities will be unnecessary.

In January 1999, the CVRWQCB approved a TMDL schedule for diazinon for the Lower Sacramento River and the Lower Feather River. The TMDL report for these rivers is scheduled for completion in June 2002, and the Basin Plan Amendment is scheduled for completion in June 2003. Also during January 1999, the CVRWQCB approved a TMDL schedule for the San Joaquin River and the Delta for both diazinon and chlorpyrifos. The TMDL schedule for the San Joaquin River includes a TMDL report by June 2002 and a Basin Plan Amendment in June 2003. The TMDL schedule for the Delta includes a TMDL report by June 2003 and a Basin Plan Amendment in June 2004. Components of a TMDL include problem description, numeric targets, monitoring and source analysis, implementation plan, load allocations, performance measures and feedback, margin of safety and seasonal variation, and public participation. It should be noted that if monitoring demonstrates that the waterways are in compliance with the numeric target, no further action is required.

Components of a TMDL include problem description, numeric targets, monitoring and source analysis, implementation plan, load allocations, performance measures and feedback, margin of safety and seasonal variation, and public participation.

Several activities are underway in the Sacramento-San Joaquin River Basin to develop agricultural BMPs in order to control orchard dormant spray runoff. These are summarized below according to the agency conducting the study.

Department of Pesticide Regulation

In addition to the activities already discussed, DPR is investigating orchard floor management as a means to reduce discharges of dormant sprays into surface waterways. At an experimental plot at UC Davis, DPR staff measured discharges of chlorpyrifos, diazinon, and methidathion from a peach orchard with three orchard floor treatments. Investigations are continuing in a commercial orchard. At the California State University at Fresno, DPR is investigating the effects of microbial augmentation and post-application tillage on runoff of dormant sprays. Results will be highlighted in DPR's own outreach activities and will be made available to other groups interested in the identification and promotion of reduced-risk MPs.

DPR also is monitoring water quality at four sites — two each within the Sacramento and San Joaquin River watersheds. During the dormant spray use season, approximately January through mid-March, water samples are collected five times each week from each site. Chemical analyses are performed on each sample; one chronic and two acute toxicity tests, using *Ceriodaphnia dubia*, are performed each week.

Novartis

The Registrant of diazinon distributed over 10 thousand brochures last winter through UC Extension, county agricultural commissioner's offices, and pesticide distributors. The brochure described the water quality problems associated with dormant spray insecticides and recommended a voluntary set of BMPs to help protect surface waters. Novartis intends to repeat the education and outreach program this winter.

Urban Pesticide Committee

The UPC has extensive experience in urban pesticide management and has completed reports on monitoring and source identification. The UPC also has drafted a Public Education and Outreach Plan. It is a stakeholder-driven and supported program that is poised to make significant strides in reducing discharges of urban pesticides.

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City of Sacramento and County of Sacramento

Under the Stormwater Management Program, the City of Sacramento and County of Sacramento have conducted monitoring and special studies to reduce urban pesticide impacts on local waterways.

Dow Agro Sciences and Novartis

Dow Agro Sciences and Novartis, the registrants of chlorpyrifos and diazinon, have undertaken a multi-year study in Orestimba Creek in the San Joaquin River Basin, with the primary objective of identifying specific agricultural use practices involved in chemical movement offsite into surface water. The study involves an evaluation of pesticide movement in both winter storms and in summer irrigation return water flows. Objectives in subsequent years include using the data to develop and field test management practices in order to reduce off-site chemical movement. The first year and second dormant-season monitoring are completed. Two reports are now available, and an ACS Symposium Series book chapter is in press. Follow-up field-scale evaluations of irrigation management practices were conducted, and a report of non-replicated comparisons with standard practices is available.

Biologically Integrated Orchard Systems

The BIOS Program pioneered community-based efforts to implement economically viable, nonconventional pest MPs. The program emphasizes management of almond orchards in Merced and Stanislaus Counties to minimize or eliminate the use of dormant spray insecticides. BIOS received a DPR pest management grant and a CWA Section 319(h) non-point source implementation grant. BIOS also received funding from CALFED.

The BIOS Program pioneered community-based efforts to implement economically viable, nonconventional pest MPs.

Biorational Cling Peach Orchard Systems

The Biorational Cling Peach Orchard Systems (BCPOS) Program has the same goals as the BIPS Program, except that it focuses on primary pests in cling peach orchards. The UC Cooperative Extension is acting as project leader, with Sacramento and San Joaquin Valley coordinators. BCPOS received a DPR pest management grant.

The BCPOS Program has the same goals as the BIPS Program, except that it focuses on primary pests in cling peach orchards.

Colusa County Resource Conservation District

The Colusa County Resource Conservation District (RCD) is leading a runoff management project in the watershed of Hahn Creek. Project participants are identifying MPs that reduce runoff from almond orchards in the watershed, thereby reducing pesticide loads in the creek. Outreach and demonstration sites are part of this project. This project received a CWA Section 319(h) grant.

Glenn County Department of Agriculture

The Glenn County Department of Agriculture is organizing local growers and pest control advisors (PCAs) to address the use of dormant spray insecticides in the county. The local RCD also is involved; they are applying for grants to facilitate the implementation of reduced-risk pest MPs.

Natural Resources Conservation Service - Colusa Office

The Colusa County office of the Natural Resources Conservation Service (NRCS) recently was awarded over $100,000 from the Environmental Quality Incentives Program (EQIP), one of the conservation programs administered by the U.S. Department of Agriculture (USDA). EQIP offers contracts that provide incentive payments and cost sharing for conservation practices needed at each site. Most of these funds should be available to help implement reduced-risk pest MPs in almond orchards in the area.

Natural Resources Conservation Service - Stanislaus Office

The Stanislaus County office of NRCS recently was awarded $700,000 from EQIP. Half of the funds are allocated to address livestock production practices, but most of the remaining funds should be available to address dormant sprays and the implementation of reduced-risk pest MPs. Local work groups, comprised of RCDs, NRCS, the Farm Services Agency, county agricultural commissioners, the Farm Bureau, and others, will determine how EQIP funds will be distributed. Applicants for EQIP funds will be evaluated on their ability to provide the most environmental benefits.

The Nature Conservancy

The Nature Conservancy is enrolling more prune growers in the BIPS project as it proceeds with its Phelan Island restoration project in the Sacramento Valley. This project received a CWA Section 319(h) grant.

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UC Statewide Integrated Pest Management Project

In late 1997, the UC Statewide Integrated Pest Management (UCIPM) Project was awarded a 2-year grant by the SWRCB to: (1) identify alternate orchard MPs to prevent or reduce off-site movement of dormant sprays, (2) provide outreach and education on these new practices to the agricultural community, and (3) design and initiate a monitoring program to assess the success of the new practices. A steering committee, composed of representatives from community groups, state agencies including CVRWQCB staff, and UC academicians, was formed to serve as a peer review body for the study. UCIPM received CALFED funding.

6. ORGANOCHLORINE PESTICIDES

6. ORGANOCHLORINE PESTICIDES AND RELATED COMPOUNDS

6.1 SUMMARY

Organochlorine (OC) pesticides (DDT, toxaphene, dieldrin, and chlordane) were widely used in the Central Valley until the 1970s. OC pesticide residue are still widespread in the Central Valley. Many OC pesticides have been banned over time. Because of their characteristics and behavior in the environment, however, residuals still are being detected through monitoring. This section addresses OC pesticides that are no longer used in California and other related compounds. Control of OC pesticides currently in use is the jurisdiction of the DPR. The OC pesticides are persistent in the environment and are characteristically associated with the organic component of small particles, such as in sediment. Also persistent in the environment are polychlorinated biphenyls (PCBs), which were used as a dielectric (an electric insulator); and dioxins and dioxin-like compounds, which are predominantly associated with combustion compounds containing chlorine. The body burden of OC pesticides, PCBs, and dioxins in aquatic organisms represents an integration of the routes by which that organism is exposed. Exposure can occur through the food chain, direct contact with water or sediments, or other routes. OC pesticides, PCBs, and dioxins are a concern to water quality because they tend to bioaccumulate and can be toxic or carcinogenic to aquatic species and humans. This section identifies OC pesticide concerns, OC pesticide levels found in the Delta, and proposed actions that can minimize impacts associated with these pesticides. PCB pollution is somewhat common in the urban environment and is also common in larger predatory fish. Dioxins and dioxin-like compounds are listed on the CWA Section 303(d) list for impairing the San Francisco Bay and part of the Bay-Delta. PCB and dioxin pollution and remediation will be further addressed by the CALFED Program as more is known and as experts can be assembled to address sources of impairment and remedial strategies.

Many OC pesticides have been banned over time. Because of their characteristics and behavior in the environment, however, residuals still are being detected through monitoring.

6.2 OBJECTIVE

The objective is to reduce concentrations of OC pesticides in biota in the San Joaquin and Sacramento Rivers and the Delta, which will require reducing the transport of OC pesticides from agricultural lands to the rivers. The measure of success will be lower levels of OC pesticides in biota as determined from monitoring. PCB, dioxin, and dioxin-like compound concentrations and environmental (including public health) impacts will be monitored and solutions devised, if feasible.

6.3 PROBLEM DESCRIPTION

One of the most comprehensive sources of information to characterize problems associated with regionwide OC pesticides is the joint SWRCB-DFG Toxic Substances Monitoring Program (TSMP). Results from other important studies also are included in this report.

The TSMP has been monitoring pollutants in aquatic life since 1976. Twenty-two sites were monitored by the TSMP in the Bay-Delta watershed for 5 years. Of these sites, the Sacramento River near Hood and the San Joaquin River near Vernalis were monitored for 10 years. Most of the sites monitored revealed continually high levels of metals or OC pesticides in tissue samples. OC pesticides were widely used in the Central Valley in the 1950s and 1960s. Use has declined greatly since the early 1970s, and several OC pesticides have been banned. DDT was widely used as a general purpose insecticide until it was banned by the EPA in 1972. DDT and its breakdown products, DDD and DDE, are very persistent and result in bioaccumulative toxic effects on fish and birds. Toxaphene replaced many DDT uses until it was banned for most uses in 1982. Dieldrin was banned for all uses except termite control in 1974, and banned for all uses in 1987. Chlordane was banned for all uses except termite control in 1983, and banned for all uses in 1988.

OC pesticides were widely used in the Central Valley in the 1950s and 1960s. Use has declined greatly since the early 1970s, and several OC pesticides have been banned.

Chlordane was found to exceed the 300 parts per billion (ppb) U.S. Food and Drug Administration's (FDA's) action level in channel catfish from the San Joaquin River near Vernalis and in carp from Paradise Cut near Tracy. DDT was found to exceed the FDA's action level of 5,000 ppb in channel catfish near Vernalis and in carp from Paradise Cut. DDT also was found at relatively high levels in carp from the Sacramento River near Hood. Concentrations of OC pesticides were generally much lower in bed sediment and biota in the Sacramento River Basin compared to the San Joaquin River Basin.

All fish fillet samples collected from the San Joaquin River near Vernalis from 1978 to 1987 exceeded recommended safe levels for fish-eating wildlife set by the National Academy of Science/National Academy of Engineering (NAS/NAE) for total DDT (the sum of DDD, DDE, and DDT), chlordane, and toxaphene. Fish fillet samples collected from the major east side tributaries to the San Joaquin River (the Merced, Tuolumne, and Stanislaus Rivers) also exceeded NAS/NAE-recommended levels for total DDT, chlordane, and toxaphene. Recently, the toxaphene concentration in a whole carp from the Colusa Basin Drain in the Sacramento River Basin exceeded the NAS/NAE-recommended level.

Concentrations of OC pesticides in bed sediment and clams of west side tributaries were consistently higher than those in east side tributaries of the San Joaquin River. A 1998 USGS study concluded that concentrations of OC pesticides in biota, and perhaps in bed sediment of the San Joaquin Valley, have declined from the concentrations measured in the 1970s and 1980s but remain high compared to other regions of the United States.

In a study comparing winter storm transport of OC pesticides to irrigation season transport in the San Joaquin River Basin, instantaneous loads of OC pesticides at the time of sampling were substantially greater during the winter storm. However, due to the infrequent occurrence of sizable winter storms, overall transport was probably similar or greater during the irrigation season. As expected, most transport of OC pesticides during the winter storm runoff was in the suspended sediment. The suspended fractions (the ratio of OC pesticide concentration in suspended sediment in μg/L to total OC pesticide concentration in the water column in μg/L) ranged from 0.52 to 0.98 for chlordane, dieldrin, total DDT, and toxaphene. With lower overland flow and streamflow velocities and subsequently lower suspended sediment concentrations during the irrigation season, the suspended fractions ranged from only 0.14 to 0.57 μg/L. Most calculated whole-water concentrations of p,p'-DDT, chlordane, dieldrin, and toxaphene during both the winter storm runoff and the irrigation season exceeded EPA's chronic criteria for the protection of fresh-water aquatic life.

PCBs were used in industry as a dielectric compound, such as in transformers in the municipal electric industry. PCBs are lipophilic (soluable in oils but not water) and persist in the environment. It is thought that most of the PCBs in the environment are in sediment. Fish tissue from the rivers and the Bay all contain levels of PCB. The levels vary, depending on the type and age of fish and the location of the habitat.

PCBs were used in industry as a dielectric compound, such as in transformers in the municipal electric industry. Fish tissue from the rivers and the Bay all contain levels of PCB.

These compounds are persistent in the environment even after they have been carried offsite and into the estuary. In some cases, not necessarily in the Bay-Delta, disturbed sediment reintroduces these compounds at high concentrations, which leads to fish kills and other impacts on habitat. It is unclear whether any mitigation is feasible on sediments for two reasons:

- Mitigation by removal would disturb sediment and create the very situation to be avoided.
- Costs associated with remediation would be prohibitive.

The impacts of allowing current levels of OC pesticides to reside in Bay-Delta sediment, coupled with long-term declines in pesticide levels in fresh sediment, should be weighed against other mitigation measures if the solutions presented here fail to meet the stated objective.

6.4 APPROACH TO SOLUTIONS

A large portion of the OC pesticide transport is associated with suspended sediment during both winter storm runoff and the irrigation season, especially for total DDT (suspended fraction of 0.87 µg/l in the irrigation season and 0.98 µg/l in winter storm runoff). Thus, a likely solution to reducing transport of OC pesticides to the San Joaquin and Sacramento Rivers is to reduce the transport of sediment from the agricultural fields, especially the fine grained sediments from the west side of the valley. Irrigation season sediment losses are much easier to control than those due to winter storm runoff because the runoff from irrigation is contained within furrows and the water source causing the runoff is controllable.

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6.4.1 *Priority Actions*

1. It is recommended that CALFED support conservation efforts to help achieve the Water Quality Program objectives.

   The conservation practices shown on the following page (either singly or in combination) have proven to be cost-effective methods of achieving significant water quality improvements through reducing tailwater runoff that contains sediments, pesticides, and nutrients to water bodies or conveyance systems in the area. When combined in a "whole-farm plan" as provided by the NRCS, additional benefits include reduced electrical energy consumption, improved water conservation, improved water infiltration; and, in some cases, improved air quality, improved biodiversity, and improved crop yields.

2. It is proposed that CALFED help support additional research on the widespread use of PAM as a BMP (and other related erosion-control agents) to control erosion and improve aquatic habitats.

   A new conservation practice has been developed concurrently by the USDA Agricultural Research Service, UC Riverside, and UC Cooperative Extension. The use of high-quality polyacrylamide (water-soluble, anionic, high molecular weight PAM) as defined in the NRCS Field Office Technical Guide virtually halts irrigation-induced erosion, eliminates sedimentation, and keeps farm chemical residues on the farm. PAM is added to irrigation water at rates less than 10 ppm and is strongly attracted to soil particles, which results in preserving soil structure, maintaining infiltration rates, and flocculating any soil particles that may become suspended. This practice results in reduced volumes of tailwater runoff that is sediment free, with virtually no residues leaving the farm.

Conservation Practices to Achieve Water Quality Improvements

Conservation Practice	Process	Effects	
Tailwater ditch checks	Decreases slope	Reduces ditch erosion	Traps sediment
Land leveling	Decreases slope	Reduces water velocity	Reduces erosion
Cutback stream	Reduces runoff	Reduces water flow when water reaches furrow end	
Surge irrigation	Reduces runoff	Automates water management	Reduces erosion
Sprinkler germination	Reduces water	Eliminates pre-irrigation	Reduces erosion
Drip irrigation	Reduces water	Automates water management	Reduces erosion
Shorten length of run	Reduces stream	Reduces water volume	Reduces erosion
Gated surface pipe	Reduces runoff	Improves water management	Reduces erosion
Vegetated filter strip	Stabilizes soil	Reduces water velocity	Traps sediment
Cover crop	Stabilizes soil	Reduces water velocity	Reduces erosion
Grassed waterway	Stabilizes soil	Reduces water velocity	Reduces erosion
Conservation tillage	Stabilizes soil	Reduces water velocity	Reduces erosion
Sediment basin	Reduces runoff	Reduces water velocity	Traps sediment
Tailwater return system	Reduces water	Returns water to land	Reduces sedimentation
Irrigation management	Reduces water	Improves water management	Reduces erosion
Nutrient management	Reduces inputs	Improves water management	Reduces runoff
Integrated pest management	Reduces inputs	Improves water management	Reduces runoff
Tailwater management	Reduces runoff	Improves water management	Reduces sedimentation

3. It is proposed that CALFED support projects that will recreate the stream channels and increase the size of flow structures, such as culverts, to help achieve reduction in OC pesticides.

   Most of the BMPs listed above apply only to reducing the inputs of OC pesticides during the irrigation season and do not address the problem of winter storm transport. A few of the BMPs would be effective year-round (such as a vegetated filter strip, cover crop, and grassed waterway). In addition, some flooding occurs in west side tributaries to the San Joaquin River, especially in Hospital and Ingram Creeks, that may be preventable. The lack of channel capacity to carry even moderate winter storm runoff forces much of the flow onto freshly-plowed agricultural land. This greatly increases the transport of sediment and OC pesticides to the San Joaquin River during winter storm events.

4. Financial incentive programs should be tied to a whole-farm approach that addresses water use, water quality, soil health and erosion, and reduced chemical use. This approach will avoid shifting environmental problems from one medium to another, and also will help focus resources on techniques with multiple benefits. The USDA program described in the West Stanislaus case study demonstrates that such an approach can be extremely effective in achieving water conservation and water quality benefits.

5. Strategies should be developed to implement conservation measures and fund local conservation efforts in the following manners:

   a. The state and federal governments should consider providing a permanent source of funding for RCD pollution prevention and resource conservation programs. RCDs are a valuable, underutilized resource. RCDs were formed as an independent local government liaison between the federal government and private landowners. When motivated and given the necessary resources, RCDs can play a valuable role in offering technical assistance and promoting sustainable farming practices. However, many RCDs have no source of income and are thus severely limited in the conservation assistance that they can offer.

When motivated and given the necessary resources, RCDs can play a valuable role in offering technical assistance and promoting sustainable farming practices.

   b. The CALFED Program should condition the receipt of any Program benefits by agricultural water users on implementation of conservation measures, including water conservation and water quality benefits.

   c. Major engineering works, including urban development, inter-state highways, large canals, creek alignments and dams and diversions, geologic tectonic activity, and other changes in these landscapes, may contribute to additional erosion and sedimentation of the river systems and the Bay-Delta. These works should be examined.

   d. CALFED could contribute to an existing delivery system of "locally led conservation" through RCDs and NRCS, resulting in immediate positive water quality benefits. Farmers have responded positively to USDA's new EQIP cost-share program, which provides for whole-farm planning and cost sharing to address the water quality resource concerns. This program is available throughout the CALFED area but is severely under-funded. Many existing high-priority applications will not be implemented because of the high expense of installing the measures and the limited NRCS funding.

Farmers have responded positively to USDA's new EQIP cost-share program, which provides for whole-farm planning and cost sharing to address the water quality resource concerns.

6. CALFED should monitor the environmental and public health impacts of PCBs in the Bay-Delta. If it appears that solutions to the pollution are feasible, a PCB Work Group could be formed to address possible solution strategies and CALFED's future involvement.

6.4.2 Information Needed

Projects that provide information needed should be supported based on priorities set by CALFED work groups and administration. Governmental and private efforts should be sought for contributions in this effort to control OC pesticide-laden sediment. Some potential projects include the following.

1. Data from continued monitoring efforts.

   Scientific and technical needs associated with the problem of OC pesticides in the Bay-Delta and watershed include the need for continued monitoring of levels in biota and of sources in the basins. More data are needed on sources of OC pesticides in the Sacramento River Basin, similar to the information developed for the San Joaquin River Basin.

   The TSMP continues to be one of the few overviews of the impacts of toxic substances in the environment. Regional elevations can be detected and put in perspective, although the TSMP is limited in detecting quickly changing types of contaminants or acutely toxic materials. Predatory fish are long lived and may travel considerable distances. A single fish with an elevated tissue concentration of a particular toxic substance cannot be linked with certainty to a potential source. However, repeated detections over many years in the same watershed can be revealing. Only through sustained monitoring can significant problems be distinguished from an isolated and highly contaminated individual specimen.

   The TSMP continues to be one of the few overviews of the impacts of toxic substances in the environment.

   The CMARP's support for the TSMP sampling site at Vernalis would offer the opportunity to examine fish whose body burdens of toxic substances integrate contaminants from all of the San Joaquin River tributaries. Whenever elevated levels of toxicants appear at Vernalis, additional samples from upstream of the San Joaquin River and its tributaries could be taken to trace the contaminant to a source region. Once a source region was determined, watershed-based source control efforts could be initiated.

2. Design and assessment of various BMPs to reduce OC pesticides.

   A better understanding is needed of the effectiveness of various proposed BMPs to control sediment losses during the irrigation season. Some BMPs also need to be developed to reduce sediment losses during winter storm runoff.

3. Relationship between soil fertility and pest management.

   Additional research is needed on the relationship between soil fertility, pest management, and water use. Farmers in case studies found that soil fertility was key to reducing chemical inputs. Some also found that an extensive soil-building program could reduce water use.

4. Efficient irrigation technologies.

   Additional research dollars should be directed toward improving efficient irrigation technologies. Continued advances in technology are possible and should be aggressively pursued.

5. Agricultural runoff and water quality stressors.

   Continued research and technology transfer is needed to respond to increasing concerns related to surface water runoff from agricultural lands and their contribution to water quality stressors in the Delta.

6. Winter flood control and control of OC pesticide-laden sediment.

   The relationship of OC pesticide control with flood control measures to protect farmland should be studied. Projects should be encouraged where flood control measures also control off site migration of OC pesticides.

6.4.3 Existing Activities

The TSMP was designed to follow the fate of pesticides in the California environment. This cooperative program, involving DFG and the SWRCB, has been monitoring pollutants in aquatic life since 1978. Although procedures have changed over time, the program continues to characterize the degree to which aquatic organisms and food chains are exposed to toxic materials and contaminants.

The TSMP was designed to follow the fate of pesticides in the California environment. This cooperative program, involving DFG and the SWRCB, has been monitoring pollutants in aquatic life since 1978.

Initially, benthic invertebrates, forage and predator fish, and sediments were analyzed at each site. Sediment sampling soon was dropped because of unsatisfactory results. Pollutants found during sediment analyses related more closely to the quantity of runoff from year to year than to the quantities emitted from point or non-point sources. Therefore, the program focused on the analysis of toxic contaminants in organisms. The body burden of toxic material in organisms represents an integration of the routes by which that organism is exposed to pollutants. A predatory fish, for example, may accumulate toxins directly through contact with the water or sediments, or by ingestion of smaller organisms with similar routes of accumulation.

The TSMP used several measures to put pollution in perspective. Human health concerns were reflected by using FDA MCLs, which would address concerns about the chronic human health effects of toxic substances consumed in foodstuffs. Wildlife concerns were assessed by considering the NAS/NAE-recommended maximum concentrations of toxic substances in fish tissue. Other reference levels were drawn from the United Nations Food and Agriculture Organization, and an internal standard reflecting elevated data from the range of samples collected during the program.

Since 1991, farmers in western Stanislaus County have participated in a very successful USDA water quality initiative project called the West Stanislaus Hydrologic Unit Area. The purpose of the project is to accelerate the voluntary implementation of BMPs through a locally led process, with financial, technical, and educational assistance from the USDA. Primary agencies include the West Stanislaus RCD, USDA Farm Service Agency, NRCS, and UC Cooperative Extension. Participation has grown to more than 25 local, state, and federal agencies that assist farmers in reducing off site impacts from irrigation-induced erosion and sedimentation of the impaired San Joaquin River and Delta.

> Since 1991, farmers in western Stanislaus County have participated in a very successful USDA water quality initiative project called the West Stanislaus Hydrologic Unit Area.

The CVRWQCB funded the West Stanislaus Sediment Reduction Plan (PLAN) that (1) benchmarked existing conditions and solutions, (2) provided practical self-evaluation tools and BMPs, and (3) defined an implementation strategy. The PLAN documented that up to 95% of the sediment leaving farmed fields could ultimately reach the San Joaquin River. Several hundred copies of the PLAN have been distributed to farmers. The PLAN has been used as a template in similar landscapes in nearby counties with similar resource concerns. All conservation practices are well defined in the NRCS Field Office Technical Guide, as well as standards, specifications, and performance measures.

7. SALINITY

7. Salinity

7.1 Summary

Over 130 miles of the main stem San Joaquin River is listed as water quality-impaired for salinity on the CWA's Section 303(d) list. Salt concentrations in this segment of the river impair the beneficial use of agricultural supply on a periodic basis.

Surface and subsurface agricultural drainage waters are the major source of salt in the lower San Joaquin River Basin. Agricultural drainage is also a source of salt in the Sacramento River. Salt loading leads to impairment of water quality in the lower San Joaquin River and in the Delta Region. Processes that affect salinity of water in a basin occur over short and long periods because of the interactions of surface and subsurface water and soil salinity.

Salt loading leads to impairment of water quality in the lower San Joaquin River and in the Delta Region.

The length of time over which a process occurs determines the sustainability (or durability) of the solution approach. Therefore, time is an important consideration in identifying the best solution approach. The CALFED Program principles mandate durable solution approaches that allow productive land use concurrent with reductions in salinity and selenium discharges to the environment.

The listed approaches, in various forms, have been studied and partially implemented over many years. Current technology for reverse osmosis and cogeneration is expensive, making these approaches less likely to be implemented over the short term. Source control, reuse, and integrated on-farm drainage management programs could be expanded immediately.

Much that can be achieved strictly through source control (exclusive of land retirement) and cycling or blending reuse already has been achieved; additional increased short-term load reductions likely will come at the expense of long-term increases in salt buildup in the San Joaquin River Basin (and associated increases in long-term loading to the San Joaquin River). These measures could continue to be used as a short-term solution for decreasing salt loads in the Delta, although drainage volumes and salt loads may increase in normal water years following dry years. Salt concentrations in shallow groundwater areas (0–10 feet) remained mostly constant from 1990 to 1994, but increased between 1994 and 1997.

Integrated on-farm drainage management, including sequential water reuse and solar evaporators, has more potential for success. Salt marketing of residual salts depends on the quality of salts produced and the price of salt. The price will need to compete with abundant local and foreign markets.

Basinwide real-time management approaches can be promoted by districts through internal district policies. The CVRWQCB can also use its regulatory authority to encourage the districts or dischargers to promote these policies. Use of incentives, such as grants and low-interest loans for drainage reuse, drainage reduction, and improved irrigation efficiency, should be considered.

Proposed solution approaches involving DMC recirculation require coordination among government agencies, local districts, farmers, and other stakeholders. Many outstanding technical issues still surround the proposed DMC recirculation. Use of memoranda of understanding (MOU) and formation of working groups such as the San Joaquin River Management Program - Water Quality Subcommittee (SJRMP-WQS) (comprised of CRWQCB, Reclamation, DWR and Lawrence Berkeley National Laboratory [LBNL]) are recommended to gain user acceptance.

CALFED funding may be a significant source of funding for these proposed water quality actions. Government agencies, districts, and other stakeholders possess technical expertise and other resources needed to accomplish the actions. Existing programs both at the government and local level are important institutional resources that need to be utilized to the maximum extent.

None of the actions proposed here are expected to entirely solve the salinity problems. However, the combination of local-level actions and basinwide approaches will improve water quality to a large degree.

7.2 PROBLEM STATEMENT

Portions of rivers and the Delta are impaired by discharges from agriculture, wetlands, mines, industries, and urban areas. Significant amounts of TDS enter the rivers and the Delta from these sources. Natural tidal fluctuation (and resulting intrusion of sea water) is a major source of salinity in the Delta. Salinity primarily affects agricultural and drinking water beneficial uses of water.

Water intakes for drinking water and agricultural water supply in the CALFED study area have locally and seasonally elevated salt concentrations in excess of water quality objectives established to protect beneficial uses. Fish and wildlife also can be affected by locally and seasonally elevated salinity, with a potential for even more sensitivity due to specific ion toxicity. Seasonal and site-specific objectives for salt routinely are exceeded in some regions.

Water intakes for drinking water and agricultural water supply in the CALFED study area have locally and seasonally elevated salt concentrations in excess of water quality objectives established to protect beneficial uses.

Salinity in Delta export supplies is highly variable. When salinity is high, considerable impacts on local water management programs, such as groundwater conjunctive use and water recycling, occur. Impacts due to high salinity may result in local users abandoning such programs and reverting to imported supplies. Further, low-salinity SWP water is essential for blending purposes to extend the benefits of local water management programs.

The quality of source waters for various discharges must be considered. Supply water in the San Joaquin River watershed generally is higher in salts than supply water in the Sacramento River watershed. Salt loads from similar sources in different watersheds will, therefore, vary greatly because of the variability in the initial base salt load of the water supply. Some sources substantially discharge to land. Although such discharges will not immediately affect surface water quality, salt loading of groundwater may result in significant future effects.

The salt concentrations of water in the lower San Joaquin River and south Delta frequently exceed desirable levels for agricultural beneficial uses. The 700-micro siemens-per centimeter (µS/cm) 30-day running average specific conductance (or electrical conductivity) water quality objective for the San Joaquin River near Vernalis for the April to August period has been exceeded 54% of the time from 1986 through 1997 (Figure 12). The 1,000-µS/cm water quality objective for the September to March period has been exceeded 13% of the time. These rates of exceedance are higher than has been estimated for longer periods (using model studies) because of the high frequency of critically dry years between 1986 and 1997.

The salt concentrations of water in the lower San Joaquin River and south Delta frequently exceed desirable levels for agricultural beneficial uses.

Although agricultural drainage can be a major source of wastewater in the Sacramento River, the generally higher quality of supply water and higher river flows result in relatively little adverse impact on Sacramento River water quality. Water in the lower Sacramento River (at Freeport) is of much higher quality compared to the San Joaquin River (near Vernalis). The 340-µS/cm CVRWQCB objective for the Sacramento River at the I Street Bridge was not exceeded between water years 1985 and 1997. Figure 13 compares the water quality of the Sacramento and San Joaquin Rivers.

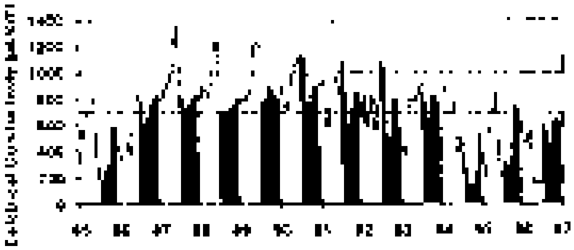

Figure 12. San Joaquin River near Vernalis 30-Day Running Average Electrical Conductivity

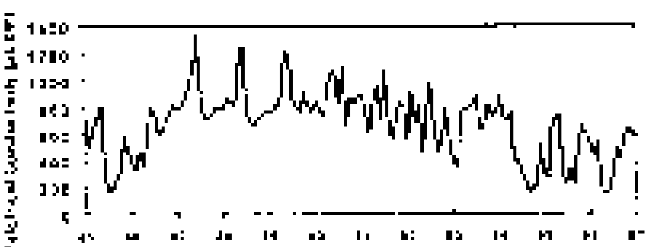

Figure 13. Comparison of Sacramento and San Joaquin River Water Quality

7.3 Objective

The primary objective is to reduce or manage salinity in the San Joaquin River and in the Delta Region to meet water quality objectives and protect beneficial uses by such means as relocating points of drainage discharge, improving flow patterns using flow barriers, reducing and managing drainage water, reducing salts discharged to these water bodies, real-time management, and using the assimilative capacity of the river through the DMC circulation. Currently, the timing of the discharges of drainage from the Grassland area is not coordinated with reservoir releases; consequently, the assimilative capacity of the San Joaquin River is frequently exceeded at the point of discharge and at Vernalis.

Protection of existing beneficial uses can be accomplished over the short term through a variety of solution approaches, but many of these approaches have limited long-term sustainability. An important secondary objective, therefore, is to implement solution approaches that do not adversely affect water quality in the San Joaquin River over the long term. It is not sufficient to consider short-term improvement of water quality in the San Joaquin River or the Delta as an assessment endpoint because such an assessment may ignore the long-term ability of sustaining such an improvement. The desired goal therefore must include the more complexly defined ability to achieve water quality objectives to protect beneficial uses and to meet those water quality objectives over the long term.

Protection of existing beneficial uses can be accomplished over the short term through a variety of solution approaches, but many of these approaches have limited long-term sustainability.

7.4 Problem Description

7.4.1 Lower San Joaquin River Basin Salt Balance

Salt balance is discussed here in the context of the lower San Joaquin River Basin because of the significant import of salt into the basin. No such import occurs in the Sacramento River Basin, except capture of high-quality water from adjacent watersheds. Water imports into the San Joaquin River Basin have high salt concentrations and loads because the water source is the Delta. Intake to the DMC is a mix of San Joaquin and Sacramento River water. In the absence of barriers in the south Delta, the San Joaquin River has, at times, provided the majority of the water exported back into the San Joaquin Valley, leading to a short- to long-term recycling of salts in the San Joaquin Valley. Solution approaches that do not consider salt balance in the San Joaquin Valley generally will have limited success over longer time periods.

Water imports into the San Joaquin River Basin have high salt concentrations and loads because the water source is the Delta.

Approximately 600,000 tons of salt per year, on average, were imported into the DMC service area on the west side of the San Joaquin River via the DMC between 1985 and 1994. Another 160,000 tons per year, on average, were imported into the west side via diversions from the San Joaquin River. Dissolution of in-situ salts averaged 250,000 tons per year for the same period, resulting in gross salt import and salt dissolution of 1,010,000 tons per year on the west side of the San Joaquin River north of the Mendota Pool. Mean annual salt exported out of the basin was approximately 770,000 tons per year, which includes 150,000 tons per year from tributaries on the east side of the San Joaquin River. The net discharge of salt from the west side of the San Joaquin River is

620,000 tons per year, suggesting an increase of 390,000 tons per year. This leads to increasing salt loading to the San Joaquin River via groundwater accretions. The 1985-1994 period for which data were available included an unusual number of dry years and, therefore, may not be representative of general conditions.

7.4.2 Local Actions

Surface agricultural runoff and subsurface agricultural drainage are the major sources of salt in the lower San Joaquin River Basin. Salt loading from agricultural drainage in the San Joaquin River leads to impairment of water quality in the lower San Joaquin River and south Delta. Surface agricultural runoff is also a significant source of salt in the Sacramento River, but salt concentrations of agricultural discharges in the Sacramento River watershed are substantially lower than in the San Joaquin River watershed. This, in part, is due to agricultural supply water of better quality (lower salinity) in the Sacramento River watershed than in the San Joaquin River watershed. Sacramento River flows are also generally much higher than the San Joaquin River, providing greater dilution flows and lower salt concentrations. Although the Sacramento River may have locally acceptable salt concentrations, increased background loads of salt in the Sacramento River make it a less effective source of dilution water for the much more saline San Joaquin River when mixed in the Delta.

Surface agricultural runoff and subsurface agricultural drainage are the major sources of salt in the lower San Joaquin River Basin. Salt loading from agricultural drainage in the San Joaquin River leads to impairment of water quality in the lower San Joaquin River and south Delta.

7.4.3 Sources

Surface agricultural runoff contributes a large load of salt to the San Joaquin and Sacramento Rivers, although at low concentrations relative to subsurface agricultural runoff. Surface agricultural runoff flows contribute salt load to the San Joaquin and Sacramento Rivers throughout the basins, compared with subsurface drainage with a much more limited areal extent (mostly in the San Joaquin River Basin). Salt in supply water can represent a large proportion of the salt in surface agricultural runoff. Irrigation supply water quality is therefore a critical factor in determining surface agricultural runoff water quality. In areas where water conservation measures (such as on-farm recycling) are used, surface agricultural runoff will, in general, be more saline than in areas using no recycling. Although a lower volume of water may be discharged through the use of conservation and recycling measures, remaining surface and subsurface drainage will contain elevated salt concentrations.

Salt in supply water can represent a large proportion of the salt in surface agricultural runoff.

Application of water in excess of leaching requirements leads to both increased surface agricultural runoff and increased salt leaching from the root zone. This excess salt leaching results in short- to moderate-term loading of salt to

Application of water in excess of leaching requirements leads to both increased surface agricultural runoff and increased salt leaching from the root zone.

groundwater and ultimately in indirect, long-term loading via groundwater accretions to surface waters if the salt is not removed. Surface agricultural runoff can result in additional adverse impacts due to other constituents of concern (see the "Pesticides" section). Although it is an important source of salt, surface agricultural runoff also may provide the majority of flow in the San Joaquin River upstream of the major east side tributaries during low flow periods. Surface agricultural runoff may at times exceed existing water quality objectives but still provide dilution flow relative to subsurface drainage and groundwater accretions.

Subsurface drainage is a much more concentrated source of salt than surface agricultural runoff. Subsurface drainage from specific geographic areas, such as the drainage problem area of the Grassland watershed in the San Joaquin River Basin, also are associated with adverse impacts related to selenium. High salinity in irrigation supply water can increase the need for additional water to leach imported and in-situ salts.

Subsurface drainage is a much more concentrated source of salt than surface agricultural runoff.

7.4.4 Impacts

Elevated salinity in the San Joaquin River leads to frequent exceedance at the Airport Way Bridge near Vernalis of existing water quality objectives for the San Joaquin River. Objectives for the San Joaquin River were established by the SWRCB to protect agricultural beneficial uses in the south Delta (Figure 6). These elevated salt concentrations also impair water quality exported from the Delta for agricultural, municipal, and industrial uses. Salinity is important to agriculture because in elevated concentrations it harms crops. Salinity also reduces the ability to reuse irrigation water and, thus, conserve fresh-water supplies. Salt in drinking water supplies is important because it can reduce the useful life of water systems and water-using equipment and appliances. Also, especially in Southern California where water supplies are blended, salt reduces the ability to stretch water supplies. In addition, high-salinity water is much less useful for water recycling, thus further inhibiting the ability to use water efficiently.

Fish and wildlife also can be affected by locally and seasonally elevated salinity levels. Frequent releases currently are made from New Melones Reservoir on the Stanislaus River exclusively to provide dilution flows in the San Joaquin River that are required to meet established water quality objectives. Current Basin Plan amendment work by the CVRWQCB likely will result in the geographic expansion of salinity water quality objectives in the San Joaquin River Basin. Seasonal environmental impacts to the environment can be related both to salinity and specific ion toxicity to some species.

Fish and wildlife also can be affected by locally and seasonally elevated salinity levels.

7.5 APPROACH TO SOLUTIONS

7.5.1 Local Actions

Local actions discussed below include source control and drainage reduction, reuse, reverse osmosis, cogeneration, and integrated on-farm drainage management.

Priority Actions

Source Control and Drainage Reduction

Agricultural drainage water volume could be reduced through reduction or elimination of unnecessary deep percolation that results from application of irrigation water in excess of leaching requirements and through the sequential reuse of drainage water on selected crops grown in the area. Salt application to the irrigated lands of the San Joaquin River Basin also could be reduced through conservation measures. The San Joaquin Valley Drainage Program (SJVDP) identified the most effective means of achieving higher irrigation efficiencies:

Agricultural drainage water volume could be reduced through reduction or elimination of unnecessary deep percolation that results from application of irrigation water in excess of leaching requirements and through the sequential reuse of drainage water on selected crops grown in the area.

- Improving management of irrigation systems;
- Adopting new or improving existing irrigation practices, including shortening furrows and installing tailwater return systems; and
- Improving irrigation scheduling.

Further, higher irrigation efficiency also can be achieved by sequentially reusing drainage water to irrigate salt-tolerant crops.

Adequate data are available from the large body of work performed by the SJVDP and UC Salinity Drainage Program to evaluate the feasibility and effectiveness of these methods. Ongoing work of the SJVDP, UC Salinity Drainage Program, San Joaquin River Management Program (San Joaquin River MP), and the Grassland Bypass Project has added to this knowledge base. Considerable data exist on drainage water management in the San Joaquin River Basin. Data on irrigation efficiencies in the Grassland area have been published by the districts, the CVRWQCB, and others. Published data indicate that irrigation efficiencies have indicate that irrigation efficiencies have improved significantly since 1990. Irrigation efficiencies up to 75% have been reported.

Data are lacking on the irrigation efficiencies on the lands that are not tile drained. Less data are readily available for the Sacramento River watershed.

Additional reductions in loading for source control, drainage reduction, and reuse (further discussed below) can be achieved through the following methods.

- Prepare salt reduction plans for each source of TDS (prepare water conservation plans and drainage and wastewater operation plans).

- Provide incentives for water conservation and drainage water use.

- Improve irrigation methods, irrigation management, and sequential reuse of drainage water (to improve water use efficiency).

- Use sprinkler irrigation combined with furrow irrigation to reduce drainage volume.

- Use salt-tolerant crops in a farm cropping system.

For all methods, adequate leaching of salts is required to prevent salt accumulation in the soil profile. Irrigation improvements can be accomplished by better irrigation technology, and water management can be encouraged by availability of low-interest loans to districts.

Irrigation improvements can be accomplished by better irrigation technology, and water management can be encouraged by the availability of low-interest loans to districts.

These actions could be encouraged by water districts (continued education and implementation of BMPs) and larger entities, such as the Grassland Area Drainers coordination of subsurface drainage as part of the Grassland Bypass Project. The promotion of on-farm salt management systems would significantly help to achieve these goals. The CVRWQCB could use its regulatory authority to require implementation of these actions (use of drainage operation plans). Establishment of water quality objectives upstream on the main stem San Joaquin River or development of TMDL allocations for affected water bodies would provide regulatory incentive for implementation of these actions. Use of incentives such as grants, low-interest loans for drainage reuse, tiered water pricing, and establishment of demonstration projects should be considered. CALFED should support establishment of water quality objectives upstream of Vernalis, development and implementation of BMPs, development of TMDLs, and financial incentives for salt control.

Existing institutional opportunities (such as district policies, agreements, MOUs, MAAs, ordinances, planning process, and technical assistance) must be used. The

San Joaquin River MP and the SJVDIP are two inter-agency programs that encourage implementation of in-valley drainage measures.

Reuse

The SJVDIP identified three forms of agricultural drainage reuse: recycling, blending, and sequential reuse. These methods reduce the volume of drainage water discharged to surface waters or even eliminate these discharges when combined with salt treatment, storage, or transport options. Relatively high-quality surface agricultural runoff could be reused with on-farm recycling and blending with other supply water to irrigate crops with low salt tolerance. More saline or unblended waters could be sequentially reused on salt-tolerant crops. Still more saline subsurface agricultural discharges could be collected and used for irrigation of salt-tolerant trees and halophytes (see "Integrated On-Farm Drainage Management" discussion below). Residual brines, while much decreased in volume, still would need to be processed through the combination of producing distilled water, evaporation of remaining water, salt recovery, and salt handling.

Drainage water reuse by blending and recycling will increase the concentration of salts in soils, which will adversely affect crop yield. Sequential reuse of drainage water is needed to enhance and sustain land productivity. If not properly managed, deep percolation of the concentrated salts could affect groundwater quality.

Drainage water reuse by blending and recycling will increase the concentration of salts in soils, which will adversely affect crop yield.

As with source control and drainage reduction, adequate data are available from the SJVDIP and UC Salinity Drainage Program to evaluate the feasibility and effectiveness of reuse methods.

Reverse Osmosis

Reverse osmosis is potentially a useful means of removing salts and trace elements from agricultural drainage water so that the water can be used as agricultural or other supply. Residual salts still would need to be used, stored, marketed, or disposed of. Reverse osmosis methods do not currently appear feasible due to high costs, although continuing research suggests costs could be reduced. Reverse osmosis may be economically justifiable if it produces salt and water as marketable commodities. The progress of reverse osmosis research and development efforts should be monitored by CALFED.

Cogeneration

Waste heat from thermal generation of energy could be used to further concentrate saline drainage water and produce distilled water. Residual salts still would need to be used, stored, marketed, or disposed of. Cogeneration methods do not currently appear feasible due to high costs but are subject to further research and development. Cogeneration may be economically justifiable if it produces salt and water as marketable commodities.

Integrated On-Farm Drainage Management

Integrated on-farm drainage management systems operate on the principle that drainage water, salt, and selenium are resources of economic value.

Integrated on-farm drainage management systems sequentially reuse drainage water to produce salt-tolerant crops and tree biomass, and concentrate the salinity of residual brines. Integrated on-farm drainage management systems operate on the principle that drainage water, salt, and selenium are resources of economic value. This concept distinguishes integrated on-farm drainage management from other drainage management approaches that view drainage water only as waste to be reduced and salt to be discharged. Residual salts would be used, stored, marketed, or disposed of. This approach has significant potential to reduce the discharge of salts to the San Joaquin River, thus improving salinity in the river and the Delta. This action requires installation of tile drains in the problem area, collection of drainage water, and sequential reuse on more salt-tolerant crops and plants, followed by discharge of brine to solar evaporators or other salt recovery facilities. This approach is a practical method of in-valley drainage and salt management.

Integrated on-farm drainage management systems must be managed in a way that prevents access of wildlife to potential sources of selenium. Evaporation ponds, which differ significantly from solar evaporators, can affect wildlife and the mitigation costs can be prohibitive. Wildlife safety is accomplished with minimal water ponding, combined with hazing. The objective of integrated on-farm drainage management is to substantially reduce drainage water, salts, and selenium discharged from farms into rivers and other water bodies.

Solar evaporators use only about 0.5% of the farmland area, which is a fraction of the land required by evaporation ponds (about 10% of the farmland). Evaporation ponds contain a few feet of standing water, while solar evaporators have no standing water or a fraction of an inch of water for a limited time.

Trees are a component of integrated on-farm drainage management systems that could create wildlife habitats in the otherwise nearly treeless environment of the San Joaquin Valley.

Trees are a component of integrated on-farm drainage management systems that could create wildlife habitats in the otherwise nearly treeless environment of the San Joaquin Valley. New habitats could enhance the ecological quality of irrigated farmland for the benefit of both agriculture (integrated pest management) and wildlife. In addition to providing windbreaks for crops and structures, trees also improve air quality.

Where concentration of selenium in drainage water is high, the integrated on-farm drainage management approach (similarly to other methods) may result, if not properly managed, in significant impacts on waterfowl. However, the integrated on-farm drainage management approach separates selenium flows from waterfowl by controlling the volume of water discharged into a solar evaporator to eliminate water ponding. Consequently, the solar evaporator does not attract waterfowl. The small area of a solar evaporator provides for efficient hazing, which further enhances wildlife safety.

The San Joaquin Valley growers are interested in this integrated on-farm drainage management system and view it as a practical farming method for managing salinity. As with any drainage management method, adequate leaching of salts to maintain soil productivity is a necessity and must also be an essential component of an integrated on-farm drainage management system. Deep percolation of concentrated salts, if not managed, could affect groundwater quality.

Where concentration of selenium in drainage water is high, the integrated on-farm drainage management approach (similarly to other methods) may result, if not properly managed, in significant impacts on waterfowl.

On-farm and districtwide source control, drainage reduction, and reuse should continue to be encouraged. Investigation of integrated on-farm drainage management, sequential drainage reuse, selection of salt-tolerant plants and trees, management of wildlife habitats, and salt and selenium separation concepts should continue. Potential uses of and markets for salt should be investigated. Additional demonstration projects and training programs for integrated on-farm drainage management systems should be developed.

Integrated on-farm drainage management and solar evaporators are being tested for their adequacy and operational feasibility in the San Joaquin Valley. Salt separation from drainage water is feasible, but salt purification and marketing requires additional studies. Presence of dust particles and trace elements may naturally affect the use of any salt, but this can be prevented by using appropriate salt recovery methods. Further research and development are needed on:

- The selection of salt-tolerant plants and trees;
- Complete utilization of drainage water through sequential reuse and solar distillation;
- Distillation (using solar or other sources of energy);
- Salt recovery, utilization, and marketing;
- Management of wildlife habitats;
- Sustainability of agriculture and environment; and

- Management of solar evaporators to assure protection of wildlife and groundwater

Existing Activities

Source Control and Drainage Reduction

The California Agricultural Water Management Planning Act requires all agricultural water suppliers delivering over 50,000 acre-feet of water per year to prepare an Information Report and identify whether the district has a significant opportunity to reduce drainage water volume through improved irrigation techniques. An MOU regarding efficient water MPs by agricultural water suppliers in California was signed in May 1997. This MOU provides a mechanism for planning and implementing cost-effective water MPs.

The SJVDIP continues to promote source control as one in-basin method to reduce salt loading in the San Joaquin Valley. Much work in this area has already been done under the guidance of the CVRWQCB through drainage operation plans.

Through 1992, the Grassland Area Farmers in the San Joaquin Valley increased irrigation efficiencies to just under 80% through water conservation. Additional increases in efficiency were realized associated with selenium load limitations imposed by the Grassland Bypass Project. Mechanisms such as tiered water pricing, low-interest loans, and other economic incentives have contributed to these increased efficiencies by Grassland Area Farmers. These increased efficiencies have greatly reduced and, in some cases, eliminated surface return flows but have only slightly reduced subsurface drainage. The Grassland Bypass Project is an example of a successful program that has improved water quality. The project enables the rerouting of agricultural drainage from a 97,000-acre area away from wetlands supply channels and into Mud Slough (and, ultimately, the San Joaquin River) via part of the San Luis Drain. The discharge, governed by a Use Agreement between the San Luis and Delta-Mendota Water Authority and Reclamation, is subject to WDRs issued by the CVRWQCB, which set limits on selenium discharges. The local water districts affected by the project formed a regional drainage district, enabling the growers to work together to reduce drainage and collectively manage and reduce selenium loads. While the project primarily has emphasized selenium management, the efforts of the Grassland Area Farmers also have led to reductions in the discharge of salts and boron from the area.

Through 1992, the Grassland Area Farmers in the San Joaquin Valley increased irrigation efficiencies to just under 80% through water conservation.

As a result of the Grassland Bypass Project, the amount of salt, boron, and selenium discharged by Authority members within the Grasslands area has been significantly reduced. In the 1999 water year, salinity was reduced by 32%, boron by 14%, and selenium by 48% of the historical levels of similar water-year types. These reductions should be discussed in the Water Quality Program, and the Grassland Bypass Project may be further developed as an element of the Water Quality Program Plan.

Opportunities for drainage management in the Delta also should be explored. Improvement in water use efficiencies in agriculture has been accomplished in various areas. More opportunities still exist.

Reuse

Reuse is a key element of the SJVDIP recommendations for drainage management. The intent of drainage reuse is to improve irrigation water use efficiency, hence reducing the volume of drainage requiring disposal. A simple drainage reuse increases soil salinity, however, and it prevents creating sustainable environmental and agricultural systems. In some cases, reuse of drainage cannot be accomplished without installation of tile drains. This action requires the installation of subsurface recirculation systems that can require substantial plumbing of the existing system. Reducing drainage water by reuse requires the installation of on-farm tile drainage for existing croplands and for salt-tolerant tree and halophyte plantings to enhance evapotranspiration. A total of 7,500 acres was recommended for drainage reuse in the Grassland area by 2000.

Reuse is a key element of the SJVDIP recommendations for drainage management.

Studies have continued based on proposals by the SJVDIP. Grassland Area Farmers were able to reduce salt loads discharged into the Grassland Bypass Project by 32% from previous years as a result of recirculation and other activities. Research on the potential for phytoremediation and volatilization of selenium in an agricultural drainage reuse system setting is continuing. Sequential reuse systems, in combination with water cycling or blending, are basic components of integrated on-farm drainage management systems currently being tested on several farms in the San Joaquin Valley.

Integrated On-Farm Drainage Management

Integrated on-farm drainage management has been practiced on several farms in the San Joaquin Valley. The Westside RCD manages experimental and demonstration projects. State and federal agencies and universities continue to develop and evaluate integrated on-farm drainage management systems. These activities include the management of drainage water, salt harvesting in a solar evaporator, salt processing, solar distillation of drainage water, the selection of trees and plant crops for highly saline conditions, and management of wildlife habitat. DWR, working with other agencies, districts, and growers, is developing integrated on-farm drainage management components. Management schemes are

Integrated on-farm drainage management has been practiced on several farms in the San Joaquin Valley.

being developed to assess the long-term viability of integrated on-farm drainage management. Research and demonstration projects are focusing on:

- Long term maintenance of soil conditions that ensure growth of trees and halophytes using high salt/boron content drainage water for irrigation.
- Identification of adverse wildlife impacts associated with integrated on-farm drainage management's irrigating with drainage water containing selenium and prevention of those impacts.
- Development of agronomic design and management of integrated on-farm drainage management to improve evapotranspiration, growth, and sustainability.
- Recovery or use and marketability of salts.

7.5.2 *Basinwide Actions*

Basinwide actions discussed below include water quality objectives, the quality of supply, real-time management, recirculation of DMC water, and salt disposal.

Priority Actions

Water Quality Objectives

Water quality objectives are set by the RWQCB to ensure protection of beneficial uses of a surface water. The RWQCB could use its regulatory authority to establish water quality objectives on the main stem San Joaquin River in the 130-mile segment that is listed on the CWA Section 303(d) list as impaired. Should corrective actions not result in achieving those water quality objectives, the RWQCB could develop TMDL allocations for affected water bodies, which would provide regulatory incentive for implementation of further actions to meet objectives. Use of financial incentives, such as grants, low-interest loans for drainage reuse, tiered water pricing, and establishment of demonstration projects, should be considered.

> Use of financial incentives, such as grants, low-interest loans for drainage reuse, tiered water pricing, and establishment of demonstration projects, should be considered.

- **Recommended actions:** CALFED should support establishment of water quality objectives, development and implementation of BMPs, development of TMDLs (as necessary), and financial incentives for salt control.

Improved Quality of Supply

Improved quality of water supply, specifically for water imported from the Delta, would result in lower salt concentrations of surface and subsurface drainage. Over the short term, salinity of surface runoff would be lower because of the direct effect of supply water quality on surface runoff. Salinity of surface return flows typically increase slightly above levels of the irrigation supply water. Over the longer term, the quality of subsurface drainage would improve and the quantity would be reduced because of the decreased need for leaching of salts in the root zone. Approaches to improving the quality of source water to the San Joaquin Valley would include reducing salts in Delta water by improving water quality through conveyance alternatives, such as isolated facility or through-Delta improvements, relocation of drainage from the Delta islands, and south Delta and Delta Region circulation barriers.

Improved quality of water supply, specifically for water imported from the Delta, would result in lower salt concentrations of surface and subsurface drainage.

South Delta barriers would improve water quality in some south Delta channels (although possibly worsen water quality in other channels) and thus improve water for Delta agriculture and export uses south of the Delta. South Delta barriers also could affect other urban users taking water from the central Delta. DWR's ISDP is designed to comply with all regulatory standards, including the salinity objectives in the May 1995 SWRCB WQCP for the Delta. Therefore, the operation of ISDP is not expected to result in significant adverse impacts due to non-compliance with any salinity standards. However, any increases in salinity at export facilities may result in additional treatment costs, which could be considered a significant adverse impact, even if the WQCP standards are being met.

South Delta barriers would improve water quality in some south Delta channels (although possibly worsen water quality in other channels) and thus improve water for Delta agriculture and export uses south of the Delta.

ISDP operational changes required to avoid potential adverse impacts on protected fish and wildlife positively affect water quality. Consequently, ISDP is currently reevaluating its salinity impacts, based on revised operating criteria resulting from ongoing Endangered Species Act (ESA) consultation.

Reducing salt import to the area of use should be considered. This action item includes south Delta barriers, intake relocation for urban users, discharge reduction or relocation for some Delta agricultural drainage, and the DMC circulation proposal. South Delta barriers can be used to manage drainage flows, tidal currents, and stages in the San Joaquin River, Middle River, and interconnecting channels. However, the impact of flow barriers on the quality of source water for CCWD and in-Delta users should be evaluated. One approach would be to investigate relocation of discharge points in the Delta away from source water intakes. Drainage discharge reduction in Old River and drainage reduction into Rock Slough will help improve water quality at CCWD intakes.

Reducing salt import to the area of use should be considered.

- **Recommended actions:** Identify drainage reduction measures for Delta islands, identify potential drainage discharge relocation projects, and study water quality benefits and ecological effects of south Delta barriers.

Real-Time Management

This approach proposes to actively manage the assimilative capacity of the San Joaquin River by controlling discharge of salts from agriculture and wetlands through an inter-agency program of real-time water quality management. The assimilative capacity of a water body is defined as the mass of a contaminant that a receiving water can accept without violation of the concentration limit for that contaminant, at a given rate of discharge of both source and receiving water bodies.

Opportunities for adjusting the timing of discharges and reservoir releases have been identified, although the practical constraints to such adjustments have not been thoroughly explored. By making such adjustments, temporal variations in water quality can be minimized and the frequency of violation of water quality objectives can be reduced. A real-time water quality management system, along with pollutant load reduction, could allow continued discharge of salt from agricultural lands and wetlands while minimizing impacts on the San Joaquin River and minimizing violations of water quality objectives.

The goal of real-time water quality management is to make multiple use of water that is already being stored or released for other purposes. For example, releases currently are being made from tributaries to the San Joaquin River for the explicit purpose of providing pulse attraction flows for fish; releases also are being made from New Melones Reservoir for the explicit purpose of providing dilution flows to meet water quality objectives at Vernalis (in accordance with SWRCB Water Rights Decision 1422). Coordination of existing reservoir releases for fish flows with existing discharges of salt can result in reducing overall reservoir releases needed explicitly to provide dilution flows. Real-time management applied in this example would result in water savings but would not reduce salt load to the river. Should dilution flows cease, the real-time management would use the assimilative capacity of the San Joaquin River. The CALFED Program is not requiring new releases of fresh water for dilution but seeks to use what is already available.

The goal of real-time water quality management is to make multiple use of water that is already being stored or released for other purposes.

Real-time management of the river for salinity may involve drainage recycling, which may affect crop yields if root zone salinity is not carefully managed. Short term surface storage may negatively affect wildlife, if the ponds are poorly designed or if water remains ponded during the wildfowl nesting season. This concept requires close cooperation between agencies without a history of coordinated interaction; consequently, some institution building will be required. Real-time management shifts the temporal distribution of salt loads. Therefore,

Real-time management of the river for salinity may involve drainage recycling, which may affect crop yields if root zone salinity is not carefully managed.

concentrations of salinity could increase during some periods, which may result in an environmental impact.

Previous real-time water quality modeling efforts in the Grassland Basin primarily focused on screening-level assessments of operational constraints on, and opportunities for, agricultural drainage discharges. Reclamation developed a sophisticated planning model that considered several alternatives to meet selenium and boron water quality objectives in the San Joaquin River. The alternatives considered were irrigation improvements, drainage water reuse, land retirement, and the use of holding reservoirs to regulate the release of drainage to the river. These alternatives were optimized to minimize the size of the regulating reservoirs and to ensure that the constraining water quality objective (selenium or boron) was not exceeded.

The results of the modeling analysis suggested that, with investments in drainage recycling facilities and the construction of regulating reservoirs with a total capacity of 4.3 million cubic meters, water quality objectives could be met at all times. The Reclamation model assumed perfect forecast and response to receiving water assimilative capacity and that the water quality of irrigation water and groundwater pumpage remained constant over the simulation period. During the first year of the Grassland Bypass Project, considerable investment was made by water districts in the Grassland Basin in facilities to allow recycling of subsurface drainage water and to prevent co-mingling of tailwater and subsurface drainage water. Sumps were retrofitted with controllers to allow tile drainage systems to be shut down during high rainfall-runoff periods, allowing more control over drainage discharge and mass loading of salts and other contaminants. Continued investment in these types of technologies and adaptive management to continually refine the operation of these systems will be needed to achieve SJVDIP goals.

- **Recommended actions:** Encourage coordination among diverters and dischargers and other beneficiaries of the San Joaquin River, and provide incentives for coordination and implementation of measures that help to manage salinity in the San Joaquin River.

Recirculation of Delta-Mendota Canal Water

A project has been proposed by south Delta stakeholders to temporarily store drainage water from the Grassland area (agricultural drainage and wetlands releases) from March until April 15 and also to circulate DMC water during drainage release from April 16 to May 15. The proponents contend that the project would help to meet the pulse flow requirements at Vernalis, per the 1994 Bay-Delta Accord, and would improve water quality in the south Delta. The circulation of water in the river and the Delta, combined with south Delta barriers, may help to improve water quality in parts of the Delta.

The circulation of water in the river and the Delta, combined with south Delta barriers, may help to improve water quality in parts of the Delta.

Utilizing periods of high rainfall runoff, fish flow releases, and other periods of high assimilative capacity in the San Joaquin River has been demonstrated by the San Joaquin River MP-WQS to have potential for reducing violation of water quality objectives at Vernalis. Recirculation of Delta water and discharge at Newman Wasteway or Mendota Pool increase the assimilative capacity of the river for salts and other contaminants, and improve the water quality in the river. Urban water users have voiced concerns on the potential impacts of the proposed circulation on the quality of water in the central Delta and at the intake locations. DMC recirculation requires holding water in wetlands and agricultural lands, which may result in an impact. Circulation of water may affect the fisheries, water supply exports at the SWP and DMC, and water quality in the CCWD intakes. Other issues, such as potential impacts on sediment transport from Newman Wasteway to the river and flooding, have not been studied.

Simulation results indicate that salinity would be reduced at Vernalis during drainage retention periods, and that salinity would not change during periods of circulation and release of drainage water. However, salinity would be reduced during drainage retention and during circulation upstream of Vernalis. If south Delta barriers were operating during circulation, water quality for agricultural use in the south Delta would be improved. This improvement in water quality for the south Delta would result in less salts discharged to the Delta channels. If less salts are discharged to the Delta channels and the Delta outflow is the same, long-term water quality should be improved at the intake location (CVP and perhaps SWP and CCWD intakes). The use of Delta barriers would divert the river water from the south Delta to the central Delta and thus improve the quality of water to agriculture in the south Delta and export uses south of the Delta. At this time, however, the beneficial and adverse impacts of these actions on the water quality at the state and federal diversion points and at the CCWD water intakes are unknown. It appears that the circulation would reduce the fish flow release requirements by about 2,000 acre feet.

The DMC proposal predicts some improvement in water quality in the river and the south Delta. The next step would be to conduct more studies, including modeling, to identify and evaluate the impacts on fisheries, on the SWP and DMC export, and on water quality for CCWD. Studies also are needed to determine whether such an action would conflict with state and federal policies or laws concerning water quality degradation.

The next step would be to conduct more studies, including modeling, to identify and evaluate the impacts on fisheries, on the SWP and DMC export, and on water quality for CCWD. Studies also are needed to determine whether such an action would conflict with state and federal policies or laws concerning water quality degradation.

- **Recommended actions:** This proposal is controversial because some CALFED agencies believe that such a project could violate state and federal policies against water quality degradation, while other CALFED agencies do not agree. This proposal will need to be formulated in detail to determine whether it would conform to these policies. It is understood that the current configuration of the pumping systems and the conveyance systems may not support such a project and that considerable improvements would be necessary. The project also would significantly increase energy costs for facility operations. When a detailed proposal has been formulated, numerical modeling and simulation studies would be conducted to examine the benefits and impacts on the Delta, fisheries, the export water users, and physical systems. If the results appear promising and consistent with non-degradation policies, a demonstration project would be implemented.

Salt Disposal

Salt disposal requires transport out of the valley, long-term in-valley storage, or use of residual salts as a commodity. Currently, the San Joaquin River is the conduit for out-of-valley salt disposal. Reducing water quality impacts of this disposal on the San Joaquin River and Delta could ultimately require construction of an out-of-valley drain or other conveyance mechanism to transport salt from the San Joaquin Valley. An out-of-valley drain could convey saline water to the Pacific Ocean either directly or through the Bay and Delta.

- **Recommended** actions: The out-of-valley drain proposal is very controversial, with suspected negative ecological impacts, and therefore is not recommended as a priority action.

Information Needed

Water Quality Objectives

To establish water quality objectives, the RWQCB needs information on the effects of elevated salt concentrations on the beneficial uses. Monitoring of the spatial and temporal extent of elevated salts, coupled with special studies to determine effects of elevated salts, will provide the necessary information for establishment of water quality objectives. CALFED should support the monitoring and studies.

> To establish water quality objectives, the RWQCB needs information on the effects of elevated salt concentrations on the beneficial uses.

Improved Quality of Supply

Information on CALFED alternatives can be found in the Programmatic EIS/EIR, and information on the south Delta barriers can be found in DWR's Draft EIR/EIS (DEIR/EIS) for the ISDP. DWRDSM modeling performed subsequent to release of the DEIR/EIS depicts salinity changes due to ISDP for 71 years of hydrology. No detailed feasibility analysis has been conducted for the DMC circulation proposal. The impact analysis in Section 5.3 in the CALFED Programmatic EIS/EIR contains data on the water quality of supply water from the Delta. Additional modeling work would be required to estimate the long-term impact of improved water supply water quality on agricultural drainage salt loading to the Delta.

Real-Time Management

Modeling studies have been conducted to forecast potential opportunities for river discharge. The CVRWQCB published a report on the water quality data in the San Joaquin River from 1985 to 1995.

The techniques required to collect and transmit flow and stage data are well established. In California, public water agencies such as DWR, Reclamation, and the USGS measure flow and stage routinely for a variety of applications. The California Data Exchange Center, a branch of DWR, provides river stage and flood warning information on a real-time basis. The major clients of this system are local and state agencies concerned with flood management and the provision of emergency services. Agencies such as the Corps use this information to determine reservoir release schedules during high runoff periods.

The real-time water quality management system under development for the San Joaquin River Basin takes advantage of some of the features of the existing hydrologic data acquisition and forecasting programs. Unique aspects of the real-time water quality management system that are not replicated by current programs are:

The real-time water quality management system under development for the San Joaquin River Basin takes advantage of some of the features of the existing hydrologic data acquisition and forecasting programs.

- Use of automatic electronic water quality sensors. Currently, only EC, temperature, and pH are continuously logged. A number of other constituents of concern that are present in California's river systems cannot be measured on an automatic level.

- A continuous and integrated system of data error checking and validation because the data are used for regulatory purposes.

- Addition of control systems that can be used to manage agricultural and wetland drainage water flow and water quality.

- Institutions that coordinate actions and responses of regulators, operators, and other public and private entities; and long-term commitment by agencies to support real-time data collection and water quality forecasting efforts.

Recirculation of Delta-Mendota Canal Water

Preliminary modeling results are available for reduction of fish flow releases due to proposed DMC circulation and recirculation of discharge of drainage water to the river. Further studies of water quality effects are needed to determine the proposal's technical feasibility and its consistency with state and federal non-degradation policies for water quality. Studies also are required to determine whether this action could be incorporated into the operation of the CVP. It is understood that the current configuration of the physical systems may not support such a project and that considerable improvements would be necessary.

Considerable data show a salt imbalance in the San Joaquin Valley, but more work must be done to fully assess the feasibility of salt storage or marketing and the impacts of drainage at specific locations.

Salt Disposal

Considerable data show a salt imbalance in the San Joaquin Valley, but more work must be done to fully assess the feasibility of salt storage or marketing and the impacts of drainage at specific locations.

Existing Activities

Improved Quality of Supply

Operation of south Delta barriers to improve fish migration and water levels in Old River, Middle River, and Grant Line Canal restrict the diversion of San Joaquin River water into south Delta channels and can help to improve water quality in some locations. The ISDP proposes to install flow-control structures to improve water levels and circulation in south Delta channels. Water quality in the south Delta is influenced in varying degrees by natural tidal fluctuation, San Joaquin River flow and water quality, CVP and SWP export pumping, local agricultural diversions and drainage water, inadequate channel capacity, and regulatory constraints. When the CVP and SWP are diverting water, water levels in local channels can be drawn down, affecting the availability of water at local diversion points. In combination with tidal cycles, diverging and converging flows can occur in some channels, creating isolated "null zones," areas where net flows over a complete tidal cycle approach zero. Because of the generally poor quality of water coming down the San Joaquin River, and because agricultural diversions discharge poor-quality water into channels that are narrow and shallow, isolated portions of channels where null zones or low flows occur can become stagnant. Therefore, the south Delta flow-control structures are being proposed to improve water levels and water circulation in south Delta channels, to eliminate null zones, and to correct water circulation problems in south Delta channels that result from the SWP and CVP operations.

When the CVP and SWP are diverting water, water levels in local channels can be drawn down, affecting the availability of water at local diversion points.

The three CALFED conveyance alternatives, if modified to provide water of good quality for the south Delta, CCWD, and export south of Delta, would improve water quality. These alternatives are not discussed in this report. No drainage discharge point relocation has been identified, but CCWD proposes elimination of the Veale Tract agricultural drainage into Rock Slough and reduction of the local drainage into Old River in the vicinity of the district's intake.

The three CALFED conveyance alternatives, if modified to provide water of good quality for the south Delta, CCWD, and export south of Delta, would improve water quality.

Opportunities for real-time management of drainage discharge are being explored. CALFED has recently funded a project by the SJRMP-WQS (consisting of staff from DWR, CVRWQCB, and LBNL) to conduct studies of real-time water quality management. Past analysis using mass balance models of the river suggest that considerable opportunity exists for improved coordination of drainage discharges and reservoir releases to more efficiently use the river's assimilative capacity for salts.

The SJRMP-WQS was awarded a grant in 1994 to demonstrate that improved management and coordination of tributary releases and agricultural drainage from west side sources could significantly reduce the frequency of violations of water quality objectives for salinity, selenium, and boron on the river. The SJRMP-WQS developed a decision support system that retrieves current flow and water quality data and allows forecasts of river assimilative capacity to be made for salinity at Vernalis. These forecasts will become increasingly useful to water districts and other agencies for timing and coordinating flows and loads from agricultural fields, wetlands, and wildlife refuges on the west side with east side reservoir releases for salmon migration, recreation, and water quality.

The SJRMP-WQS developed a decision support system that retrieves current flow and water quality data and allows forecasts of river assimilative capacity to be made for salinity at Vernalis.

Salt Disposal

The SWRCB's DEIR for Implementation of the 1995 Bay-Delta WQCP, November 1997, Chapter VIII states:

> The existing CVRWQCB Basin Plan states that there are two major options for the disposal of salts produced by irrigated agriculture: out-of-valley export and discharge to the San Joaquin River. The plan states that a valley-wide drain remains the best technical solution to the water quality problems of the San Joaquin River and Tulare Lake Basins caused by agricultural drainage (VIII-14.)

Some districts in the San Luis Unit of the CVP have been engaged in litigation against Reclamation, claiming that Reclamation is obligated to provide drainage facilities. This matter was decided in favor of the plaintiffs and is currently before the federal court of appeals. Several parties interested in water quality of the delta were jointly opposed to the construction of a drainage facility. In a related matter, Westlands Water District (WWD), Reclamation, and the SWRCB began preparing an MOU two years ago, whereby WWD, SWRCB, and Reclamation would proceed with environmental documentation needed to evaluate alternatives for a long-term drainage solution, including a permit for disposal of drainage through a constructed drain. There has been no progress on this MOU in 2 years, but Reclamation has indicated its intent to reinitiate this process.

7.5.3 *Evaluation of Other Sources of Salinity*

An evaluation of salt discharges from urban runoff and wastewater and from industrial plant discharges has been combined in this section so that the relative magnitude of these loadings can be easily compared and contrasted. In addition to loading from these sources, this program action has been expanded to include all sources of salt, except for irrigated agricultural. This expansion of scope will allow:

> An evaluation of salt discharges from urban runoff and wastewater and from industrial plant discharges has been combined so that the relative magnitude of these loadings can be easily compared and contrasted.

- Ranking of all non-agricultural sources of salt relative to one another and relative to irrigated agricultural sources.
- Inclusion of other significant salt sources, such as wetland discharges and dairies.

In addition, the scope has been expanded to include other beneficial uses that are affected by salinity. Environmental, agricultural, municipal, and industrial beneficial uses will be considered. Sources in the San Joaquin River, Sacramento River, and the Delta will be considered.

This action item specifies the need to evaluate loading of salt from a variety of sources and over large geographic areas. Possible approaches to perform this evaluation are:

- Compile readily available data for all sources from CALFED cooperating agencies.
- Evaluate and rank sources based on existing reports.
- Establish monitoring programs to monitor and evaluate specific sources.

Sources

The following non-agricultural sources of salinity must be quantified:

- Urban runoff
- Wastewater treatment plants
- Industrial discharges
- Wetlands
- Mine drainage
- Other sources, such as dairies and fertilizer

Note that sea water intrusion is not considered here.

Each of these sources may have individual components that will require additional study. Wastewater treatment plants, for example, may contain a large volume of salt contributed from municipal sources such as water softeners. Specific sources may be limited in geographic extent or be more significant in only one of the river basins or the Delta.

Impacts

Effects of elevated salt concentrations on the beneficial uses must be quantified. A survey of beneficial uses and impacts of salinity in the San Joaquin River Basin can be found in the Regional Board Amendment Addressing Salinity and Boron that was prepared by the CVRWQCB in 1988. The following beneficial uses are considered in the amendment:

Effects of elevated salt concentrations on the beneficial uses must be quantified.

- Drinking water and human health impacts.
- Industrial use and economic impacts.
- Agriculture uses and impacts related to productivity, increased water usage, and economics.
- Environmental uses and impacts related to aquatic habitat.

Approach to Solution

Priority Actions

Salt is widely distributed throughout the San Joaquin-Sacramento River and Delta system. Salinity of water supplies is increasing with the increased reuse of water as a means of conservation. Salt from all sources similarly affects beneficial uses (exclusive of specific ion toxicity and other specific ion sensitivities). The largest sources of salt need to be identified so that appropriate actions to reduce salt loading from these sources can be developed. Sources of salt need to be quantified and ranked in order of magnitude of impact, including an assessment of the effect of controlling specific sources on the ability to meet water quality objectives. A combination of the following approaches can be used to obtain the information necessary to evaluate the relative loading of salts.

Salinity of water supplies is increasing with the increased reuse of water as a means of conservation.

1. Estimate and rank sources based on existing reports.

   Obtain reports from cooperating CALFED agencies and other entities to generate a ranked list of salt loads:

   - Quantify salt load of non-agricultural sources by type.

- Quantify salt loads by region
- Identify location and magnitude of beneficial use impairment
- Identify data gaps
- Identify specific approaches to reduce loading for each type and area of discharge

After initial ranking, present a range of specific approaches that should be considered for each type and area of discharge, such as wetlands in the San Joaquin River versus wastewater treatment plants in the Sacramento River. A listing of possible solution approaches for the specific sources then can be developed, including restricted timing of releases, changes in management, and more restrictive NPDES permits.

2. Compile readily available data for all sources from CALFED cooperating agencies and other entities.

3. Compile more detailed data from cooperating agency files (such as salinity data from NPDES permits) that are not readily accessible. This step will require an increased investment in time and cost, compared to acquiring the readily available data.

4. Establish monitoring programs to monitor and evaluate specific sources.

5. Prepare a report that identifies salinity impacts, the sources that reduction measures are slated to improve, costs for improvements, and redirected impacts and associated costs.

Information Needed

The CVRWQCB is compiling load and concentration data for all sources of salt in the San Joaquin River Basin, based on a survey of NPDES permits and water quality model data. Similar data will need to be compiled for the Sacramento River Basin and the Delta.

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Existing Activities

Existing activities include the SJRMP-WQS real-time management effort, the Sacramento River Watershed Program, the CVRWQCB Salinity Basin Plan Amendment Process, the CVPIA wetland water supply, the Grassland Bypass Project, and the SJVDIP.

8. SELENIUM

8. Selenium

8.1 Summary

Selenium is a semi-metallic trace element that is widely distributed in the earth's crust at levels less than 1 milligram per kilogram (mg/kg) and with chemical properties similar to sulfur. Selenium is naturally abundant in the marine shale sedimentary rocks and soils weathered from the rocks of the Coast Ranges west of the San Joaquin Valley. The natural source of selenium in the San Joaquin Valley is erosion of the mountain soils, followed by deposition of sediment in the valley, forming the parent material for valley soils. Accelerated mobilization and transport of selenium into valley aquatic ecosystems occurs when the selenium-bearing geologic formations and soils are subjected to large flood events or disturbed by land uses such as road building, over-grazing, mining, and irrigated agriculture.

Selenium can be highly toxic to aquatic life at relatively low concentrations but is also an essential trace nutrient for many aquatic and terrestrial species. Selenium can exist in several different oxidation states in water, each with varying toxicities, and can undergo biotransformations between inorganic and organic forms. The biotransformation of selenium can significantly alter its bioavailability and toxicity to aquatic organisms. Selenium also has been shown to bioaccumulate in aquatic food webs, which highlights dietary exposures to selenium as a significant exposure pathway for aquatic organisms.

8.2 Problem Statement

Irrigation water applied to agricultural lands in the Grassland area of the west side San Joaquin Valley leaches selenium from the soil to the shallow groundwater table. Tile drains have been installed on some farm acreage in order to reduce the harmful effect of shallow groundwater and salt reaching the crop root zone. These drains have resulted in unintentional acceleration of selenium leaching and discharge of selenium-laden drain water into drainage ditches and the surface waters of the San Joaquin Valley. Consequently, portions of the San Joaquin River and its tributary, Mud Slough, contain elevated levels of selenium. Waterborne selenium concentrations in affected channels and sloughs frequently exceed levels considered safe for fish and wildlife species. In addition to selenium, agricultural drainage waters also contain elevated levels of boron and salts (refer to discussion under Section 7, "Salinity").

8.2.1 Current Regulatory Status

The EPA listed San Pablo Bay, Carquinez Strait, and Suisun Marsh as impaired water bodies in 1990 due to elevated selenium levels in diving ducks, which had triggered health advisories. The SFBRWQCB amended discharge permits for each of the oil refineries with the highest selenium loading to include an effluent limit of 50 ppb (daily maximum) and a mass-based limit (in pounds per day) related to the average annual flow rate and the 50-ppb concentration limit. The aquatic life criteria at that time was 71 ppb. In 1992, the EPA established an aquatic life criteria of 5 ppb for the entire Bay-Delta estuary because the salt water criteria appeared to be underprotective, as evidenced by the high potential for selenium bioaccumulation and increasing levels of selenium in Bay organisms.

The EPA listed San Pablo Bay, Carquinez Strait, and Suisun Marsh as impaired water bodies in 1990 due to elevated selenium levels in diving ducks, which had triggered health advisories.

The National Toxics Rule established the more protective fresh-water effluent limitations for the estuary for similar reasons. Several Petitions for Review were filed by various parties that ultimately were dismissed by the SWRCB because the SFBRWQCB was to address the issues. Cease and Desist Orders related to selenium discharges were issued to three refineries, requiring implementation of full-scale treatment systems or control or removal strategies by 1998. All three refineries – Tosco, Shell, and Exxon – started full-scale treatment facilities and are currently in compliance.

The SFBRWQCB determined that treatment technologies would provide the greatest emission reduction and the fastest and most economical methods to achieve selenium reduction, compared to conversion to a cleaner crude oil. Bench-scale and pilot-scale testing has occurred throughout the 1990s, and more detailed evaluations and implementation of the most promising technologies continue. Control strategies include waste stream treatment (ion exchange, biochemical treatment, and iron co-precipitation), sour water reuse, the use of an alternative crude oil, and wetland discharge. Additional environmental studies (impacts on resources, selenium-mercury interactions, immunosuppression, site-specific bioconcentration factors, and seleno-amino acids) are needed to guide resource agencies, regulators, and dischargers on improving current regulatory goals and source control actions.

The CVRWQCB has set water quality objectives for selenium and an implementation timetable for the San Joaquin River to protect beneficial uses. These objectives are most difficult to meet in the San Joaquin River just downstream of where Mud Slough discharges. In certain months, these water quality objectives have been exceeded. Further downstream, east side tributaries provide dilution water, which tends to lower the concentrations.

8.2.2 Data Gaps

No two refineries use the same processing methods or similar amounts of San Joaquin Valley crude oil in their facilities. Thus, identifying and implementing the best treatment technologies for each waste stream in each refinery have been difficult. Continued work is needed to improve the current treatment technologies and to develop new ones.

Tissue monitoring has documented selenium in bivalves (such as clams), fish, and waterfowl at concentrations known to cause impacts in similar species; but no studies have fully documented the extent of impacts that may be occurring. Additional study is needed to guide resource agencies, regulators, and dischargers on fine tuning current or proposed regulatory goals and source control actions. Data gaps include:

Additional study is needed to guide resource agencies, regulators, and dischargers on fine tuning current or proposed regulatory goals and source control actions.

- Selenium bioconcentration factors from water to low trophic-level organisms (algae).
- Impacts of selenium on the reproduction of fish and waterfowl in the Bay-Delta area.
- Impacts of selenium and mercury interactions.
- Other chronic impacts on fish and wildlife, such as immunosuppression and sensory damage.
- Bioaccumulation rates and impacts of selenium in an estuarine environment versus a fresh water environment.
- Evaluation of various seleno-amino-acids in biota to establish the toxic and ecotoxic mechanisms of selenium, critical to the establishment of site-specific water quality criteria.

8.3 Objective

The objective is to reduce the impairment of environmental beneficial uses in the Delta Region and in the lower San Joaquin River that is associated with selenium concentrations and loadings.

8.4 Problem Description

8.4.1 Sources

Selenium in the lower San Joaquin River and Bay and Delta Regions originates primarily from two sources: sub-surface agricultural drainage discharged from the Grassland area on the west side of the San Joaquin Valley through Mud Slough, and waste streams from oil refineries in the Suisun Bay and Carquinez Strait area. The selenium is a byproduct of the crude oil refining process. San Joaquin Valley crude oil, used primarily by Bay Area refineries, has from 2 to 12 times higher levels of selenium compared to crude oil from other sources. Substantial amounts of selenium also are conveyed to the San Joaquin River in natural storm runoff in years with high rainfall, primarily by Panoche and Silver Creeks.

Selenium in the lower San Joaquin River and Bay and Delta Regions originates primarily from two sources: sub-surface agricultural drainage discharged from the Grassland area on the west side of the San Joaquin Valley through Mud Slough, and waste streams from oil refineries in the Suisun Bay and Carquinez Strait area.

Annual selenium loads in the San Joaquin River near Vernalis between 1986 and 1995 averaged 4,040 kg (8,906 pounds), with a range of 1,615–7,819 kg (3,558–17,238 pounds). The maximum load was in 1995, while the lowest load was in 1992. In 1991, the average riverine selenium loads that reached the estuary were approximately 2 kg/day (730 kg), while refinery loads averaged 7.1 kg/day (2,592 kg), and municipal loads averaged 2.2 kg/day (803 kg). The estimated loads from municipal sources are based on limited data; concentrations of selenium in these discharges have met the 5-µg/l criteria. The riverine load infrequently reaches the estuary, as flows are generally insufficient and south Delta diversions draw most of the San Joaquin River water throughout the year. Only during heavy spring runoff does a significant portion of this load reach the central Delta and North Bay areas. Consequently, the selenium loads from oil refinery and municipal treatment plant activities result in the most significant impacts on the North Bay area, particularly during low riverine flow periods. From 1959 to 1992, the average annual selenium load from refineries was 2,162 kg (4,766 pounds).

8.4.2 Biological Effects of Selenium

Although selenium is an essential nutrient, levels of safe dietary uptake are narrowly bounded on both sides by adverse-effects thresholds, thus distinguishing selenium from other nutrients. Excessive levels of selenium in the diet result in reproductive impairment, poor body condition, and immune system dysfunction; similar problems are seen in low-selenium diets. Adequate human dietary levels (from food) is generally 0.1–0.3 micrograms per gram (µg/g), but the toxicity

Excessive levels of selenium in the diet result in reproductive impairment, poor body condition, and immune system dysfunction; similar problems are seen in low-selenium diets.

threshold for sensitive animals is only 10 times higher at around 2 µg/g. Data suggest regulatory standards for selenium should be placed no more than 10 times higher than normal background levels for an adequate margin-of-safety (unless species-specific or site specific data justify a variance from the general rule).

In fresh water ecosystems, normal background levels of selenium in water range from 0.1 to 0.4 µg/l. Estuarine and marine ecosystems contain selenium levels in water ranging from 0.009 to 6.0 µg/l, but most levels are less than 1.0 µg/l. Sediment background levels are below 1.0 µg/g, while levels in aquatic plants are generally below 1.5 µg/g. Normal selenium levels in fish and invertebrates (whole body) are usually less than 2.0 µg/g but have been reported as high as 4.0 µg/g. Whole-body levels in reptiles, amphibians, and birds are also less than 2.0 µg/g. In mammals, tissue levels of selenium typically average less than 2 µg/g.

Selenium occurs in natural waters primarily in two forms, selenate and selenite. Wastewater related to fossil fuel and similar sources contains mostly selenite. Drainwater from irrigated agriculture contains mostly selenate. Based on traditional bioassay measures of toxicity (24- to 96-hour exposure of an aquatic organism to contaminated water without selenium in the diet), selenite is more toxic than selenate to most aquatic organisms. Also, selenite is more readily accumulated by biota into the food chain than selenate. Direct contact with selenium in the water has only a minor effect on aquatic organisms. Adverse effects levels for selenate and selenite are generally above 1,000 µg/l. Sulfate in the water can lessen the effects of short-term exposure to high levels of selenate in agricultural drainwater but does not appear to effect the overall bioaccumulation potential of low levels of selenium.

Selenium occurs in natural waters primarily in two forms, selenate and selenite. Wastewater related to fossil fuel and similar sources contains mostly selenite. Drainwater from irrigated agriculture contains mostly selenate.

As little as 0.1 µg/l of selenomethionine, an organic form of selenium, can accumulate in zooplankton to an average level of 14.9 µg/g total selenium. This level of selenium in zooplankton, if fed to most species of fish, would cause dietary toxicity. Only 3.2 µg/g selenium in the diet was sufficient to adversely affect early life stages of chinook salmon under controlled conditions. Salmonids are very sensitive to selenium pollution. Survival of juvenile rainbow trout (*Oncorhynchus mykiss*) was reduced when whole-body levels of selenium exceeded 5 µg/g. Smoltification and sea water migration among juvenile chinook salmon (*Oncorhynchus tshawytscha*) were impaired when whole-body tissue levels reached about 20 µg/g. Mortality among larvae, a more sensitive life stage, occurred when levels exceeded 5 µg/g. Bluegill embryos resulting from ovaries containing 38.6 µg/g selenium exhibited 65% mortality.

The interactive effects of winter stress syndrome and selenium on fish are important even for waters containing less than 5 µg/l selenium. These effects should be a critical part of selenium hazard assessments. The effects of other forms of stress (such as cold weather, migration, smoltification, disease, and parasites) could be increased due to dietary exposure to selenium. More than 60 years ago, it was noted that chickens exposed to elevated levels of dietary selenium were susceptible to diseases. More recently, this susceptibility was confirmed for mallard ducks. Numerous other studies have confirmed selenium-induced immune system problems in wildlife.

> Numerous studies have confirmed selenium-induced immune system problems in wildlife.

A very strong effect between the combination of dietary selenium and mercury in mallard hens has been reported. Selenium protected the adults from the effects of mercury, but the mercury increased the effects of selenium on the embryos in eggs laid by the adults. Selenium and mercury together in the diet of the adult hens led to significantly enhanced rates of embryo deformities (73.4% versus 36.2%) and embryo death (98.6% versus 76%). Elevated mercury levels in the North Bay and Delta due to historical mining activities and other discharges may increase the risks of selenium exposure.

8.4.3 *Selenium Risk Guidelines*

Attempts to manage risk by assessing concentrations of selenium in water is troublesome. Measurements of water column concentrations of selenium are imperfect, and measures of total selenium loading and food web bioaccumulation are uncertain. For example, a low level of waterborne selenium can be measured either because total loading into the system is low (a low potential for hazard to fish and wildlife) or because rapid biotic uptake or sediment deposition from elevated loading has occurred (a high potential for hazard to fish and wildlife).

> Water levels of selenium are useful guides for risk management only to the extent that they protect aquatic food chains from excessive bioaccumulation of selenium.

Water levels of selenium are useful guides for risk management only to the extent that they protect aquatic food chains from excessive bioaccumulation of selenium. The current EPA chronic criteria for selenium is 5 µg/l. Site-specific criteria for water delivery channels in the Grassland area of the San Joaquin Valley is 2 µg/l to protect wetland uses. Numerous peer-reviewed papers, using different evaluation methods, recommend that to protect aquatic and semi-aquatic organisms, water concentrations of selenium should be from around 0.9 to 2.0 µg/l. A summary of field data shows that fish and wildlife toxicity commonly occurs in nature at waterborne selenium levels below 5 µg/l, supporting recommendations from researchers. Selenium bioaccumulates rapidly in aquatic organisms. A single pulse of selenium (≥10 µg/l) into aquatic ecosystems could have lasting ramifications, including elevated selenium levels in aquatic food webs.

> A single pulse of selenium (>10 µg/l) into aquatic ecosystems could have lasting ramifications, including elevated selenium levels in aquatic food webs

Toxicity to fish and wildlife ultimately is determined by how much selenium moves into the food web. Therefore, tissue levels of selenium are more useful in developing risk guidelines. Based on a review of more than 100 papers, the following toxic effects thresholds for the overall health and reproductive vigor of fresh-water and anadromous fish exposed to elevated levels of selenium was recommended by one researcher: whole body (4 µg/g), skinless fillets (8 µg/g), liver (12 µg/g), and ovary and eggs (10 µg/g). This individual also recommended 3 µg/g as the toxic threshold for selenium in aquatic food web organisms consumed by fish. Ecological risk guidelines were developed in 1993 to evaluate monitoring results from the Grassland Bypass Project in the San Joaquin Valley. These guidelines include: bird eggs (3 µg/g), whole-body fish (4 µg/g), vegetation as diet (2 µg/g), invertebrates as a food (3 µg/g), sediment (2 µg/g), and water (2 µg/l). Another researcher summarized selenium effect levels from hundreds of reviewed papers and identified similar risk thresholds.

The SFBRWQCB used ecological assessment guidelines to determine selenium loading reductions needed for the Mass Emissions Reduction Strategy for Selenium. These include total suspended material (0.45 µg organic selenium per gram [Se/g]), algae and other aquatic plants (0.45 µg organic Se/g), sediment (1.5 µg/g, dry weight), bivalves (3.2 µg/g as elevated and 4.5 µg/g as an alert level), and rallid (of the family *Rallidae*) eggs (2.9 µg/g as elevated).

8.4.4 Selenium Levels in the Bay-Delta

Although waterborne levels are relatively low, selenium has bioaccumulated to adverse levels in biota, leading SFBRWQCB staff to recommend decreasing current selenium loading to the estuary by 50% or more.

Waterborne levels of selenium in the Bay-Delta estuary are currently less than 1 µg/l and have been measured no higher than 2.7 µg/l in the estuary. Although these levels are relatively low, selenium has bioaccumulated to adverse levels in biota leading SFBRWQCB staff to recommend decreasing current selenium loading to the estuary by 50% or more.

Bivalve tissue from several monitoring programs in the late 1980s and early 1990s shows elevated selenium levels in the North Bay area, ranging from 0.6 to 7.3 µg/g. Recent monitoring of the now predominant, non-native bivalve *Potamocorbula amurensis* shows that selenium levels in bivalve tissues have tripled, ranging from 10 to 18.9 µg/g in 1995 and 1996.

In 1990, studies found up to 3.3 µg/g whole-body selenium in juvenile striped bass from three sites in the Bay-Delta estuary. This value is just below the recommended 4 µg/g toxicity threshold, even though waterborne selenium typically averages less than 1 µg/l in the estuary. Striped bass collected from Mud Slough in 1986, when the annual median selenium level in water was 8 µg/l, averaged 6.9 µg/g for whole-body selenium and contained up to 7.9 µg/g.

White sturgeon remain nearly year-round in the San Pablo Bay area, the part of the Bay-Delta estuary with some of the highest selenium levels. A 1991 report documented that developing ovaries of white sturgeon from the Bay contained as much as 71.8 µg/g selenium, or seven times over the recommended threshold for reproductive toxicity of 10 µg/g. It is highly probable that these fish are severely reproductively impaired due to selenium exposure, based on everything known regarding toxicity response functions for avian and fish eggs.

Selenium levels in clapper rail eggs have been reported as high as 7.5 µg/g. Human health advisories have been implemented due to elevated selenium levels in waterfowl from the North Bay area. Selenium levels in livers of North Bay waterfowl (scaup and scoter) are in a range (14–209 µg/g) similar to waterfowl found at Kesterson National Wildlife Refuge.

Human health advisories have been implemented due to elevated selenium levels in waterfowl from the North Bay area.

8.5 APPROACH TO SOLUTION

8.5.1 Agricultural Sources

Priority Actions

The following approaches have been identified to potentially reduce the impact of selenium discharged into agricultural drainage waters on the beneficial uses of waters.

- Drainage treatment
- Phytoremediation
- Selenium marketing
- Active land management
- Upper watershed management
- Tradable loads
- Land retirement
- Source control and drainage reduction
- Timing of release
- Drainage reuse
- Long-term solution to salinity
- Integrated on-farm drainage management and salt separation

The last five bulleted items have been discussed in Section 7, "Salinity." The remaining items are discussed below.

Drainage treatment, phytoremediation, agroforestry, and evaporation systems activities supported by CALFED must be wildlife safe. Thus, appropriate system design and biological monitoring is necessary during pilot and implementation phases.

Drainage treatment, phytoremediation, agroforestry, and evaporation systems activities supported by CALFED must be wildlife safe.

Drainage Treatment

Drainage treatment is the removal of selenium from agricultural drainage water through processes that include ion exchange, reverse osmosis, reduction with zero-valent iron, reduction with ferrous hydroxide, reduction with bacteria and other algal-bacterial treatments, phytoremediation in agricultural drainage reuse systems, volatilization from evaporation ponds and drainage reuse systems, and flow-through wetlands.

CALFED should continue to encourage and solicit proposals for funding drainage treatment pilot projects that show potential for efficient removal of selenium from agricultural drainage water. Concurrently, CALFED could encourage and solicit proposals for marketing studies to investigate the potential for marketing selenium separated from treated drainage.

CALFED should continue to encourage and solicit proposals for funding drainage treatment pilot projects that show potential for efficient removal of selenium from agricultural drainage water

Phytoremediation

Selenium may be removed from agricultural soils by phytoremediation with selenium-accumulating crop species, either by harvesting and removal of plant material or by volatilization of selenium during the growing season.

CALFED should encourage and solicit proposals for trial demonstration projects and full-scale projects for selenium phytoremediation through uptake and volatilization by selenium-accumulating plant species with either an established or potential marketability. These trial demonstration projects would be integrated with drainage reuse through the recycling of subsurface drainage and blending with surface water irrigation supplies, in order to maximize phytoremediation, reduce selenium in discharged drainage, and reduce the recycling of selenium leached through the soil back into shallow groundwater for future discharge.

Further, CALFED should encourage and solicit proposals for the construction of small pilot evaporation systems in the Grassland area to test bioremediation of selenium and production and harvest of brine shrimp. The small evaporation systems ideally would be integrated into a drainage reuse system. CALFED could support the existing research at the Lost Hills Drainage District by funding a monitoring program.

Selenium Marketing

The goals of selenium management are to develop on-farm production of selenium utilization products from the San Joaquin Valley and to develop marketing opportunities. Selenium products include forage and nutritional supplements for animal use, vegetable and grain food products and nutritional supplements for human use and compost and fertilizers for soil amendments. Marketing opportunities are found in selenium-deficient areas, both in California and worldwide. Additionally, the possibility exists of refining and marketing industrial-grade selenium as a corollary to drainage treatment.

> Marketing opportunities are found in selenium-deficient areas, both in California and worldwide.

CALFED should encourage and solicit proposals to conduct a market analysis for selenium products, existing and projected demand, current sources of supply, product manufacturing techniques, economic feasibility, regulatory requirements, and new marketing opportunities.

Active Land Management

Active land management includes demonstration trials of alternative crop selection, and modification of irrigation practices and operation of individual farms, with the primary goal of reduction in subsurface drainage and selenium load discharge.

CALFED should encourage the development and use of alternative cropping and irrigation practices that will reduce subsurface drainage volumes as well as selenium discharges.

Upper Watershed Management

In years of high rainfall on the west side of the San Joaquin Valley, large flood flows from the upper watershed extend to the San Joaquin River near Mendota. The flows from the Panoche/Silver Creek watershed contribute a substantial selenium load in the form of sediment and dissolved selenium in the flood waters discharged to area wetlands, agricultural lands, and the San Joaquin River.

> The flows from the Panoche/Silver Creek watershed contribute a substantial selenium load in the form of sediment and dissolved selenium in the flood waters discharged to area wetlands, agricultural lands, and the San Joaquin River.

CALFED should address selenium in stormwater runoff from Panoche and Silver Creeks, and provide funding to (1) determine the specific contribution of upper watershed areas to selenium loads in discharged agricultural drainage, (2) identify and evaluate remediation alternatives, and (3) ultimately assist with implementing the selected alternatives for reducing high selenium runoff from upper watershed areas. CALFED also should encourage and facilitate the ongoing effort to develop a Panoche/Silver Creek Coordinated Resource Management Plan.

Tradable Loads

Tradable load programs for selenium, which allow districts to trade independently agreed upon loads within a geographic area, can give participants greater flexibility in meeting selenium load targets.

CALFED should encourage and support the use of a tradable loads program, as well as other economic incentives, such as tiered-water pricing, as a means to achieve selenium load reductions. CALFED should work with the Grassland Area Farmers to build on the results of their program.

Land Retirement

Land retirement is not a specific objective of the CALFED Water Quality Program. However, it is a tool available to help meet the program's objectives in the San Joaquin Valley, aimed at controlling degradation from selenium, as well as salinity, associated with agricultural drainage. To further expand on this premise, several aspects need to be understood:

Land retirement is not a specific objective of the CALFED Water Quality Program. However, it is a tool available to help meet the program's objectives in the San Joaquin Valley.

1. Land retirement along the west side of the San Joaquin River watershed is included in the CALFED No Action Alternative to reflect actions planned by the federal government under the Central Valley Project Improvement Act (CVPIA). These actions would occur irrespective of the CALFED Program.

2. Several other water quality management tools exist that would be exercised to their fullest extent to correct water quality problems associated with selenium from agricultural drainage in the San Joaquin River watershed. These tools (for example, drainage treatment and phytoremediation) will help to retain current agricultural lands in agricultural production.

3. CALFED would consider implementing a program to retire lands in order to help meet water quality objectives for selenium under a tiered approach:

   (a) Initially, up to 3,000 acres of lands with the greatest concentrations of selenium present in agricultural drainage would be targeted for retirement.

   (b) If, and only if, 3,000 acres are still inadequate to meet program goals, retirement would be expanded up to a total of 37,400 acres of lands with high selenium concentrations.

These values are based on the report of the SJVDP (now the SJVDIP), titled "A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley," published in September 1990 (commonly referred to as the "Rainbow Report"). On page 93 of the report, Table 15 shows 37,400 acres of the Grassland subarea with selenium concentrations in the shallow groundwater greater than 200 µg/l. These values were developed for the Rainbow Report to identify lands that could be considered for retirement. The Rainbow Report also determined how much of the identified acreage has the poorest quality soil and determined that about 3,000 acres fit both criteria. The Rainbow Report estimated that retirement of up to 3,000 acres would enable meeting water quality objectives for selenium. For purposes of CALFED environmental analysis, soil quality is not considered a constraint.

Solving the problem will require owners of affected agricultural lands in production working cooperatively to investigate and implement land and water use practices. The Grassland Bypass Project, an effort by local agricultural interests to manage drainage problems, is an excellent example of the kind of activities in which CALFED could participate. So, too, is the Active Land Management Program of the San Luis-Delta Mendota Water Authority. This project is directed at managing lands to remain in production while minimizing or completely eliminating drainage flows and constituent loads. To the extent that more intensive measures may be required, CALFED plans to work with local interests to investigate options such as compensated rotational fallowing, consistent with good agricultural practice, to reduce selenium problems. Other options include investigating cropping changes and irrigation system alteration. Even with these and other measures, permanent retirement of some lands still may be needed. Properties already under government ownership should receive first priority for retirement, which would lower the economic impacts of land retirement.

Solving the problem will require owners of affected agricultural lands in production working cooperatively to investigate and implement land and water use practices.

CALFED is committed to minimizing the number of acres retired by cooperating in the successful implementation of the other options. In the event that land retirement becomes a necessity, land acquisition will be voluntary and compensated, and will be implemented with due regard to impacts on local communities and economies. Water made available through retirement of lands would remain under the control of the local water management district.

In the event that land retirement becomes a necessity, land acquisition will be voluntary and compensated, and will be implemented with due regard to impacts on local communities and economies.

Information Needed

A question has been raised over the adequacy of concentration-based standards if control activities prove that concentration objectives can be met. The EPA has convened a nine-member panel in a Peer-Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation that is investigating the need for differentiating the toxicity of different forms of selenium and developing site-specific objectives for selenium. If that protocol is developed, monitoring will be needed to determine what the appropriate standard would be for the San Joaquin River.

Additional field trials of selenium-accumulating crop and forage species are needed to determine the potential for phytoremediation over successive cropping, under varying physical and chemical soil conditions and agronomic methods. A selenium market analysis is needed to determine the best market opportunity for Grassland area selenium products.

Existing Activities

The Grassland Area Farmers and the San Luis-Delta Mendota Water Authority have submitted a report to the CVRWQCB, titled "Long-Term Drainage Management Plan for the Grassland Drainage Area." This report addresses in detail the measures to be implemented in order to reduce selenium discharges to Mud Slough and the San Joaquin River from agricultural subsurface drainage. The recommendations of the report are similar to those made in this Water Quality Program Plan with a few exceptions.

The Grassland Bypass Project is an example of a successful program that has improved water quality. The Grassland Bypass Project authorizes the discharge of subsurface drainage from a 97,000-acre area within the Grassland Authority to the San Joaquin River. This discharge is governed by a Use Agreement between the Authority and Reclamation and by WDRs that require a reduction in the amount of selenium loads discharged.

The Grassland Bypass Project is an example of a successful program that has improved water quality.

As a result of this project, the amount of salt, boron, and selenium discharged by Authority members within the Grasslands area has been significantly reduced. In the 1999 water year, salinity was reduced by 32%, boron by 14%, and selenium by 48% of the historical levels of similar water year types. The Grassland Bypass Project may be further developed as an element of the CALFED Water Quality Program.

Drainage Treatment

Research and development of treatment projects for the removal of selenium from agricultural drainage have been ongoing since the mid 1980s. Progress is continuing on several treatment methods, as listed above. Substantial progress is being made in the testing of two pilot treatment projects. The Algal-Bacterial Selenium Removal Facility at UC Berkeley has been operating for 2 years in the Panoche Drainage District near Firebaugh. CALFED recently funded the continuation and development of this project for an additional 3 years. The Flow-Through Wetland Treatment Pilot Project for the bioremediation of selenium in agricultural drainage at UC Berkeley has been in operation for more than 1 year in the Tulare Lake Drainage District.

Research and development of treatment projects for the removal of selenium from agricultural drainage have been ongoing since the mid 1980s

The Drainage Treatment Technical Committee, working under the auspices of the joint state-federal inter-agency SJVDIP, currently is evaluating the status and progress of treatment methods for the removal of selenium from agricultural drainage, including an economic evaluation. The committee's report was completed in February 1999.

Land Retirement

Reclamation has initiated a voluntary land retirement program under the CVPIA. Applications have been received from interested landowners in the Westlands Water District (WWD). Reclamation currently is evaluating those applications, as well as planning a land retirement demonstration project that will include restoration of wildlife habitat. Presently, no applications for voluntary land retirement under the CVPIA program have been received from growers in the Grassland area. Land retirement may not be a permanent solution to the problem of managing selenium, as land retirement retains the existing selenium in the shallow groundwater, where unforeseen future rises in the water table could bring selenium to the surface or discharge it to regional water bodies. The pilot projects conducted by Reclamation of the Westlands and Tulare/Kern Subareas will yield valuable information on the effectiveness of the program.

Reclamation has initiated a voluntary land retirement program under the CVPIA.

The Land Retirement Technical Committee, working under the auspices of the joint state-federal inter-agency SJVDIP, also is evaluating the previous assumptions regarding the efficacy of land retirement, including the elimination of selenium-containing subsurface drainage from retired lands. The committee is reviewing computer models that were developed and refined since the SJVDIP land retirement recommendation was made in 1990. The models evaluate the potential reduction in drainage volume and selenium load, as well as soil, water, and air quality impacts from projected land retirement. The committee's report was completed in February 1999.

Phytoremediation

Research on the potential for phytoremediation and volatilization of selenium in agricultural and drainage reuse systems is continuing. Past research has shown that crops such as broccoli, cabbage, mustard, cotton, and canola have a substantial ability to extract selenium from soil and water, incorporate selenium into their tissues, and volatilize it to the atmosphere. Other forage and plant species, such as astragalus, birdsfoot trefoil, tall fescue, kenaf, and atriplex (including some natives), have the same or enhanced ability. Some genuses of plants, such as *Astragalus* and *Atriplex*, are called selenium accumulators and can achieve selenium tissue concentrations of from several hundred up to 1,000 ppm.

Research on the potential for phytoremediation and volatilization of selenium in agricultural and drainage reuse systems is continuing.

Other plants are called selenium non-accumulators, including most crop and forage species; nevertheless, many plants can achieve selenium concentrations in tissue of up to about 50 ppm. The advantage in using crop and forage species over selenium accumulators is twofold: (1) the crop and forage species may be harvested and marketed as beneficial human vegetable and livestock feed supplementation or as an organic matter soil amendment and fertilizer for selenium-deficient soils, and (2) the concentration of selenium in accumulator species could be toxic as forage for animals and other uses unless it is carefully blended with other low-selenium forage.

Both greenhouse and field trials have demonstrated the ability of certain plant species to extract selenium from the soil. Field trials with mustard resulted in the removal of 46% of the total soil selenium in only 3 years. Simulated field trials with tall fescue have demonstrated that leachate selenium concentrations and soil selenate concentrations are reduced with successive harvests. A UC Berkeley research project was conducted to ascertain the degree of selenium accumulation and volatilization from each of the components of the drainage reuse integrated on-farm drainage management (agroforestry) system at Red Rock Ranch near Five Points in Fresno County. The final report was submitted in December 1998.

Phytoremediation has been found to be an inherent feature of evaporation ponds, as at least three resident microphytes actively biotransform and volatilize selenium -- which may account for the declining selenium concentration observed in the ponds during the evapoconcentration of salts. Further, a Bay Area company that is a major producer and marketer of brine shrimp as food for aquarium species has found that evaporation ponds are an excellent medium for the production of brine shrimp. The shrimp uptake and biotransform selenium from the drainage water. A minimal standard selenium concentration in brine shrimp is considered a necessity for the aquarium market. Although brine shrimp can be a major food source for waterfowl, frequent shrimp harvesting combined with traditional hazing methods breaks the food chain and prevents selenium ingestion by waterfowl. UC Davis researchers currently are conducting a project designed to determine the ecologic processes ongoing in the Lost Hills Water District evaporation pond. The project would identify the function of brine shrimp growth and harvest in the bioremediation of selenium, and would establish optimum management techniques for salt utilization as well as selenium bioremediation.

A Bay Area company that is a major producer and marketer of brine shrimp as food for aquarium species has found that evaporation ponds are an excellent medium for the production of brine shrimp.

Selenium Marketing

Current investigation of opportunities to produce and market selenium products is limited. Efforts are underway to develop markets for drainage reuse products, such as wood fiber from eucalyptus, forage from saltgrass and other forage crops, and salicornia as a salad vegetable (considered a delicacy in parts of Europe). A market for selenium-containing brine shrimp produced in evaporation ponds already exists.

Efforts are underway to develop markets for drainage reuse products, such as wood fiber from eucalyptus, forage from saltgrass and other forage crops, and salicornia as a salad vegetable (considered a delicacy in parts of Europe).

Active Land Management

Assessment of the efficacy of current source control practices in selenium drainage load reduction under the Grassland Bypass Project is ongoing, as well as evaluation of opportunities for further reductions. In addition, the Panoche Water District has implemented an alternative cropping trial, using sudangrass on three parcels and using minimal surface irrigation to enhance crop utilization of shallow groundwater. A significant reduction in the volume of drainage generated from one parcel has been observed. Broadview Water District is implementing alternative cropping and minimal irrigation practices on a one-quarter section, and monitoring the quantity and quality of the drainage generated by this parcel in comparison to traditional cropping systems. The alternatively managed parcel will be rotated within a section, which would be similar to retiring a quarter parcel in each section while still maintaining the land under production.

Upper Watershed Management

Planning efforts are underway to control flood flows and selenium discharge from Panoche/Silver Creek through a Coordinated Resources Management Program with participation by Reclamation, Panoche/Silver Creek landowners, the City of Mendota, Silver Creek Drainage District, and others. Possible actions include implementation of erosion control measures and construction of detention dams.

Tradable Loads

The Grassland Area Farmers initiated a tradable selenium loads program within the drainage project area to help meet established monthly selenium load discharge targets. The program provides incentive to individual districts to more fully and quickly implement some of the other listed approaches.

The Grassland Area Farmers initiated a tradable selenium loads program within the drainage project area to help meet established monthly selenium load discharge targets.

8.5.2 Refineries

The following approaches have been identified to potentially reduce the impacts of selenium that is a by-product of the crude oil refining process.

Priority Actions

1. Reduce selenium concentrations in biota to levels below human health advisories. The issuance of health advisories on the consumption of waterfowl from the Suisun Bay area was one of the key driving forces leading to regulatory actions.

2. Reduce selenium concentrations in biota to levels below ecological risk guidelines. Concentrations of selenium in many biota from the Bay-Delta area are at levels above recommended risk guidelines. Evaluating the impacts of selenium on Bay-Delta estuary organisms will provide useful site-specific ecological risk guidelines to fine-tune selenium mass reduction needs.

3. Reduce selenium loads from refineries by 90% by 2001. This goal has been set by the SFBRWQCB with the intent of reducing selenium concentrations in estuary organisms. If goals 1 and 2 above are met before the full 90% selenium reduction has occurred, this goal may be amended accordingly. If those goals are not reached, the SFBRWQCB may need to take additional actions.

Treatment of Waste Streams

Selenium occurs in several different waste streams in the refining process. Due to the different chemistries of each waste stream within a facility and between facilities, different treatment processes are needed to obtain the maximum removal efficiency at reasonable costs. These treatments include ion-exchange treatments, Sorbplus treatment (a formulation of aluminum and magnesium), iron co-precipitation, activated alumina treatments, primary stage treatments at wastewater treatment plants, and aerobic and anaerobic biochemical treatments.

The San Joaquin Valley crude oil, used primarily by Bay Area refineries, contains from 2 to 12 times higher levels of selenium compared to crude oil from other sources. A change to a cleaner crude oil would reduce selenium at the front end of the refining process.

Use of Alternative Crude Oil

As stated earlier, the San Joaquin Valley crude oil, used primarily by Bay Area refineries, contains from 2 to 12 times higher levels of selenium compared to crude oil from other sources. A change to a cleaner crude oil would reduce selenium at the front end of the refining process.

Sour Water Reuse

Water used for desalting in the refining process (sour water) can be recycled and reused. Reuse may reduce the volume of sour water discharged, but concentrations of selenium will be higher and treatment will be necessary.

Wetland Discharge Treatment

As a final end-of-pipe removal process, wastewater may be discharged through a wetland to remove selenium before its final discharge to the Bay. This treatment method needs to be safe for wildlife.

Information Needed

New research of the impacts of selenium in the estuary is needed to provide regulatory agencies with information to refine current actions.

The potential interactions between selenium and mercury need to be evaluated.

Monitoring efforts to document improvement in the estuary from reduced selenium loadings should be continued and refined.

CALFED should work with regulatory agencies on developing incentives for selenium load reduction by the refineries.

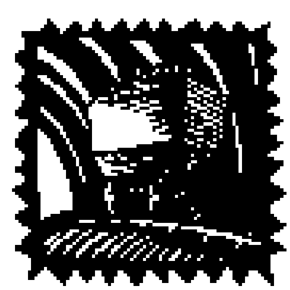
Existing Activities

Refineries and regulatory agencies have spent millions of dollars studying the chemistry of selenium in the various wastewater streams and evaluating treatment and control technologies. Bench- and pilot-scale testing has occurred throughout the 1990s, including the evaluation of filtration, selenium reduction, carbon adsorption, acid/filtration, iron co-precipitation, and ion exchange. Removal success ranged from 25 to over 90%. Detailed evaluations and implementation of the most promising technologies, such as iron co-precipitation and ion exchange, continue. These efforts have culminated with issuance of Cease and Desist Orders to the refineries. Construction of full-scale treatment systems have brought the refineries into compliance. The SFBRWQCB, along with dischargers, is monitoring selenium loads from municipal wastewater discharges and urban runoff to determine the significance of these sources.

Refineries and regulatory agencies have spent millions of dollars studying the chemistry of selenium in the various waste-water streams and evaluating treatment and control technologies.

Current environmental research includes the evaluation of selenium sources, levels, and consequences in the Delta, in a study proposed by USGS and selected for funding by CALFED. An evaluation of the impacts of methyl mercury and selenium interactions on clapper rail reproduction is being performed by the USFWS. Ongoing monitoring of trace elements in water, sediment, and bivalves is being conducted through the San Francisco Estuary Regional Monitoring Program (RMP).

9. TRACE METALS



9. TRACE METALS

9.1 SUMMARY

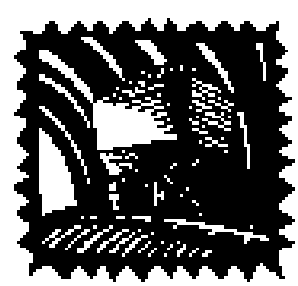
Heavy-metal loading in the watershed has been suspected as a possible source of aquatic toxicity throughout the Bay-Delta and its tributaries. Studies of abandoned mines in the upper watershed have shown toxic effects on aquatic species. Other sources in the tributaries and Bay-Delta contribute to total metal loading in the Bay-Delta. Loading in lower tributaries and the Bay-Delta causes excursions of guidelines for protection of fresh-water and marine species. Insufficient information is available to determine the ecological impacts or spatial and temporal extent of the metals in the Bay-Delta. Corrective measures should be taken in the upper watershed to protect specific species habitat. Corrective measures downstream should be based on the extent of impacts as determined by further studies.

9.2 PROBLEM STATEMENT

Heavy-metal aquatic toxicity has been documented in the upper watershed. Much of the increase in heavy metal loading is attributed to abandoned mines. Copper loading from other sources, such as agriculture and urban discharges, adds to the total copper load to the Bay-Delta. The types and extent of ecological effects in the Bay-Delta from metal loading are not well defined.

9.3 OBJECTIVE

The objective is to reduce metal loading of the Bay-Delta and its tributaries to levels that do not adversely affect aquatic habitat, other beneficial uses of Bay-Delta estuary waters, and species dependent on the estuary.



9.4 Problem Description

9.4.1 *Water Concentrations*

Four metals of concern were identified in the March 1998 Draft Water Quality Program Plan: mercury, copper, cadmium, and zinc. Mercury is addressed separately from the other metals as it is more well defined and has fewer overlapping potential mitigation measures than the other metals.

Cadmium and zinc are addressed briefly here due to lack of data and lack of evidence that these metals cause environmental harm. Other metals such as chromium and lead have been suggested as potentially significant to Bay-Delta water quality. Data on chromium and lead will be sought and evaluated to further determine their potential significance.

Elevated levels of copper have been found in river water at various times of the year. Copper has serious toxic effects on aquatic life. Investigations have identified three main sources of copper in the Bay-Delta ecosystem: abandoned mines, agriculture, and urban runoff. Other sources may exist that are not well documented.

> Investigations have identified three main sources of copper in the Bay-Delta ecosystem: abandoned mines, agriculture, and urban runoff. Other sources may exist that are not well documented.

For six sampling periods between July 1996 and June 1997, the USGS prepared colloid (small "clay" particles in water) concentrates, using a tangential flow ultra filtration of large (~100 liter) water samples from six main stem Sacramento River sites (below Shasta Dam, below Keswick Dam, at Bend Bridge, at Colusa, at Verona, and at Freeport), plus the Yolo Bypass at Interstate-80 (during high flow). The concentrates were analyzed for total metals, and some also were subjected to sequential extractions to determine forms of metals (speciation).

It generally was found that the sum of dissolved and colloidal concentrations using ultra-filtrates and colloid concentrate samples was a more reliable way to estimate total water-column loadings than conventional whole water analyses.

A significant proportion of the trace-metal loading in the Sacramento River occurs from metals in colloidal form (grain size between about 0.005 and 1.0 micrometer (µm)). Colloids represent the dominant form of aluminum, iron, and lead in the water column, and are an important factor in the distribution of other trace metals. Generally speaking, the colloidal fraction of copper is higher than zinc, and the colloidal fraction of zinc is higher than cadmium.

The influence of metal-laden acidic drainage from the Iron Mountain Mine site (via Spring Creek and the Spring Creek Arm of Keswick Reservoir) is apparent in water samples from the site below Keswick Dam, where occasionally water quality standards for copper (5.6 µg/l, based on a hardness of 40 mg/l) have been exceeded. The water quality standard exceedances continued in January 1997, despite ongoing operation of the lime neutralization plant at Iron Mountain, which reportedly removes about 80% of copper loads and about 90% of zinc and cadmium loads from Spring Creek.

In mid-December 1996, conventionally filtered copper concentrations were from 4.6 to 5.1 µg/l, and zinc ranged from 6 to 9 µg/l. During flood conditions in early January 1997, conventionally filtered copper concentrations were from 4 to 9 µg/l, and zinc ranged from 9 to 16 µg/l. Ultra-filtrates (0.005-µm equivalent pore size) of water samples from below Keswick Dam in December 1996 and January 1997 contained copper concentrations about 40–70% lower than the conventional (0.40- and 0.45-µm) filtrates. In 1998, the USGS reported that zinc concentrations were 10–50% lower, indicating significant colloidal transport of copper and, to a lesser extent, of zinc.

The proportion of cadmium, copper, lead, and zinc loads entering the Bay-Delta that are associated with the areas above Keswick Dam can be estimated by comparison of metal loadings at Keswick Dam with those at the site sampled furthest downstream, generally at Freeport (plus the Yolo Bypass, when flowing). The results highly depend on the flow regime, as shown below.

The proportion of cadmium, copper, lead, and zinc loads entering the Bay-Delta that are associated with the areas above Keswick Dam can be estimated by comparison of metal loadings at Keswick Dam with those at the site sampled furthest downstream.

Proportion of Cadmium, Copper, Lead, and Zinc Loads Entering the Bay-Delta by Flow Regime

		Metal (%)			
Date	Flow Regime	Cadmium	Copper	Lead	Zinc
December 1996	Moderately high flows	[illegible]	35	19	50
January 1997	Flood conditions	23	[illegible]	2	15
May-June 1997	Irrigation drainage season from rice fields	[illegible]	53	22	96

Note: The above estimates must be qualified by loadings from Colusa in December 1996 and Verona in May-June 1997. Loadings do not account for other inputs from urban sources.

Available data suggest that trace-metal loadings from agricultural drainage may be significant during certain flow conditions; however, additional scrutiny of these data is needed before definitive conclusions can be drawn. Loadings data for copper in July and September 1996 and May-June 1997 show increases in dissolved and colloidal copper and in colloidal zinc between Colusa and Verona, the reach of the river along which the Colusa Basin Drain and the Sacramento Slough and other agricultural return flows are tributaries. Monthly sampling of these two agricultural drains by the USGS NAWQA Program shows seasonal variations in metal concentrations. For example, dissolved (0.45-μm filtrate) copper concentrations in the Colusa Basin Drain reached 6 μg/l in May 1996 and 3 μg/l in June 1997, whereas dissolved copper in the Sacramento Slough reached a maximum of 4 μg/l in December 1996.

To put the copper loadings associated with agricultural drainage in perspective, the total (dissolved plus colloidal) loadings of copper from the Colusa Basin Drain in June 1997 were 39.7 lbs/day, whereas the loadings of copper from Iron Mountain Mine via Spring Creek were 44 lbs/day during the same sampling period. Overall, the majority of copper and zinc loading appears to enter the river upstream of Colusa and therefore upstream of the influence of the most intense agricultural drainage return flows in the Sacramento River Basin.

Fine-grained, metal-rich sediments in the Spring Creek Arm of Keswick Reservoir and in the main channel of Keswick Reservoir between the Spring Creek Arm and Keswick Dam were inventoried by USGS in 1993 at more than 200,000 cubic meters. The sediments have been sampled as part of EPA's Remedial Investigation. Extremely elevated concentrations of cadmium, copper, and zinc have been found in sediments and pore waters from sediments in the Spring Creek Arm of Keswick Reservoir.

Fine-grained, metal-rich sediments in the Spring Creek Arm of Keswick Reservoir and in the main channel of Keswick Reservoir between the Spring Creek Arm and Keswick Dam were inventoried by USGS in 1993 at more than 200,000 cubic meters.

Lead-isotope data in colloid concentrates and bed sediments provide a useful "fingerprint" that can be used as a natural tracer for lead pollution from Iron Mountain Mine drainage via Spring Creek and Keswick Reservoir. In streambed sediment and suspended colloid samples taken during 1996 and 1997, the source of lead pollution from the Iron Mountain Mine is a relatively significant component of the total lead found at sampling sites near Redding and Anderson, a much lesser component at Balls Ferry, and a relatively minor component of the total lead loads at Bend Bridge (near Red Bluff) and at sites further downstream.

DWR measured concentrations of 9 trace metals in May and September at 11 stations in the Bay-Delta and in Suisun Bay from 1975 to 1993. Trace metals frequently exceeded guidelines for marine and fresh-water toxicity and for drinking water standards. Trace metals (most frequently copper) exceeded guidelines for fresh-water acute and chronic toxicity 34 times. Marine acute and chronic toxicity guidelines were exceeded 181 times, 160 of which were for copper. Most exceedances were in the upper estuary. Cadmium and zinc rarely exceeded toxicity or drinking water guidelines, and chromium never did.

The Sacramento Stormwater Management Program has prioritized chemicals for the development of proactive pollutant reduction programs, in accordance with a municipal stormwater permit. Copper is one of the constituents of concern that has been investigated to identify potential sources, prioritize sources, and identify BMPs. The copper source identification work produced information on the many sources of copper in the urban environment. While some of the sources are not exclusive agents, some contribute significantly on their own. Sources include air emissions, rainfall, tap water, brake pad wear, streets and parking, pesticides, and erosion. Some point source discharges also were considered, such as swimming pool discharge and cooling towers.

Contributions from each source were roughly estimated, using readily available actual measurements where possible and estimations based on results from other studies. The largest single estimated contribution is from automobile brake pad wear. When asbestos was phased out as a brake pad material, the industry began making "semi-metallic" brake pads. These new brake pads incorporated metal alloys into the pad structure, which lead to long-life pads without asbestos. The most common metal used in these semi-metallic brake pads is copper. Using rough estimates of the study, several tons of copper could be discharged in the urban areas in the Bay-Delta region each year from automobile brake pad wear.

Using rough estimates of the study, several tons of copper could be discharged in the urban areas in the Bay-Delta region each year from automobile brake pad wear.

The methodology used in the estimations was taken primarily from similar studies conducted in Santa Clara. Noting that urban areas will not differ dramatically in sources of copper, all urban areas throughout the Sacramento and San Joaquin River watersheds will contribute to copper loading in the creeks and rivers from automobile brake pad wear.

9.4.2 *Biological Effects*

Until recently, most of the information on toxicity of metals was derived from acute toxicity tests. The toxicity tests in the USGS study address bioaccumulation. Toxicity of particles of metals also has not been well studied. Although not well documented, it is thought that toxicity to fish eggs is caused by higher concentrations of copper particles.

The USGS assessed bioaccumulation in caddisfly larvae at five sites in the Sacramento River between Redding and Tehama, and at one reference site (Cottonwood Creek near Redding). Samples were taken in October 1996. Cadmium concentrations in caddisfly larvae from Sacramento River sites were enriched from 5 to 36 times the concentrations of those from the reference site. Cadmium concentrations of the whole body ranged from 0.7 to 2.2 µg/g dry weight. Of this total, approximately 60% (from 0.4 to 1.3 µg/g dry weight) was associated with the cell cytosol, an intracellular fraction that is indicative of metal bioavailability. Concentrations in the Sacramento River are comparable to other areas severely affected by mining, such as the Clark Fork River downstream of Butte, Montana. Copper and zinc also showed some enrichment in caddisfly whole bodies and cytosol fractions: enrichment factors relative to the reference site were 1.4-5.0 µg/g. The caddisfly data indicate that bioavailable forms of cadmium persist in the Sacramento River downstream of Tehama.

Consumption of contaminated aquatic invertebrates is a biologically significant pathway for exposures of salmonids to metals. Recent studies show that fish held in clean water and fed a metals-contaminated diet had similar whole-body metal concentrations as fish raised in the water where the food was collected. Fish feeding on clean invertebrates while living in water with elevated metals concentrations exhibited no reductions in survival or growth.

Consumption of contaminated aquatic invertebrates is a biologically significant pathway for exposures of salmonids to metals.

Sediment toxicity at the confluence of the Sacramento and San Joaquin Rivers has been observed for a number of years by the San Francisco Estuary RMP. Metals recently have been identified as the principle component of toxicity in pore space water within sediments. Identification of specific toxic metals still must be completed.

9.5 Approach to Solution

A majority of the work relating to reduction of copper in the Bay-Delta rests on the results of studies that still need to be done. The information presented shows local impacts and temporal excursions above ambient water quality standards in the Bay-Delta. More information is needed to determine effects and specific remedial activities. Approppriateness of specific remedial activities should be determined based on all of the effects data. **No remedial activities on abandoned mine sites should be performed without federal environmental "Good Samaritan" protection. Without this protection, acting CALFED agencies may become responsible parties for the abandoned sites.**

9.5.1 Priority Actions

1. CALFED should participate in studies to better define ecological impacts and the spatial and temporal extent of heavy-metal pollution. Ecological impact evaluations would be performed under the CALFED Ecosystem Restoration Program, in coordination with the Water Quality Program.

2. Remedial activities for cleanup of mines should be implemented as deemed appropriate by impacts on habitat and the feasibility of remediation.

3. CALFED should participate with municipalities on the Brake Pad Consortium and other urban stormwater programs to assist in source reduction.

4. CALFED should continue to work with municipalities on evaluation of stormwater pollution control projects that might reduce loading of copper to the Bay-Delta.

5. Any work to reduce copper from agricultural uses should be coordinated with the RWQCB and the DPR.

9.5.2 *Information Needed*

Studies are needed to determine the spatial and temporal effects of heavy metals and their ecological significance in the Bay-Delta. Emphasis needs to be placed on monitoring the diet of fish species and sediment, in addition to much of the water samples and acute toxicity tests that have been collected.

Emphasis needs to be placed on monitoring the diet of fish species and sediment, in addition to much of the water samples and acute toxicity tests that have been collected.

Monitoring is required to assist in the study of spatial and temporal effects of metals.

9.5.3 *Existing Activities*

Municipalities are participating in a Brake Pad Consortium to influence brake pad manufacturers to use other, safer materials.

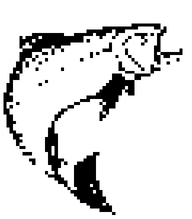
Clean-up activities are ongoing at the Iron Mountain Mine site above Keswick Dam.

Activities by the Mining Remedial Recovery Company on other mines in the upper watershed are moving toward reducing impacts of those mines.

The Sacramento Ambient Monitoring Program has been collecting data on total and dissolved copper, cadmium, and zinc since 1992.

The USGS and DWR have been collecting metals data, as previously mentioned.

10. TURBIDITY AND SEDIMENTATION



10. Turbidity and Sedimentation

10.1 Summary

Sedimentation has been linked with declining habitat in upper watershed streams. Impairment of habitat by sedimentation could cause long-term declines in certain species of fish. This section identifies existing and potential turbidity- and sedimentation related problems; scientific and other technical information needs such as monitoring, research and modeling, and targets and performance measures; and management actions to reduce, eliminate, or prevent ecological impacts associated with these parameters. Turbidity and sedimentation environmental water quality issues are covered in two regions: the Bay and San Joaquin River Regions. Drinking water and pesticides concerns associated with these parameters in the CALFED geographic regions are addressed in other sections of the Water Quality Program Plan. High turbidity and sedimentation are not ecological water quality concerns in the Delta. Water-column turbidity decreased and water clarity (secchi disk depth) increased in the Delta from 1970 to 1995. Turbidity and sedimentation in the Sacramento River watershed typically has little nexus to the Bay-Delta but may be of local ecological significance. Turbidity and sedimentation also are not issues for the Other SWP and CVP Service Areas.

Sedimentation has been linked with declining habitat in upper watershed streams.

10.2 Problem Statement

Turbidity and sedimentation affect spawning habitat of some fish species, estuarine and fresh-water benthic habitat and organisms, treatment of drinking water, productivity in estuarine waters, and aesthetics. Excessive high turbidity and sedimentation resulting from anthropogenic sediment loading have been previously identified as water quality concerns affecting (or potentially affecting) environmental and drinking water beneficial uses.

Excessive high turbidity and sedimentation resulting from anthropogenic sediment loading have been previously identified as water quality concerns affecting (or potentially affecting) environmental and drinking water beneficial uses.

10.3 Objective

The objective is to reduce sediment in areas to the degree that sediment does not cause negative impacts on beneficial uses of the surface water, including ecosystem benefits and municipal uses. (Please note: A balance exists between the amount of sediment needed in Delta water and an amount that is harmful to the ecosystem and troublesome for drinking water treatment.)

10.4 PROBLEM DESCRIPTION

Individual regions discussed below have been identified by responsible RWQCBs as containing water bodies that are, or have been, impaired by turbidity and sedimentation. Much of the problem details for these individual sites are still unknown. Additional problem characterization and solution studies need to be performed.

10.4.1 Bay Region

High turbidity is not an ecological water quality concern in central and south San Francisco Bay, San Pablo Bay, or Suisun Bay. Turbidity can limit phytoplankton production in San Francisco Bay; however, high turbidity is a natural attribute of this estuary, and thus not a water quality concern in this area. Turbidity levels in Suisun Bay decreased from 1970 to 1993. Turbidity and water clarity (secchi disk depth) levels in San Pablo changed little from 1970 to 1993.

Sediment supply to the San Francisco Bay from the Sacramento and San Joaquin River watersheds has declined over recent years due to dams on rivers and other water management actions, resulting in less sediment available to build and maintain mud flats. This, in turn, increases wave energy on marshes, causing them to erode. This issue is more fully addressed by the CALFED Ecosystem Restoration Program Plan.

Sediment supply to the San Francisco Bay from the Sacramento and San Joaquin River watersheds has declined over recent years due to dams on rivers and other water management actions, resulting in less sediment available to build and maintain mud flats.

Napa River, Petaluma River, and Sonoma Creek

Turbidity is a water quality concern in the Napa River, Petaluma River, and Sonoma Creek—all tributaries to San Pablo Bay and included on the CWA Section 303(d) list as impaired water bodies. Agricultural and urban runoff are the sources of the turbidity water quality problems in these water bodies.

10.4.2 San Joaquin River Region

Tuolumne River

The Tuolumne River experiences fine-sediment (fine bed material) loading primarily from agricultural land use practices and in-channel mining activities. The major sources of fine sediments are typically tributary stream channels and large gullies. Non-point sources are usually erosion from agricultural lands

The Tuolumne River experiences fine-sediment (fine bed material) loading primarily from agricultural land use practices and in-channel mining activities.

Gasburg Creek, lower Dominici Creek, and Peaslee Creek are major producers of fine sediment. Much of the sediments transported by Gasburg Creek originates from runoff from a sand extraction operation. Anthropogenic fine-sediment loading adversely affects the quality and quantity of spawning and rearing habitat for salmonids and other fishes. Pore space in the gravel stream beds is filled in, which reduces egg survival. Macroinvertebrate production also may be affected. Sediment loading to Gasburg Creek results in the greatest potential impacts on salmon habitat. Reducing fine-sediment loads to the river from anthropogenic sources, particularly near LaGrange, will improve fish spawning and rearing habitat quality and extent, and increase the longevity of efforts to improve gravel quality.

Merced and Stanislaus Rivers

The Merced and Stanislaus Rivers also experience fine-sediment loading from anthropogenic sources, including adjacent and upslope agricultural land use practices and in-channel mining activities. Sedimentation has affected the quality and quantity of rearing and spawning habitat for salmonids and other fishes in the Merced and Stanislaus Rivers. Pore space in the gravel stream beds is filled in, which reduces egg survival. Macroinvertebrate production also may be affected. Although few streams are tributary to these rivers below the dams, the existing tributaries often contribute large fine-sediment loads to the lower sections of these rivers. The Technical Watershed Groups for each of these rivers are developing river corridor assessments and management strategies for water quality and other ecological problems (similar to the Tuolumne River Corridor Restoration Plan).

Sedimentation has affected the quality and quantity of rearing and spawning habitat for salmonids and other fishes in the Merced and Stanislaus Rivers.

Cosumnes River

The Cosumnes River receives large loads of fine sediment from soil erosion in the upper watershed related to forestry activities (timber harvest and road building). This sediment loading and resulting sedimentation adversely affects fish spawning habitat and likely causes other water quality problems. These effects have largely been qualitatively assessed, however, and have not been quantified. The USFS is conducting an upper watershed sediment source survey and impact assessment.

The Cosumnes River receives large loads of fine sediment from soil erosion in the upper watershed related to forestry activities (timber harvest and road building).

10.5 Approach to Solution

10.5.1 Priority Actions

Bay Region

1. Implement erosion control BMPs on urban construction and BMPs for agricultural lands to reduce sediment in the Napa River, Petaluma River, and Sonoma Creek.

San Joaquin River Region

Tuolumne River

1. Evaluate constructing a sedimentation pond near the mouth of Gasburg Creek. This action would prevent nearly all harmful fine sediments from entering the Tuolumne River.

2. Evaluate constructing a head control structure on lower Dominici Creek.

3. Develop and implement land use BMPs, particularly along tributary watercourses, to reduce soil erosion and fine sediment inputs.

4. Manage floodplains to help diminish the negative impact of fine-sediment loads from anthropogenic sources by facilitating natural deposition on floodplain surfaces.

5. Mechanically remove fine sediments to reduce fine-sediment storage in the bankfull channel, including excavating sand stored in pools, excavating sand from riparian berms and backwaters, and mechanically flushing and removing sand from riffles (to be accomplished through the CALFED Ecosystem Restoration Program as habitat restoration actions).

Constructing a sedimentation pond near the mouth of Gasburg Creek would prevent nearly all harmful fine sediments from entering the Tuolumne River.

Targets and Performance Measures: Tuolumne River

Reduce fine sediment loads to the Tuolumne River from anthropogenic sources, particularly near LaGrange, and reduce sedimentation in the river. Measure sediment loads to the river and the suspended sediment content and sedimentation rate in the river.

Reduce fine-sediment storage in the bankfull channel. Measure fine-sediment storage in the Tuolumne River.

Reduce or eliminate any ecological impacts in the Tuolumne River due to fine-sediment loading and sedimentation from anthropogenic sources. Measure sediment loads to the river and suspended sediment content, sedimentation rate, and fine-sediment storage in the river. Perform appropriate biological surveys in the river through the CALFED Ecosystem Restoration Program, in coordination with the Water Quality Program.

In addition, the USFS study may recommend management actions.

Merced and Stanislaus Rivers

1. Quantitatively determine Merced and Stanislaus River sediment loads, budgets, and sources.

2. Perform quantitative ecological assessments of the effects of sedimentation on the Merced and Stanislaus Rivers through the CALFED Ecosystem Restoration Program, in coordination with the Water Quality Program.

3. Develop a Technical Watershed Group for each river and address corrective actions.

Targets and Performance Measures: Merced and Stanislaus Rivers

Reduce fine-sediment loads from anthropogenic sources and reduce sedimentation in the Merced and Stanislaus Rivers. Measure sediment loads, suspended sediment content, and sedimentation rate in the rivers.

Reduce fine-sediment storage in the bankfull channel. Measure fine-sediment storage in the Merced and Stanislaus Rivers.

Reduce or eliminate ecological impacts in the Merced and Stanislaus Rivers due to fine sediment loading and sedimentation from anthropogenic sources. Measure sediment loads, suspended sediment content, sedimentation rate, and fine-sediment storage in the Merced and Stanislaus Rivers. Perform appropriate biological surveys in the rivers through the CALFED Ecosystem Restoration Program, in coordination with the Water Quality Program.

10.5.2 Information Needed

Tuolumne River

The following scientific needs are specific to sediment loading in the Tuolumne River corridor:

- Document fine-sediment bedload transport rates as a function of hydrology, combining monitoring and modeling.
- Document changes in fine-sediment in-stream storage
- Monitor fine-sediment loads to the river, suspended sediment concentrations, and turbidity as part of a river-wide monitoring and adaptive management program.

Cosumnes River

The following scientific needs are specific to sediment loading in the Cosumnes River watershed:

- Quantitatively determine Cosumnes River sediment loads, budget, and sources. The USGS study may meet this need.

11. TOXICITY OF UNKNOWN ORIGIN

11. Toxicity of Unknown Origin

11.1 Summary

All elements causing toxicity in the Sacramento and San Joaquin River watersheds and in the Delta have not been identified in current evaluations. Without identification, corrective actions cannot be taken to stop toxicity. A program to identify toxicants and their individual environmental effects is presented here.

11.2 Problem Statement

In approximately half of the toxicity tests conducted in the Sacramento River watershed, the toxicity detected in test species has not been linked to specific chemicals. This is also true for approximately 30% of the toxic samples collected in the Delta and the San Joaquin River watershed. A toxic must be identified before actions can be proposed to control its toxic effects.

In approximately half of the toxicity tests conducted in the Sacramento River watershed, the toxicity detected in test species has not been linked to specific chemicals. This is also true for approximately 30% of the toxic samples collected in the Delta and the San Joaquin River watershed.

11.3 Objective

The objective is to further identify parameters of concern in the water and sediment in the Delta, Bay, Sacramento River, and San Joaquin River Regions and to implement actions in order to reduce the toxicity of identified parameters to aquatic organisms. The methodology used to control unknown toxicity is a staged procedure.

11.4 Problem Description

11.4.1 Background

A toxicity test is a laboratory procedure to determine the toxicity of a water or sediment sample using a test species. Protocols have been developed and promulgated by the EPA for both fresh- and salt-water species (fish, invertebrates, and algae) in both water and sediment samples. In a toxicity test, field samples are collected and brought back to the laboratory, and the test species is introduced to the field sample. Survival or other end points (such as measures of growth or reproduction) are monitored for the duration of the test. Essentially, the tests ask the test species if they can live, grow, or reproduce in a site sample. Toxicity is suggested when performance of a test species is statistically different than its performance in a clean laboratory control. The tests are one way to assess compliance with the narrative standard of "no toxics in toxic amounts," which is part of each RWQCB's WQCP (Basin Plan). The tests indicate whether the test species survive (or perform less well) in site water. However, the test does not indicate why toxicity occurred. Chemical monitoring and a toxicity identification evaluation (TIE) are used to determine the cause of toxicity. The TIE is a set of procedures designed to identify the specific causative agents responsible for the observed toxicity. An unknown toxicity or a "toxicity of unknown origin" refers to the situation where toxicity has been detected but a TIE either has not been performed or has not successfully identified a toxicant. An unknown toxicity suggests that a water quality problem exists for aquatic organisms and also indicates a violation of the narrative standard; therefore, it is a regulatory problem. To eliminate the toxicity from the location where sampling occurred, it is useful to know the specific chemical cause and the source(s). Once this information has been determined, MPs can be implemented to eliminate the observed toxicity.

Toxicity is suggested when performance of a test species is statistically different than its performance in a clean laboratory control.

11.4.2 Toxicity Found

Since 1986, the CVRWQCB and DFG have tested the surface waters of the Central Valley for toxicity. Sediment testing also has occurred but on a more limited basis. The fresh water aquatic test species recommended by the EPA are the fathead minnow, a cladoceran (*Ceriodaphnia dubia*), and a unicellular green algae (*Selenastrum capricornutum*). In addition to testing with these species, limited testing has been performed using indigenous species, including striped bass, rainbow trout, and two invertebrates (*Neomysis* and *Brachionus*). The fresh-water species used in bulk sediment toxicity testing are an amphipod (*Hyalella azteca*) and a midge (*Chironomus*). Tests on the pore space water within

Since 1986, the CVRWQCB and DFG have tested the surface waters of the Central Valley for toxicity.

sediments frequently are performed using *Ceriodaphnia*. The San Francisco Estuary Institute's RMP performs toxicity tests on both water-column and sediment samples using marine species.

In approximately half of the toxicity tests conducted in the Sacramento River watershed, the toxicity detected with these test species has not been linked to specific chemicals. This is also true for approximately 30% of the toxic samples collected in the Delta and in the San Joaquin River watershed. The entire Delta, reaches of both the Sacramento and San Joaquin Rivers, and several tributaries are listed under the CWA Section 303(d) for unknown toxicity.

The San Francisco Estuary RMP for San Francisco Bay also has conducted toxicity testing in the Delta and Bay. In brackish and salt water, a number of test species can be used. Unknown toxicity has been detected using *Mysidopsis bahia* (mysid shrimp). In sediment bioassays, significant amounts of unknown toxicity have been detected using *Eohaustorius* and *Mytilus*.

Unknown toxicity is of significant concern because it indicates that agents exist that are bioavailable and causing toxicity that remains to be identified. Unknown toxicity is also an issue for the Sacramento River watershed and the Delta because unidentified toxicants lead to the noncompliance of these water bodies with the narrative toxicity objective of the Basin Plan. A number of stakeholders are interested in resolving the issue of unknown toxicity, including regulatory agencies, point and non-point source dischargers, environmental advocates, farmers, miners, water supply agencies, and the general public.

Unknown toxicity is of significant concern because it indicates that agents exist that are bioavailable and causing toxicity that remains to be identified.

11.4.3 Known Data Gaps

By definition, the problem of unknown toxicity is the existence of data gaps. Where toxicity has been detected, several other factors need to be determined before control strategies can be implemented. The specific contaminants must be identified. Once identified, the duration, magnitude, and frequency of pollution needs to be determined. Sources and the practices or actions that allow the toxicants to enter receiving waters also must be identified.

By definition, the problem of unknown toxicity is the existence of data gaps.

Knowledge is limited about the ecological impacts of the unknown toxicity that is identified with selected bioassay species. Some bioassay testing has been done with native species. It has been argued that use of native species is the appropriate toxicity test. It is also realized that thousands of native species exist. In different test conditions, one species cannot approximate the response of the masses.

Toxicity testing has not been conducted throughout the watershed. To date, testing has focused on the major tributaries and downstream of the major reservoirs.

Toxicity testing has not been conducted throughout the watershed. To date, testing has focused on the major tributaries and downstream of the major reservoirs.

The toxicity testing conducted by the RMP has used marine species on fresh-water samples. Once the cause of toxicity is identified, the impact of salinity must be evaluated.

11.5 Approach to Solution

The following approaches are proposed:

- Determine the extent of toxicity in water and sediments.
- Identify toxicants.
- Determine the sources of toxicants.
- Develop techniques and protocols in toxicity bioassays for indigenous species.
- Evaluate source control measures.

11.5.1 Priority Actions

Ideally, when toxicity is detected, a TIE is performed and a causative agent is identified. Once a chemical is identified, it can be monitored in the field to identify its source and to characterize its spatial and temporal distribution. This information, along with concentration data, can be compared to values in the toxicological literature to provide a rough estimate of ecological risk. This is the process that was used for several of the chemicals that currently are included in CALFED's list of constituents of concern (for example, diazinon and chlorpyrifos).

Ideally, when toxicity is detected, a TIE is performed and a causative agent is identified. Once a chemical is identified, it can be monitored in the field to identify its source and to characterize its spatial and temporal distribution.

CALFED already has approved funding to follow up on the unknown toxicity observed with fathead minnows and *Selenastrum* (algae). Activities to address these toxicity events follow the process outlined here.

Determining the chemical(s) responsible for toxicity requires using all the information available. Work would occur simultaneously in all of the following areas:

- Conduct a TIE
  - Phase I. Determine the general class or characteristics of the toxicant (Is it a metal or an organic compound? Is it volatile, filterable, or sublatable (neutralized)?)
  - Phase II. Determine the specific chemical(s)
  - Phase III. Confirm the chemical(s)
- Determine the spatial and temporal variability of toxicity.
- Determine the source of toxicity
- Examine land use in the watershed to determine potential contaminants. For example, for agricultural land use, look at cropping patterns and pesticide/fertilizer application patterns. Work with the county agricultural commissioner, DPR, farm advisors, pesticide applicators, and growers.
- Consider species sensitivity. Review the toxicological literature to determine the relative toxicity of potential contaminants (determine whether the species that is exhibiting toxicity is sensitive to potential contaminants and whether it is more sensitive to potential contaminants than species not exhibiting toxicity). This action also involves consideration of additivity or synergism of multiple toxicants.
- Work with an analytical laboratory. Frequently, samples contain compounds below reporting limits or contain unknown peaks. Analytical laboratories can work to lower detection limits and identify unknown spikes. This step must be closely coordinated with TIE work.
- Consider factors besides contaminants. Salts, minerals, physical factors (high total suspended solids), and biological factors (pathogens) may be the source(s) of toxicity. Apparent toxicity may be due to a deficiency of a physiologically required element (for example, poor performance in soft water).

11.5.2 *Information Needed*

Work should begin immediately on determining the cause of toxicity exhibited by the following species:

1. *Ceriodaphnia* toxicity occurs throughout the Central Valley and Delta. Chronic toxicity has been detected over large geographic areas and over several months. The toxicity is detected during critical spawning times and locations. Ceriodaphnia chronic toxicity is commonly detected in water supplies and effluents that originated as groundwater. As we begin relying more on groundwater supplies, it is essential to determine why this water frequently causes chronic toxicity to *Ceriodaphnia*.

2. Striped bass toxicity tests conducted during the late 1980s and early 1990s indicated significant toxicity in the Sacramento River. Striped bass testing should resume during their spawning season, at all locations where eggs and larvae occur.

3. Rainbow trout embryo larval tests recently were initiated in the Sacramento River watershed. Acute mortality was observed at locations dominated by urban stormwater runoff. Testing should be resumed and should focus on critical habitats and critical periods for salmonid spawning.

Rainbow trout embryo larval tests recently were initiated in the Sacramento River watershed. Acute mortality was observed at locations dominated by urban stormwater runoff.

4. *Neomysis* has been used as a test species intermittently in the Sacramento River watershed, the Delta, and other fresh-water habitats characterized by high conductivity. *Neomysis* is an important food species for larval fish. Testing needs to be resumed.

5. The San Francisco Estuary RMP for Trace Substances (managed and administered by the San Francisco Estuary Institute) has detected significant amounts of toxicity in their RMP. Much of the toxicity appears to originate in tributaries to the Delta. Sediment toxicity is persistent. The San Francisco Estuary RMP efforts should be supplemented with sufficient resources to characterize the toxicity that has been detected.

Coordination with ongoing programs is essential. Multi-year monitoring programs should be developed for each condition listed above. The first year would focus on characterizing the toxicity spatially and temporally. The second year should focus on contaminant identification. The third year should focus on confirmation.

Coordination with ongoing programs is essential.

It is critical that CALFED develop techniques and protocols for toxicity testing with indigenous species. This type of work already has been suggested to

CALFED by the Interagency Ecological Program Contaminant Effects Project Work Team and will not be repeated here.

This document does not focus on locations without toxicity information. Most of the toxicity testing conducted over the past 10 years has focused on the main stem rivers below the major reservoirs. It is critical that CALFED implement a more comprehensive monitoring program that includes critical habitats and the tributary watersheds to the Delta.

11.5.3 Existing Activities

Both the SFBRWQCB and the San Francisco Estuary Institute's RMP implement long-term toxicity monitoring programs to monitor toxicity in the Sacramento River, San Joaquin River, Delta, and San Francisco Bay. Recently, the Sacramento River Watershed Program began a toxicity monitoring program for the Sacramento River watershed. DeltaKeeper is about to initiate a monitoring program for the Delta. All CALFED CMARP actions should be coordinated with these existing programs.

12. IMPLEMENTATION STRATEGY

12. IMPLEMENTATION STRATEGY

12.1 INTRODUCTION

This chapter sets forth the proposed framework and organization for the initial stage of implementing the Water Quality Program. The initial stage includes early actions to be carried out during the first 2 years and Stage 1 actions to be implemented during the first 7 years after the Record of Decision (ROD) on the Programmatic EIS/EIR. Subsequent staged development will be defined based on information received from studies and actions carried out during early implementation and Stage 1. The level of funding for all proposed actions will vary and depends on decisions made by the CALFED management structure, the legislature, and state and federal agencies.

Subsequent staged development will be defined based on information received from studies and actions carried out during early implementation and Stage 1.

The water quality actions were developed for early implementation and Stage 1 based on input from the Water Quality Technical Group (WQTG). This group consists of over 200 technical experts, agency representatives, and stakeholders—representing the environment, agriculture, drinking water interests, industry, and recreation who participate in the development of the Water Quality Program. The following criteria were recommended by the WQTG and were used to select the proposed Water Quality Program early implementation and Stage 1 actions:

- Seriousness of the water quality problem to be addressed by the proposed action.
- Degree to which the problem and solutions are well understood.
- Likelihood of the proposed solution eliminating impairment of beneficial uses.
- Availability of a willing and competent lead implementing entity.
- Timeframe in which the benefits of the action can be realized and measured.
- Benefits and costs of the action in relation to other proposed actions.
- Ability to leverage CALFED funds by partnerships with other entities and funding sources, including existing sources of CALFED agency funds.

- Equitable distribution of water quality benefits regionally and by beneficial use categories.

CALFED has adopted a general target of continuously improving Delta water quality for all uses, including in-Delta environmental and agricultural uses. CALFED Program actions and studies generally fall into two categories: environmental water quality and drinking water quality. The environmental water quality actions and studies assist existing agency programs to reduce turbidity and sedimentation, reduce the impairment caused by low DO conditions; reduce the impacts of pesticides, including OC pesticides; reduce the impacts of trace metals, mercury, and selenium; reduce salt sources to protect water supplies; and increase understanding of toxicity of unknown origin. The drinking water quality actions and studies are an aggressive mix of strategies to improve in Delta water quality. These actions fall into four broad categories that: (1) enable users to capture more drinking water during periods of high Delta water quality, (2) reduce contaminants and salinity that impair Delta water quality, (3) evaluate alternative approaches to drinking water treatment in order to address growing concerns over DBPs and salinity, and (4) enable voluntary exchanges or purchases of high-quality source waters for drinking water uses. The latter action will be pursued in conjunction with other CALFED actions, such as conveyance and storage improvements, to generate significant improvements in drinking water at the tap.

The use of existing work groups or CALFED technical work groups from the Water Quality Technical Group will be used to receive input for developing implementation plans. Through existing efforts, some actions and studies are well underway to be implemented immediately, while others rely first on comprehensive monitoring, pilot studies, or research to improve the information base.

Recognizing that water quality in the Bay-Delta estuary is in immediate need of improvement, funding decisions for the first 2 years would emphasize actions that result in rapid and measurable improvements.

Recognizing that water quality in the Bay-Delta estuary is in immediate need of improvement, funding decisions for the first 2 years would emphasize actions that result in rapid and measurable improvements. This approach will assure that maximum possible water quality improvements are made in the shortest term. By the third year, emphasis will shift to a longer term perspective, where increasing investments are made in developing the understanding that is fundamental to correcting more complex and technically challenging problems. Also, investments in corrective actions will be increasingly directed at the root causes of complex problems, involving actions that may take many years to fully implement.

A more refined plan for implementation will be developed for each water quality action through an ongoing comprehensive planning process involving state and federal agencies and stakeholders.

A more refined plan for implementation will be developed for each water quality category through an ongoing comprehensive planning process involving state and federal agencies and stakeholders. The planning process will include developing a prioritization method for water quality actions and identifying resources and assurances necessary to implement the actions, establishing a governance structure, identifying the implementing agencies, developing a decision-making process, developing targets and indicators of successful implementation, determining mechanisms for adaptive management, and integrating with other CALFED resource areas and Program elements. Project site-specific environmental documents and any permits necessary will be developed and obtained prior to implementation of water quality actions.

To begin development of the implementation plans, CALFED has begun to establish working groups that consist of agency representatives and stakeholders. These groups will help to prioritize actions and to identify funding resources, appropriate decision making processes, appropriate linkages, and specific coordination mechanisms and regulatory actions that are consistent with and conducive to meeting the CALFED Program water quality goals and objectives.

To begin development of the implementation plans, CALFED has begun to establish working groups that consist of agency representatives and stakeholders.

Success in achieving the CALFED water quality objectives will depend on close coordination and collaboration among agencies with jurisdiction over water quality and stakeholders with an interest in water quality. The following agencies are identified as having key roles:

- **Federal:**
  U.S. Environmental Protection Agency
  U.S. Fish and Wildlife Service
  U.S. Department of Agriculture
  U.S. Bureau of Reclamation

- **State:**
  California Department of Water Resources
  California Department of Food and Agriculture
  California Department of Health Services
  California Department of Pesticide Regulation
  State Water Resources Control Board
  Central Valley Regional Water Quality Control Board
  San Francisco Bay Regional Water Quality Control Board

12.2 GOAL

The Water Quality Program's goal for water quality is to provide good water quality for environmental, agricultural, drinking water, industrial, and recreational beneficial uses.

The Water Quality Program's goal for water quality is to provide good water quality for environmental, agricultural, drinking water, industrial, and recreational beneficial uses.

12.3 PRINCIPLES

The following principles will be followed by the Water Quality Program throughout implementation:

The Water Quality Program emphasizes voluntary, cooperative efforts to improve water quality but will work with regulatory entities to assure program goals are accomplished where voluntary efforts may prove insufficient.

- The Water Quality Program emphasizes voluntary, cooperative efforts to improve water quality but will work with regulatory entities to assure program goals are accomplished where voluntary efforts may prove insufficient.
- Positive mechanisms will be used to assure accountability, fiscal integrity, and technical quality in implementing Water Quality Program actions.
- To the extent possible, existing water quality programs and capabilities will be used to meet Water Quality Program goals and objectives.
- Agency regulatory responsibilities will be coordinated to provide appropriate incentives for water quality improvement, and enhance opportunities to form partnerships among governmental and private interests. There will be no change in existing regulatory authority.
- Independent peer review and evaluation of the Water Quality Program and its success in implementation of actions will be used to prevent and correct water quality problems, and to provide recommendations for adaptive management.
- The Water Quality Technical Group, comprised of agencies and stakeholders, will be utilized to help plan and implement the Water Quality Program, and to help establish interim water quality targets that demonstrate continual water quality improvement.

12.4 EARLY IMPLEMENTATION AND STAGE 1 ACTIONS

The CALFED Implementation Plan lists the Stage 1 Water Quality Program actions (first 7 years commencing with the ROD on the Programmatic EIS/EIR and the Stage 1a water quality actions (2 years before the ROD on the Programmatic EIS/EIR).

12.5 Linkages

Many Water Quality Program actions both support and are linked to other CALFED resource areas and program elements. For example, watershed activities can improve water quality by helping to identify and control nonpoint sources of pollution, and identify and implement methods to control or treat contaminants flowing to the Bay-Delta. Surface and groundwater storage along with Delta conveyance improvements can help in the management of inflows to and exports from the Delta. Water use efficiency measures can improve water quality entering the Delta by reducing some agricultural and non-agricultural discharges containing pollutants. Ecosystem restoration actions may degrade drinking water quality by increasing organic carbon loads. Levee stability actions can avoid catastrophic levee failures in the Delta and avoid making the Delta waters unusable for drinking water purposes. Finally, the CALFED Science Program will be instrumental in applying adaptive management involving water quality actions and studies.

Many Water Quality Program actions both support and are linked to other CALFED resource areas and program elements.

12.6 Management And Governance

A key feature in assuring successful Program implementation is the development of a long-term governance structure for CALFED that can manage and oversee all aspects of the Program, including staged decision making, Program balance, and adaptive management. The proposal for a CALFED long-term governance structure is included in Chapter 4 in the Implementation Plan. Passing the necessary legislation and establishing new or revised governance structures may take several years. For the interim, CALFED proposes to continue the current structure but modified to serve implementation functions. Until a long-term governance structure is in place, the CALFED Policy Group will continue to make management decisions for Water Quality Program actions based on recommendations from water quality working groups, expert panels, and other public advisory groups. The role and mission of these working groups are discussed below. The proposed long-term and interim CALFED governance structures are described in detail in the Implementation Plan.

The proposal for a CALFED long-term governance structure is included in Chapter 4 in the Implementation Plan.

12.6.1 Broad Public Advisory Council

In the interim, the CALFED Program will continue to receive input and advice from the public, Indian tribes, and interested stakeholders. Either the BDAC or a

Either the BDAC or a similar advisory group will serve CALFED in the interim.

similar advisory group will serve CALFED in the interim. A new advisory committee will be established to advise the long-term governing body.

12.6.2 Delta Drinking Water Council

The Delta Drinking Water Council was formed to receive stakeholder advice and input into the decision-making process for drinking water issues. The Delta Drinking Water Council is a work group of the BDAC and consists of representatives of various stakeholder interests and representatives from designated agencies with jurisdiction over drinking water issues (for example, EPA and DHS).

The Delta Drinking Water Council was formed to receive stakeholder advice and input into the decision-making process for drinking water issues.

The functions of the Delta Drinking Water Council are summarized below:

- Serves as the advisory body related to CALFED drinking water studies and actions.
- Based on performance of drinking water studies and actions, makes recommendations to the Water Quality Program, CALFED agencies, and the BDAC on treatment, health effects, alternative water sources, additional conveyance, storage, and operations.
- Uses expert panel reviews and recommendations.

12.6.3 Ecosystem Roundtable

The Ecosystem Roundtable consists of environmental, recreational (including boating, hunting, and fishing), industrial, and local government interests with expertise in water quality. The Roundtable serves as a forum to incorporate stakeholder input into the decision-making process for actions or programs related to ecosystem restoration and ecosystem water quality. This group is a working group of the BDAC.

The Ecosystem Roundtable serves as a forum to incorporate stakeholder input into the decision-making process for actions or programs related to ecosystem restoration and ecosystem water quality.

The functions of the Ecosystem Roundtable are summarized below:

- Based on performance of ecosystem water quality studies and actions, makes recommendations to the Water Quality Program, CALFED agencies, and the BDAC.
- Coordinates with and helps to integrate ecosystem water quality actions with Ecosystem Restoration Program actions.

- Uses expert panel reviews and recommendations.

12.6.4 Water Quality Technical Group

The Water Quality Technical Group has provided significant input into the development of the Water Quality Program since its inception. The group is over 200 strong and represents agencies and stakeholders from environmental, agricultural, municipal, industrial and recreational interests. Technical teams from the Water Quality Technical Group helped to develop the Water Quality Program Plan, including the actions and studies presented in the plan. The Water Quality Technical Group or work groups formed from the Water Quality Technical Group will function as advisors on CALFED priority actions, targets, monitoring, and assessment during the interim governance period and throughout long-term implementation of the Water Quality Program. The Water Quality Technical Group is a source of expertise in all of the action categories. This group can be instrumental in assisting agencies responsible for implementing Water Quality Program actions and studies.

The Water Quality Technical Group or work groups formed from the Water Quality Technical Group will function as advisors on CALFED priority actions, targets, monitoring, and assessment during the interim governance period and throughout long-term implementation of the Water Quality Program.

The functions of the Water Quality Technical Group or individual work groups are summarized below.

- Identifies water quality actions and targets, and makes recommendations to the Water Quality Program for implementation.
- Reviews and comments on work plans and project completion reports.
- Represents a pool of resources for agency and stakeholder expertise for ad hoc technical expert panels.

12.6.5 Expert Panels

Expert panels will be commissioned at various times—for various reasons and durations—in time to address specific issues through a public setting. Each expert panel will consist of nationally and internationally known experts in the field being addressed. Membership criteria and selection will be determined by the appropriate policy or working group (for example, the CALFED Policy Group, Delta Drinking Water Council, Water Quality Technical Group, and Ecosystem Roundtable). Each expert panel will be formed at the discretion of CALFED. The panels will present their conclusions to the Water Quality Program and the appropriate working group.

Expert panels will be commissioned at various times—for various reasons and durations—in time to address specific issues through a public setting.

12.7 Adaptive Management Strategy

The simplest definition of adaptive management is "learning by doing." Adaptive management also is defined as a science-directed process whereby the possible solutions to prioritized problems are implemented, monitored, and evaluated and then either are repeated or evolve into the next round of testing.

Adaptive management is defined as a science-directed process whereby the possible solutions to prioritized problems are implemented, monitored, and evaluated and then either are repeated or evolve into the next round of testing.

Using adaptive management, appropriate modifications can be made at each step of the process to accommodate variables or conditions that were previously unknown or unforeseeable, and to provide a continual feedback mechanism. The foundation of this approach is built on data and information about water quality conditions at all sites of concern. Based on these data and information, water quality problems can be identified. Each problem is assessed, based on existing data and information, as well as more data and information gained through continual monitoring and research. Based on the assessments, it may be possible to find potential solutions to identified water quality problems. Each potential solution then is evaluated through further monitoring and research, which will lead to identification of the best alternatives. Finally, the best possible solutions then can be implemented when the best alternatives have been identified.

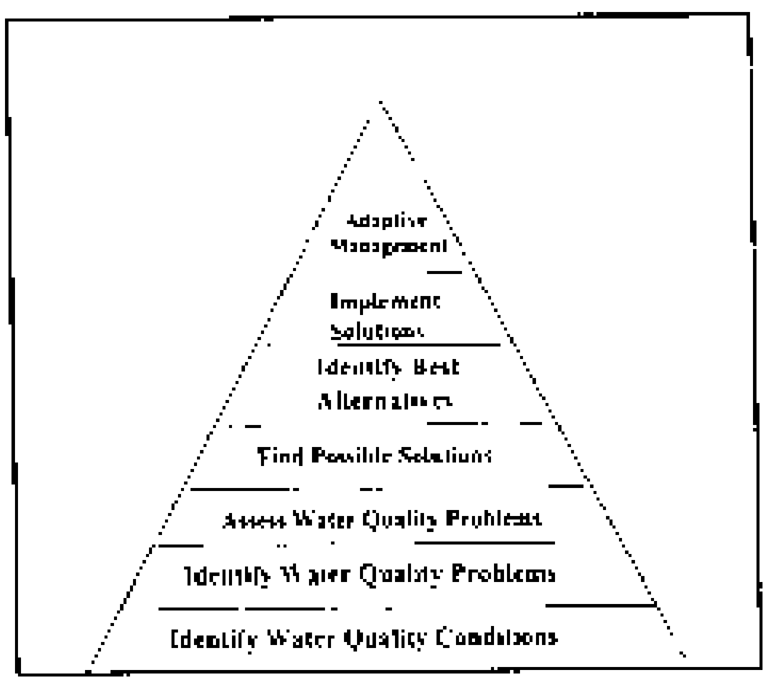


Figure 14. Adaptive Management Process

Figure 14 depicts the steps to identifying and implementing solutions that can be applied to Water Quality Program actions.

Individual strategies will be prepared for water quality parameters such as low DO, selenium, pesticides, salinity, sediment, aquatic toxicity, organochlorine pesticides, and other trace metals. Some of these water quality parameters are targeted by the regulatory agencies for development of TMDLs. Mercury is one of the targeted parameters, along with others such as diazinon and chlorpyrifos. CALFED will develop individual implementation plans for those water quality parameters targeted for TMDLs. These plans will be closely coordinated with the Ecosystem Roundtable and will complement efforts among CALFED agencies and non-CALFED agencies with existing regulatory authority. This coordination will help assure success in achieving the CALFED Program water quality goals and objectives.

CALFED will develop individual implementation plans for those water quality parameters targeted for TMDLs.

APPENDIX A

WATER QUALITY TECHNICAL GROUP MEMBERS

APPENDIX A.
WATER QUALITY TECHNICAL GROUP MEMBERS
(Alphabetical Listing)

Manucher Alemi	California Department of Water Resources
Charlie Alpers	U.S. Geological Survey
William Alsop	Chem Risk
John Andrew	California Department of Water Resources, Office of State Water Project Planning
Elaine Archibald	Archibald & Wallberg Consultants
Ed Ballman	Environmental Water Resources
Terri Barry	Cal EPA Department of Pesticide Regulation
James Beck	Kern County Water Agency
Bill Bennett	University of California, Davis, c/o Friday Harbor Labs
Brian Bergamaschi	U.S. Geological Survey
Robert Berger	East Bay Municipal Utility District
Jerry Boles	California Department of Water Resources
Roberta Borgonovo	League of Women Voters
Gerald Bowes	State Water Resources Control Board
Pat Braziel	Sacramento County
David Breninger	Placer County Water Agency
Rich Breuer	California Department of Water Resources
Dave Briggs	Contra Costa Water District
Marcia Brockbank	San Francisco Estuary Project
Robert Brodberg	Office of Environmental Health Hazard Assessment
Jerry Bruns	Central Valley Regional Water Quality Board
Jeff Bryant	Firebaugh Canal Water District
Byron Buck	California Urban Water Agencies
Patty Bucknell	Anteb
Kati Buehler	Western Crop Protection Association
Stein Buer	CALFED Bay-Delta Program
Charlie Bunker	[illegible] Engineers
Jack Burnam	Carollo Engineers
Elissa Callman	City of Sacramento
Hal Candee	National Resource Defense Council
Peter Candy	Environmental Representative
Marc Carpenter	Westlands Water District
Jean-Pierre Cativiela	California Rice Industry Association
Ken Cawley	Regional Council of Rural Counties
Vashek Cervinka	California Department of Food and Agriculture
Grace Chan	Metropolitan Water District of Southern California
David Chatfield	Clean Water Action
Francis Chung	California Department of Water Resources, Division of Planning
Lori Clamurro	Delta Protection Commission

Rosemary Clark	Sacramento Regional County Sanitation District
John Coburn	State Water Contractors
Ronnie Cohen	Natural Resources Defense Council
Deborah Condon	California Department of Water Resources
Val Connor	Central Valley Regional Water Quality Control Board
David Crane	California Department of Fish and Game
William Crooks	W. H. C. Consulting
Bill Croyle	Central Valley Regional Water Quality Control Board No. 5
Earle Cummings	California Department of Water Resources
Martha Davis	Environmental Water Caucus
Victor de Vlaming	State Water Resources Control Board
Jennifer Decker	California Department of Fish and Game
Mike Delamore	U.S. Bureau of Reclamation
Richard Denton	Contra Costa Water District
Peter Dileanis	U.S. Geological Survey
Joseph Domagalski	U.S. Geological Survey
Kevin Donhoff	Metropolitan Water District of Southern California
Neil Dubrovsky	U.S. Geological Survey
Mary Dunne	California Department of Fish and Game
Robert Ehn	FMC Corporation
Jean Elder	U.S. Fish and Wildlife Service
Jennifer Enson	Psomas and Associates
Dennis Falaschi	Panoche Water and Drainage District
Brian Finlayson	California Department of Fish and Game
Richard Fish	Lawrence Berkeley Laboratories
Chris Foe	Central Valley Regional Water Quality Board
Steven Ford	California Department of Water Resources
David Forkel	Delta Wetlands
Amy Fowler	Santa Clara Valley Water District
Phyllis Fox	Metropolitan Water District of Southern California
Russell Fuller	Antelope Valley-East Kern Water Agency
Tom Garcia	Sacramento County Public Works
John Gaston	CH2M HILL
Frank Gibbons	OHM Remediation Services Corporation
Suzanne Gibbs	Big Chico Creek Task Force
Paul Gilbert-Snyder	California Department of Health Services
Kathleen Goforth	U.S. Environmental Protection Agency
Russ Grimes	U.S. Bureau of Reclamation
Les Grober	Central Valley Regional Water Quality Control Board
Tom Grovhoug	Sacramento River Watershed Program
Susan Hatfield	U.S. Environmental Protection Agency, Region 9
Tracy Hemmeter	Santa Clara Valley Water District
Bob Herkert	California Rice Industry Association
Steve Herrera	Parsons Engineering Science
Alex Hildebrand	South Delta Water Agency

Diane Hinson	City of Stockton, Department of Municipal Utilities
Steven Hirsch	Metropolitan Water District of Southern California
Jim Hockenberry	California Department of Water Resources
Joe Horn	Citizens for Safe Drinking Water
Robert Hosea	California Department of Fish and Game
Charlie Huang	California Department of Fish and Game
Robert Hultquist	California Department of Health Services
Rick Humphreys	State Water Resources Control Board
Mary James	Sacramento County Regional Sanitation District
Carol James	C. R. James and Associates
Jeff Jaraczeski	Northern California Water Association
Bill Jennings	DeltaKeeper
Cecilia Jensen	Sacramento Regional County Sanitation District
Ron Jerveson	San Francisco Bay Regional Water Quality Control Board
Brenda Johnson	University of California, Davis
Ron Johnson	Sacramento Regional County Sanitation District
William Johnston	Modesto Irrigation District
Larry Joyce	California Department of Water Resources
Marvin Jung	Marvin Jung and Associates
Fawzi Karajeh	California Department of Water Resources
Joe Karkoski	U.S. Environmental Protection Agency, c/o State Water Resources Control Board
Revital Katznelson	Woodward Clyde Associates
Robin Kerth	DeltaKeeper
Walter Kozlchuk	Delta Protection Commission
Charlie Kratzer	U.S. Geological Survey
Cat Kuhlman	U.S. Environmental Protection Agency
John Ladd	State Water Resources Control Board
Jordan Lang	Jones & Stokes Associates, Inc
Edwin Lee	Consultant
Marshall Lee	Cal EPA Department of Pesticide Regulation
G. Fred Lee	G. Fred Lee & Associates
Randy Lee	Regional Water Quality Control Board No. 2
Peggy Lehman	California Department of Water Resources
Gail Linck	State Water Resources Control Board
Carl Lischeske	California Department of Health Services
Gail Louis	U.S. Environmental Protection Agency
Mike Lozeau	San Francisco BayKeeper
Sam Luoma	U.S. Geological Survey
Bruce Macler	U.S. Environmental Protection Agency
Frank Maitski	Santa Clara Valley Water District
Kathy Mannion	Western Growers Association
Don Marciochi	Grasslands Water District
Tanya Matson	Segnet and Associates
Tom Maurer	U.S. Fish and Wildlife Service

Larry McCollum	Contra Costa Water District
Steve McCormick	Nature Conservancy
Michael McElhiney	U.S. Department of Agriculture
Joseph McGahan	Summers Engineering, Inc.
Steve McLean	Castaic Lake Water Agency
Eugenia McNaughton	U.S. Environmental Protection Agency
Mary Meays	Sierra Club
Markus Meier	Zeneca Ag Products
Linda Mercurio	Mining Remedial Recovery Company
Alexis Milea	California Department of Health Services
Candace Miller	Cal EPA Department of Pesticide Regulation
Lee Miller	California Department of Fish and Game
Thomas Mongan	Consultant
Douglas Morrison	U.S. Fish and Wildlife Service
Thomas Mumley	California Regional Water Quality Control Board
Parviz Nader	California Department of Water Resources
Daniel Nelson	San Luis and Delta-Mendota Water Authority
Barry Nelson	Save San Francisco Bay Association
Ann Notthoff	Natural Resources Defense Council
Lynn O'Leary	U.S. Army Corps of Engineers
Sandy Oblonsky	Santa Clara Valley Water District
David Okita	Solano County Water Agency
Jenna Olsen	Environmental Water Caucus
Victor Pacheco	California Department of Water Resources
Joan Patton	San Francisco Estuary Project
Jonathan Phinney	University of California, Berkeley
Terry Prichard	University of California, Davis, Agricultural Extension
Katy Pye	Yolo County Resource Conservation District
Nigel Quinn	U.S. Bureau of Reclamation Lawrence Berkeley National Laboratory
Kerry Rae	U.S. Bureau of Reclamation
Hari Rajbhandari	California Department of Water Resources
William Ray	State Water Resources Control Board
Maria Rea	U.S. Environmental Protection Agency, Region IX
Harry Rectenwald	California Department of Fish and Game
Robin Reynolds	California Department of Food and Agriculture
Peter Rhoads	Metropolitan Water District of Southern California
Theodore Roefs	U.S. Bureau of Reclamation (Retired)
Spreck Rosekrans	Environmental Defense Fund
Eric Rosenblum	South Bay Water Recycling
Kathy Russick	County of Sacramento Public Works
Walter Sadler	Boyle Engineering
Doreen Salazar	Carollo Engineers
John Sanders	Cal EPA Department of Pesticide Regulation
Curt Schmutte	California Department of Water Resources

Rudy Schnagl	Central Valley Regional Water Quality Control Board No. 5
Scott Schneider	Kennedy Jenks Consultants
Steven Schwarzbach	U.S. Fish and Wildlife Service
Steve Shaffer	California Department of Food and Agriculture
Charles Shank	Lawrence Berkeley National Laboratory
Walt Shannon	State Water Resources Control Board
Patrick Sheehan	Chem Risk
KT Shum	Contra Costa Water District
Stella Siepmann	California Department of Fish and Game
Darrel Slotton	University of California at Davis
Polly Smith	League of Women Voters
Lynda Smith	Metropolitan Water District of Southern California
Keith Smith	Sacramento County Regional Sanitation District
Perri Standish-Lee	Standish Lee Consultants
Peter Standish-Lee	Woodward-Clyde Associates
Jane Steele	Urban Creeks Council
Mark Stephenson	Moss Landing Marine Laboratory
Karl Stinson	Alameda County Water District
Bryan Stuart	Dow Agro Sciences, Western Regional Office
Dan Sullivan	Sierra Club
David Supkoff	Cal EPA Department of Pesticide Regulation
Jeanette Thomas	Stockton East Water District
Lenore Thomas	U.S. Bureau of Reclamation
Bruce Thompson	San Francisco Estuary Institute
Raymond Tom	California Department of Water Resources
Jerry Troyan	Sacramento Regional County Sanitation District
Joel Trumbo	California Department of Fish and Game
John Turner	California Department of Fish and Game
Erwin Van Nieuwenhuys	Jones & Stokes Associates, Inc.
Wayne Verrill	California Department of Water Resources
Jane Vorpagel	California Department of Fish and Game
Walter Ward	Modesto Irrigation District
Inge Werner	Sierra Club
Dennis Westcot	Central Valley Regional Water Quality Control Board
Donald Weston	University of California, Berkeley
Victoria Willis	City of Benicia
Leo Winternitz	California Department of Water Resources, Environmental Services Office
John Winther	Delta Wetlands
Steve Wirtel	ADS Environmental Services
Roy Wolfe	Metropolitan Water District of Southern California
Carolyn Yale	U.S. Environmental Protection Agency, Region IX
Marguerite Young	Clean Water Action

Terri Young	Environmental Defense Fund
Ray Zimny	U.S. Army Corps of Engineers, Sacramento District
Tom Zuckerman	Feldman Waldman & Kline

APPENDIX B

WATER BODIES LISTED IN 1998 AS IMPAIRED UNDER CLEAN WATER ACT SECTION 303(d)

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d)

Water Body	Regional Board	Parameter of Concern	Probable Sources
		Bay Region	
San Francisco Bay	2	Mercury	Mining, stormwater, municipal and industrial point sources, atmospheric deposition
		Copper	Stormwater, municipal and industrial point sources, atmospheric deposition
		Nickel	Stormwater, municipal and industrial point sources
		Diazinon	Stormwater
		PCBs	Non-point sources
		Selenium (Central and South Bay)	Domestic use of groundwater, aquaculture
Richardson Bay	2	Mercury	Mining, stormwater, municipal point sources, atmospheric deposition
		PCBs	Non-point sources, unknown
		Coliform	Septage disposal, stormwater, vessel/boat discharges
San Pablo Bay	2	Mercury	Mining, stormwater, municipal point sources, atmospheric deposition
		Copper	Stormwater, municipal and industrial point sources, atmospheric deposition
		Diazinon	Stormwater
		PCBs	Non-point sources, unknown
		Selenium	Industrial point sources, agriculture
		Nickel	Stormwater, municipal point sources
Carquinez Strait	2	Mercury	Mining, stormwater, municipal point sources, atmospheric deposition
		Copper	Stormwater, municipal and industrial point sources, atmospheric deposition
		Diazinon	Stormwater
		PCBs	Non-point sources, unknown

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d) (Continued)

Water Body	Regional Board	Parameter of Concern	Probable Sources
		Selenium	Industrial point sources, agriculture
		Nickel	Stormwater, municipal point sources
Suisun Bay	2	Mercury	Mining, stormwater, industrial point sources, atmospheric deposition
		Copper	Stormwater, municipal point sources, atmospheric deposition
		Diazinon	Stormwater
		PCBs	Non-point sources, unknown
		Selenium	Industrial point sources, natural sources
		Nickel	Stormwater, municipal point sources
Delta	2	Mercury	Mining, stormwater, municipal and industrial point sources, atmospheric deposition
		Copper	Stormwater, municipal point sources, atmospheric deposition
		Diazinon	Stormwater
		PCBs	Non-point sources, unknown
		Selenium	Industrial point sources, natural sources
		Nickel	Stormwater, municipal point sources
Napa River	2	Nutrients	Agriculture
		Pathogens	Agriculture, land development, stormwater
		Siltation	Agriculture, stormwater
Petaluma River	2	Nutrients	Agriculture, land development, stormwater
		Pathogens	Agriculture, land development, stormwater
		Siltation	Agriculture, land development, stormwater
Guadalupe Creek, Guadalupe River, Guadalupe Reservoir, Alamitos Creek, Calero Reservoir (all South San Francisco Bay)	2	Mercury	Mining

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d) (Continued)

Water Body	Regional Board	Parameter of Concern	Probable Sources
		Central Valley Region	
Delta waterways	5	Mercury	Abandoned mine(s)
		Diazinon, chlorpyrifos	Agriculture, urban stormwater
		Unknown toxicity	Unknown source
		Salt	Agriculture
		DO	Municipal point sources, urban stormwater
		Group A pesticides, DDT	Agriculture
Grassland marshes	5	Selenium	Agriculture
		Salt	Agriculture
Arcade Creek	5	Diazinon	Urban stormwater, agriculture
		Chlorpyrifos	Urban stormwater
American River, Lower	5	Mercury	Abandoned mine(s)
		Group A pesticides	Urban stormwater
		Unknown toxicity	Unknown source
Cache Creek	5	Mercury	Abandoned mine(s)
		Unknown toxicity	Unknown source
Chicken Ranch Slough	5	Diazinon	Urban stormwater, agriculture
		Chlorpyrifos	Urban stormwater
Colusa Drain	5	Unknown toxicity Group A pesticides	Agriculture
		Carbofuran, malathion	Agriculture
		Methyl parathion	Agriculture
Dolly Creek	5	Copper, zinc	Abandoned mine(s)
Dunn Creek	5	Mercury, metals	Abandoned mine(s)
Elder Creek	5	Diazinon	Urban stormwater, agriculture

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d) (Continued)

Water Body	Regional Board	Parameter of Concern	Probable Sources
		Chlorpyrifos	Urban stormwater
Elk Grove Creek	5	Diazinon	Urban stormwater, agriculture
Fall River (Pit)	5	SED	Silviculture, grazing, construction
Five Mile Slough	5	Diazinon	Urban stormwater, agriculture
Feather River, Lower		Chlorpyrifos	Urban stormwater
	5	Diazinon	Agriculture, urban stormwater
		Mercury	Abandoned mine(s)
		Group A pesticides	Agriculture
		Unknown toxicity	Unknown source
French Ravine	5	Bacteria	Land disposal
Harding Drain	5	Unknown toxicity	Agriculture
(TID Lateral #5)	5	Diazinon, chlorpyrifos	Agriculture
		Ammonia	Municipal point sources, agriculture
Harley Gulch	5	Mercury	Abandoned mine(s)
Horse Creek	5	Copper, cadmium, zinc, lead	Abandoned mine(s)
Humbug Creek	5	Copper, zinc, mercury, sediment	Abandoned mine(s)
James Creek	5	Ni, mercury	Abandoned mine(s)
Kanaka Creek	5	As	Abandoned mine(s)
Kings River, lower	5	Mo, toxaphene, salt	Agriculture
Little Backbone Creek	5	Copper, zinc, cadmium, lead	Abandoned mine(s)
Little Cow Creek	5	Copper, zinc, cadmium	Abandoned mine(s)
Little Grizzly Creek	5	Copper, zinc	Mine tailings
Lone Tree Creek	5	Salt, ammonia, BOD	Dairies
Marsh Creek	5	Mercury, metals	Abandoned mine(s)

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d) (Continued)

Water Body	Regional Board	Parameter of Concern	Probable Sources
Merced River, Lower	5	Diazinon, chlorpyrifos	Agriculture
		Group A pesticides	Agriculture
Mokelumne River, lower	5	Copper, zinc	Abandoned mine(s)
Morrison Creek	5	Diazinon	Urban stormwater, agriculture
Mosher Slough	5	Diazinon	Urban stormwater, agriculture
Mud Slough		Chlorpyrifos	Urban stormwat
	5	Selenium	Agriculture
		PES, unknown toxicity, boron, salt	Agriculture
Natomas East Main Drain	5	Diazinon	Urban stormwater, agriculture
		PCBs	Industrial, urban stormwater
Orestimba Creek	5	Diazinon, chlorpyrifos	Agriculture
		Unknown toxicity	Agriculture
Panoche Creek	5	Sediment, selenium	Agriculture, grazing, construction
		Mercury	Abandoned mine(s)
Pit River	5	DO, temperature, nutrients	Grazing, agriculture
Sacramento River (Shasta to Red Bluff)	5	Copper	Abandoned mine(s)
		Cadmium	Abandoned mine(s)
		Zinc	Abandoned mine(s)
		Unknown toxicity	Unknown source
Sacramento River (Red Bluff to Delta)	5	Diazinon	Agriculture
		Mercury	Abandoned mine(s)
		Unknown toxicity	Unknown source

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d) (Continued)

Water Body	Regional Board	Parameter of Concern	Probable Sources
Sacramento Slough	5	Diazinon	Agriculture, urban stormwater
		Mercury	Unknown source
Salt Slough	5	Selenium	Agriculture
		Unknown toxicity, boron, salt	Agriculture
		Diazinon, chlorpyrifos	Agriculture
San Carlos Creek	5	Mercury	Abandoned mine(s)
San Joaquin River	5	Selenium	Agriculture
		Diazinon, chlorpyrifos	Agriculture
		Boron, salt	Agriculture
		Unknown toxicity	Unknown source
		Group A pesticides, DDT	Agriculture
Spring Creek	5	Copper, zinc, cadmium, acid	Abandoned mine(s)
Stanislaus River, Lower	5	Diazinon	Agriculture
		Unknown toxicity	Unknown source
		Group A pesticides	Agriculture
Strong Ranch Slough	5	Diazinon	Urban stormwater, agriculture
		Chlorpyrifos	Urban stormwater
Sulfur Creek	5	Mercury	Abandoned mine(s)
Temple Creek	5	Ammonia, salt	Dairies
Town Creek	5	Cadmium, copper, lead, zinc	Abandoned mine(s)
Tuolumne River, Lower	5	Diazinon	Agriculture
		Unknown toxicity	Unknown source
		Group A pesticides	Agriculture

Water Bodies Listed in 1998 as Impaired under Clean Water Act Section 303(d) (Continued)

Water Body	Regional Board	Parameter of Concern	Probable Sources
West Squaw Creek	5	Copper, zinc, cadmium, lead	Abandoned mine(s)
Willow Creek (Whiskeytown)	5	Copper, zinc, acid	Abandoned mine(s)
Berryessa Lake	5	Mercury	Abandoned mine(s)
Clear Lake	5	Mercury	Abandoned mine(s)
		Nutrients	Unknown source
Davis Creek Reservoir	5	Mercury	Abandoned mine(s)
Keswick Reservoir	5	Copper, zinc, cadmium	Abandoned mine(s)
Marsh Creek Reservoir	5	Mercury	Abandoned mine(s)
Shasta Lake	5	Copper, zinc, cadmium	Abandoned mine(s)
Whiskeytown Reservoir	5	Coliform	On-site disposal

APPENDIX C

POTENTIAL TOOLS AND INDICATORS OF SUCCESS

Potential Tools and Indicators of Success

Tools for Correction	Indicators of Success
Drinking Water	
Drinking Water	
Evaluate causes of increased bromide in San Luis Reservoir	Identification of all major sources of bromide in San Luis Reservoir, as determined by loading calculations based on sampling data
Investigate combinations of new supplies, operational changes, and new technology to meet drinking water standards	Implementable strategy to prevent formation of disinfection by-products (DBPs) above drinking water standards
Convene expert panel to make recommendations regarding solutions to drinking water public health issues	Recommendations for drinking water solutions from an independent, nationally recognized panel of experts
Develop a plan to meet regulatory standards for brominated and chlorinated DBPs	Implementable strategy for meeting drinking water standards
Investigate alternative sources of high-quality water supply for urban users of Delta water	Thorough evaluation of feasibility of using alternative source water for export
Support studies about public health effects from brominated DBPs	Determination of safe drinking water concentrations of brominated DBPs
Investigate use of advanced treatment technologies (e.g., membranes) at water treatment plants	Feasibility of advanced treatment is determined, based on current source water and advanced treatment technology
Quantify importance of connate groundwater in Empire Tract and adjacent islands	Determination of connate water contribution to bromide levels in island discharges
Perform more thorough evaluation of bromide origin in San Joaquin River	Identification of all major sources of bromide in San Joaquin River system, as demonstrated by loading calculations based on sample data
Bromide, Total Organic Carbon, and Nutrients	
Optimize treatment plant operations to achieve lowest DBPs with current source water and common techniques	DBP formation above drinking water standards is prevented in a cost-effective manner, based on current source water and common treatment technology
Manage ecosystem restoration projects to minimize adverse impacts on drinking water	Ecosystem restoration activities result in no adverse impacts on drinking water intakes
MTBE	
Control recreational boating to reduce MTBE in applicable State Water Project (SWP) storage facilities	Reduce MTBE in drinking water samples to non-detect levels

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Pathogens	
Provide secondary containment for sanitary facilities at SWP terminal reservoirs	Secondary containment at all sanitary facilities in terminal reservoirs
Control recreation to reduce human pathogens in SWP storage facilities	Minimized risk of pathogens to extent possible within legal and logistical constraints
Minimize pathogens from recreational boating in Bay-Delta area	Reduce risk of pathogens to drinking water supplies from boats in Delta and Delta rivers and from water-contact recreation, as established by sampling data
Pathogens and Nutrients	
Implement common elements of watershed management programs in Clifton Court Forebay area	Implemented watershed BMPs to prevent input of nutrients, pathogens, and total organic carbon (TOC), enabling drinking water standards to be met reliably and cost effectively
Identify problems and source control activities for urban runoff in Delta Region	Properly characterized urban impacts on drinking water constituents and an implementable control strategy
Total Organic Carbon and Nutrients	
Conduct pilot study on agricultural drainage control actions in Bay-Delta area	Development of pilot-scale agricultural drain treatment system to remove TOC and nutrients in order to prevent DBP formation above drinking water standards
Conduct feasibility evaluations (literature and bench scale) for treating Delta island drainage to remove TOC and nutrients	Identification of most feasible options to remove TOC from discharges of Delta islands
Study algae and macrophyte growth potential in Delta and propose corrective strategy in distribution system	Implementable corrective strategy to prevent (or reduce) algal production in drinking water storage and conveyance facilities
Implement full-scale agricultural drainage control actions in Bay-Delta area	Treatment of key agricultural drains to reduce TOC levels such that DBP formation above drinking water standards is prevented
Total Organic Carbon, Pathogens, and Nutrients	
Implement common elements of watershed management program in Lake Del Valle area	Implemented watershed BMPs to prevent input of nutrients, pathogens, and TOC, enabling drinking water standards to be met reliably and cost effectively

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Participate in controlling wastewater discharges from Discovery Bay	Reduced impacts of wastewater discharges such that DBP formation above drinking water standards is prevented
Relocate Veale Tract agricultural drain	Reduced levels of TOC, pathogens, and nutrients at Contra Costa Water District's (CCWD's) Rock Slough intake in order to prevent DBP formation above drinking water standards
Study impacts of Discovery Bay outfall and mitigate as necessary	Properly characterized and mitigated impacts from Discovery Bay outfall on drinking water intakes in Clifton Court and Old River
Evaluate relocation of Tracy's intake from Delta-Mendota Canal (DMC) to SWP	Reduced risk of pathogen contamination from City of Tracy to that of other water purveyors in Delta
Establish watershed management program for San Joaquin River	Reduced nutrients, pathogens, salt, and TOC such that DBP formation above drinking water standards is prevented, and conservation and reuse are maximized
Develop drinking water protection strategy in addressing stormwater	Comprehensive implementable strategy that protects drinking water and wastewater discharge permittees from all drinking water contaminants
Implement common elements of watershed management program for South Bay Aqueduct (SBA)	Implementable watershed BMPs to prevent input of nutrients, pathogens, and TOC, enabling drinking water standards to be reliably and cost effectively met
Evaluate feasibility and cost effectiveness of providing an alternative point of intake for North Bay Aqueduct (NBA)	Availability of alternate source water that prevents DBP formation above drinking water standards
Implement Barker Slough watershed management program for NBA	Reduced levels of TOC, pathogens, and nutrients at NBA intake that prevent DBP formation above drinking water standards
Develop BMPs for livestock grazing that can be applied in several locations	Development of implementable BMPs that effectively reduce TOC, nutrients, and pathogens in surface waters, enabling drinking water standards to be met reliably and cost effectively
Total Organic Carbon, Pathogens, Nutrients, and Turbidity	
Develop watershed management program for SWP drainage and implement as appropriate	Minimized stormwater contribution of contaminants such that sedimentation and DBP formation above drinking water standards is prevented reliably and cost effectively

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Control stormwater discharges in SWP by physical modification of facilities	Minimized stormwater contribution of contaminants such that sedimentation and DBP formation above drinking water standards is prevented reliably and cost effectively
Develop watershed management programs for Castaic and Silverwood Reservoirs	Reduced input of nutrients and pathogens such that DBP formation above drinking water standards is prevented reliably and cost effectively
Total Organic Carbon, Taste and Odor, and Physical Plugging	
Evaluate structural controls of algae in Castaic Lake and Elderberry Forebay	Elimination of nuisance algal growths in Castaic Lake and Elderberry Forebay
Evaluate and change Castaic Lake and Elderberry Forebay structures to reduce algal growth	Elimination of nuisance concentrations of taste and odor (T&O) producing algae in these reservoirs
Study algae control in Clifton Court Forebay and SBA	Reduced physical obstruction of water treatment and delivery facilities by algae and TOC levels such that DBP formation above drinking water standards is prevented, T&O problems are avoided, and treatment costs due to additional chemical usage and shortened filter runs are avoided
Control algal blooms and aquatic weeds in lower American River	Elimination of nuisance algal blooms in lower American River and reduce physical plugging of treatment plant facilities
Control algae in storage and conveyance facilities south of Delta	Minimized physical obstruction of facilities due to excessive algal growths and reduced TOC such that DBP formation above drinking water standards is prevented reliably and cost effectively
Low Dissolved Oxygen	
Dissolved Oxygen	
Develop management strategies with City of Stockton to maintain adequate oxygen levels in urban waterways	Development of effective stormwater program for City of Stockton that effectively eliminates most oxygen-depleting substances
Increase efforts to enforce waste discharge restrictions	No further potential enforcement actions in vicinity by Central Valley Regional Water Quality Control Board (CVRWQCB)
Assess current conditions for Stockton tributaries	Proper characterization of how Stockton tributaries affect DO in San Joaquin River

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Assist in new physical systems and operational strategies in Stockton Regional Wastewater Control Facility (RWCF) and Port of Stockton	No significant contributions from Port of Stockton or Stockton RWCF to low DO sags in San Joaquin River
Provide assistance and incentives to implement BMPs in San Joaquin River near Stockton	BMPs implemented in all applicable areas in Stockton vicinity
Continue lower permitted discharges of oxygen-depleting substances in San Joaquin River near Stockton	No allowance of effluent at higher concentrations of oxygen-depleting substances
Develop corrective strategies for potential sources (agriculture) in Stockton tributaries	Development of corrective measures that are feasible and cost effective
Manage lower Sacramento River stream bed enhancement program and develop river management plan	Improved inter-substrate permeability in river bed, which improves DO for salmon and steelhead
Develop and manage Merced, Tuolumne, and Stanislaus River management programs	Improved inter-substrate permeability in river bed, which improves DO for salmon and steelhead
Assess Suisun Marsh oxygen level and ecological importance	Proper characterization of Suisun Marsh inter-substrate DO concentrations
Develop BMPs to reduce oxygen-depleting substances in San Joaquin River near Stockton, based on research	Implementable BMPs to reduce or eliminate extent or duration of DO sags below 5 mg/l in San Joaquin River
Assess extent and severity of DO problem in east side tributaries and develop strategies for correction	Proper characterization of DO levels and causes of DO depletions, with corrective actions

Mercury

Tools for Correction	Indicators of Success
Mercury	
Map locations of mines and geological sources and potential for early remediation	Comprehensive listing of all mercury mines in western hills, complete with assessments of probable input and remediation potential
Develop remedial strategy for target watersheds and implement remedial activities as appropriate	Site remediation such that mercury leaving site does not cause exceedances of water quality targets
Monitor loads and forms of Hg in target watersheds	Complete database of historical loads and forms of mercury found to assist in remedial activities
Continue monitoring fish tissue for indicators of success	Mercury in fish tissue below levels considered a public health concern or that cause harm to fish species
Complete human health risk assessment	Updated human health risk assessment for mercury in Delta, Cache Creek, and Sacramento River

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Develop Geographic Information System (GIS) and public information system.	Detailed public information, complete with GIS, to assist others in research and remediation of watershed
Preliminary remediation to remove total mercury	Remediation that eliminates significant fractions of mercury inputs from more readily controllable mercury sources
Develop modeling strategy to include loading, bioavailability, and transformation	Reliable model that predicts impacts of upstream mercury input on Delta
Evaluate success of remediation	Site remediation such that mercury leaving site does not cause exceedances of water quality targets
Study mercury water and sediment levels to develop acceptable levels	Properly reviewed water quality targets for various types of mercury that will not cause public health advisories regarding fish tissue and will not adversely affect aquatic ecosystem
Fill data gaps regarding loads and forms of mercury	Properly characterized input data from mercury sources to Delta
Evaluate mercury loading on fish tissue levels	Established impacts of mercury loads in watershed on fish tissue in watershed and Delta
Determine demethylation processes and show where processes apply to conceptual model	Links of how demethylation of mercury affects mercury in ecosystem and fish tissue
Study relationship between bioavailability and transformation of forms of mercury	Established links between bioavailable forms of mercury and transformation of mercury
Study bioaccumulation mechanisms and determine indicator organisms	Selection of an organism that helps to predict whether actions have impacts on mercury levels in consumed fish tissue
Evaluate fish consumption patterns to better characterize public health hazard	Reliable demographic and consumption data to identify high-risk portions of population
Organochlorine Pesticides	
Organochlorine Pesticides and Agricultural Runoff	
Implement soil conservation efforts to retain organochlorine pesticides and soil on farms	Significant reductions in sedimentation and losses of soils on farms in western hills of San Joaquin Valley
Research into use of polyacrylamide (PAM) to retain soil and pesticides on agricultural lands	Evidence that use of PAM reduces erosion of fine sediments, as established by monitoring data
Research and incentives for whole farm approach to pest management and water use	Reductions in water and chemical use, while preserving soil and maintaining production

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Develop strategy to implement conservation measures and fund local conservation efforts	Long-term funding for local conservation efforts and implementation of conservation strategies; elimination of excessive sediment
Research irrigation conservation technology conservation	Reductions in water use and maintenance of production and soil
Reconstruct drainage channel	Reductions in erodible portions of channel following reconstruction
PCBs	
Monitor environmental and public health impacts, and strategize corrective actions if feasible	Evaluation of current PCB environmental threat and feasible solutions
Pesticides	
Pesticides	
Develop hazard assessment criteria, quantitative response limits, and water quality objectives	Development of water quality objectives (initially for diazinon and chlorpyrifos) that protect aquatic life and human health
Develop and implement BMPs for agriculture and residential use for diazinon and chlorpyrifos	Attainment of water quality targets in affected streams and channels
Evaluate effectiveness (adaptive management) and implement approach to solution for other toxic pesticides	Reductions in toxicity events attributed to pesticides of concern
Salinity	
Salinity	
Establish water quality objectives for salt in main stem San Joaquin River	Established water quality objective for salt in San Joaquin River that protects all beneficial uses
Investigation of reverse-osmosis membrane treatment systems for agricultural runoff (local actions)	Assessment of feasibility of using membrane technology to treat agricultural discharges
Investigate evaporation disposal of higher saline water (local actions)	Identification and use of a evaporation site for disposal of higher saline water
Integrated on-farm drainage management (local actions) to reduce salt concentrations in groundwater and surface water	Sustainable reductions in salt concentrations of perched water through crop selection and management
Improve supply water quality through physical and operational changes (basinwide)	Reductions in salt concentrations in supply water that make water quality objectives attainable in San Joaquin River following discharge

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Real-time manage saline discharges to San Joaquin River (basinwide)	Maximized assimilative capacity of San Joaquin River without exceeding water quality objectives
Recirculate DMC water to dispose of salts during high assimilative capacity periods (basinwide)	Increased assimilative capacity in San Joaquin River due to DMC recirculation
Dispose of salt through reclamation, to conveyance out of valley (basinwide)	Ultimate salt disposal out of basin to permanently reduce amount of salt in basin
Control sources of salt from agricultural lands through drainage reduction (local actions)	Reductions of salt in discharges by irrigation changes, while maintaining productivity
Reuse higher saline water on salt-tolerant crops (local actions)	Crop replacement that keeps land in continuous production but reduces salt discharges to San Joaquin River
Selenium	
Selenium	
Use alternative crude oil sources (refineries)	Reduced selenium loads from refineries
Reuse sour water and treat recycled sour water (refineries)	Reduced selenium loads through industrial water conservation and recycling
Retire land and permanently discontinue irrigation to eliminate contributions of selenium (agriculture)	Retirement of land to prevent contributions to selenium loads
Remove selenium in plant product by phytoremediation (agriculture)	Permanent removal of some fraction of selenium from valley soils in plant material
Manage selenium-laden stormwater flows from upper watershed (agriculture)	Reduction in overall selenium concentrations from upper watershed
Actively manage land through crop selection, irrigation, and operation (agriculture)	Reduction of selenium discharged through operational practices
Market selenium for forage supplements or nutritional supplements (agriculture)	Harvesting and removal of some fraction of selenium to market as fodder or nutritional supplement
Develop tradable loads to give dischargers flexibility in discharge concentrations and volumes (agriculture)	Operational procedures to allow dischargers to trade assimilative capacity and prevent exceedance of water quality objectives
Treat refinery discharge (refineries)	Reduction of selenium discharges from refineries
Trace Metals	
Copper	
Work with local agencies to develop stormwater pollution control facilities	Reduction of trace metals in stormwater to meet all water quality objectives for each metal

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Participate in Brake Pad Consortium, to reduce or eliminate copper from road runoff	Reduction or elimination of copper use in brake pads, thus removing it from stormwater
Copper, Cadmium, and Zinc	
Implement remedial activities at mines in upper watershed	Reduction or elimination of trace metal impacts from mines in upper watershed on biota in Bay-Delta
Trace Metals	
Study ecological impacts of trace metals and spatial and temporal extent of heavy metal pollution	Proper characterization of trace metal effects on biota in Bay-Delta
Turbidity and Sedimentation	
Sediment	
Perform quantitative ecological assessments of sediment loads in Merced and Stanislaus Rivers	Determine optimum range for sediment input to rivers
Evaluate use of a sedimentation pond at mouth of Gasburg Creek to prevent sediment in Tuolumne River	Reduced sediment from Gasburg Creek in Tuolumne River to a sustainable sediment budget level
Develop and implement BMPs along Tuolumne River tributaries	BMPs implemented to protect spawning beds in Tuolumne River and tributaries
Manage Tuolumne River floodplains to diminish negative impacts of fine sediment	Restored natural deposition of sediments in Tuolumne River floodplain
Determine Merced and Stanislaus River sediment loads	Established river sediment loads and budgeted as goals to reach in sediment input
Mechanically remove fine sediment from Tuolumne River banks	No effects on spawning beds in Tuolumne River from fine sediment in river bank
Evaluate use of flood control structure on Dominici Creek	Reduction or elimination of excessive erosion caused by Dominici Creek
Develop Technical Watershed Group for Merced and Stanislaus Rivers	Initiated stakeholder process to protect watersheds from sediment impacts
Implement sediment BMPs for construction and agriculture in Napa River watershed	No impairment of sediment on spawning beds in Napa River
Unknown Toxicity	
Aquatic Toxicity	
Monitor toxicity	Expanded aquatic toxicity testing to all parts of Bay-Delta

Potential Tools and Indicators of Success (Continued)

Tools for Correction	Indicators of Success
Implement toxicity identification evaluation (TIE) for toxic samples	TIEs performed on all samples resulting in toxic effects; identification of toxicants
Investigate cause of toxicity	Identification of sources of toxicants from TIEs
Identify cause and refer to appropriate portion of program	Prioritization of control of toxicant identified in TIE

APPENDIX D

WATER QUALITY TARGETS FOR PARAMETERS OF CONCERN

Water Quality Targets for Parameters of Concern

Parameter	Sacramento River	San Joaquin River	Delta
Boron		Water Mouth of Merced to Vernalis 2.0 mg/L (15 Mar - 15 Sept) 0.8 mg/L (monthly mean, 15 Mar - 15 Sept) 1.0 mg/L (monthly mean, 16 Sept - 14 Mar) 1.3 mg/L (monthly mean, critical year)	Water Agricultural intakes < 0.7 mg/L
Cadmium	Water River and tributaries from above State Route (SR) 32 bridge at Hamilton City 0.22 µg/L Below Hamilton City 2.2 µg/L (4-day average) 4.3 µg/L (1-hour average) Sediment 5.0 ppm (dry weight)	Water 2.2 µg/L (4-day average) 4.3 µg/L (1-hour average) Sediment 5.0 ppm (dry weight)	Water East of Antioch Bridge 2.2 µg/L (4-day average) 4.3 mg/L (1-hour average) West of Antioch Bridge 1.1 µg/L (4-day average) 3.9 µg/L (1-hour average) Sediment 1.2 ppm (dry weight)
Copper	Water River and tributaries from above SR 32 bridge at Hamilton City 5.6 µg/L Below Hamilton City 10 µg/L (no hardness connection) Sediment 70.0 ppm (dry weight)	Water 9.0 µg/L (4-day average) 13 µg/L (1-hour average) Sediment 70.0 ppm (dry weight)	Water East of Antioch Bridge 10 µg/L (no hardness connection) West of Antioch Bridge 6.5 µg/L (4-day average) 9.2 µg/L (1-hour average) Sediment 34.0 ppm (dry weight)
Mercury (inorganic)	Water 0.012 µg/L (4-day average) 2.1 µg/L (1-hour maximum) Sediment 0.15 ppm (dry weight) Tissue 0.5 µg/gm (whole fish, wet weight) These tissue targets are related to human health and do not necessarily ensure no adverse effects on fish	Water 0.012 µg/L (4-day average) 2.1 µg/L (1-hour maximum) Sediment 0.15 ppm (dry weight) Tissue 0.5 µg/gm (whole fish, wet weight) These tissue targets are related to human health and do not necessarily ensure no adverse effects on fish	Water East of Antioch Bridge 0.012 µg/L (4-day average) 2.1 µg/L (1-hour maximum) West of Antioch Bridge 0.025 µg/L (4-day average) 2.4 µg/L (1-hour average) Sediment 0.15 ppm (dry weight) Tissue 0.5 µg/gm (whole fish, wet weight) These tissue targets are related to human health and do not necessarily ensure no adverse effects on fish

Water Quality Targets for Parameters of Concern (Continued)

Parameter	Sacramento River	San Joaquin River	Delta
Selenium	Water 20 µg/L (1-hour maximum) 5.0 µg/L (4-day average)	Water South of Merced River 20 µg/L (1-hour maximum) 5.0 µg/L (4-day average) North of Merced River 12 µg/L (maximum) 5.0 µg/L (4-day average)	Water East of Antioch Bridge 20 µg/L (1-hour maximum) 5.0 µg/L (4-day average) West of Antioch Bridge 20 µg/L (1-hour average) 5.0 µg/L (4-day average)
	Tissue <4 ppm (fish, whole body, dry weight) <3 ppm (fish food items, food chain, dry weight)	Tissue <4 ppm (fish, whole body, dry weight) <3 ppm (fish food items, food chain, dry weight)	Tissue <4 ppm (fish, whole body, dry weight) <3 ppm (fish food items, food chain, dry weight)
Zinc	Water River and tributaries from above SR 32 bridge at Hamilton City 16 µg/L Below Hamilton City 100 µg/L (no hardness correction)	Water 120 µg/L (4-day average) 120 µg/L (1-hour average)	Water East of Antioch Bridge 100 µg/L (no hardness correction) West of Antioch Bridge 106 µg/L (4-day average) 117 µg/L (1-hour average)
	Sediment 120.0 ppm (dry weight)	Sediment 120.0 ppm (dry weight)	Sediment 150.0 ppm (dry weight)
Carbofuran	Water 0.4 µg/L (daily maximum and total pesticides)	Water 0.4 µg/L (daily maximum and total pesticides)	Water 0.4 µg/L (daily maximum and total pesticides)
Chlordane	Water 2.4 µg/L (instantaneous maximum) 0.0043 µg/L (4-day average, total pesticides)	Water 2.4 µg/L (instantaneous maximum) 0.0043 µg/L (4-day average, total pesticides)	Water 2.4 µg/L (instantaneous maximum) 0.0043 µg/L (4-day average, total pesticides)
	Sediment 7.1 ppm (dry weight)	Sediment 7.1 ppm (dry weight)	Sediment 7.1 ppm (dry weight)
Chlorpyrifos	Water 0.02 µg/L (4-day average, total pesticides)	Water 0.02 µg/L (4-day average, total pesticides)	Water 0.02 µg/L (4-day average, total pesticides)
Diazinon	Water 0.08 µg/L (1-hour average, total pesticides) 0.04 µg/L (4-day average, total pesticides)	Water 0.08 µg/L (1-hour average, total pesticides) 0.04 µg/L (4-day average, total pesticides)	Water 0.08 µg/L (1-hour average, total pesticides) 0.04 µg/L (4-day average, total pesticides)

Water Quality Targets for Parameters of Concern (Continued)

Parameter	Sacramento River	San Joaquin River	Delta
DDT	Water 1.1 µg/L (instantaneous maximum, total pesticide) 0.001 µg/L (4-day average, total pesticide)	Water 1.1 µg/L (instantaneous maximum, total pesticide) 0.001 µg/L (4-day average, total pesticide)	Water East of Antioch Bridge 1.1 µg/L (instantaneous maximum, total pesticide) 0.001 µg/L (4-day average, total pesticide) West of Antioch Bridge 1.1 µg/L (instantaneous maximum) 0.001 µg/L (24-hour average)
	Tissue 1 µg/L (whole fish, wet weight)	Tissue 1 µg/L (whole fish, wet weight)	Tissue 1 µg/L (whole fish, wet weight)
PCBs	Water 0.014 µg/L (4-day average) (each of seven congeners)	Water 0.014 µg/L (4-day average) (each of seven congeners)	Water East of Antioch Bridge 0.014 µg/L (4-day average) (each of seven congeners) West of Antioch Bridge 0.014 µg/L (24-hour average)
	Sediment 50 ppm (dry weight, total)	Sediment 50 ppm (dry weight, total)	Sediment 50 ppm (dry weight, total)
	Tissue 0.5 µg/L (whole fish, wet weight, total)	Tissue 0.5 µg/L (whole fish, wet weight, total)	Tissue 0.5 µg/L (whole fish, wet weight, total)
Toxaphene	Water 0.73 µg/L (1-hour average) 0.0002 µg/L (4-day average)	Water 0.73 µg/L (1-hour average) 0.0002 µg/L (4-day average)	Water East of Antioch Bridge 0.73 µg/L (1-hour average) 0.0002 µg/L (4-day average) West of Antioch Bridge 0.0002 µg/L (4-day average)
	Tissue 0.1 µg/L (whole fish, wet weight) (sum of nine organochlorine insecticides)	Tissue 0.1 µg/L (whole fish, wet weight) (sum of nine organochlorine insecticides)	Tissue 0.1 µg/L (whole fish, wet weight) (sum of nine organochlorine insecticides)
pH	Water $\geq 6.5 \leq 8.5$	Water $\geq 6.5 \leq 8.5$	Water $\geq 6.5 \leq 8.5$ Agricultural intakes < 1.5 mg/L
Ammonia	Water 0.08 - 2.5 µg/L (4-day average) 0.58 – 35 µg/L (1-hour average)	Water 0.08 - 2.5 µg/L (4-day average) 0.58 - 35 µg/L (1-hour average)	Water 0.08 - 2.5 µg/L (4-day average) 0.58 - 35 µg/L (1-hour average)

Water Quality Targets for Parameters of Concern (Continued)

Parameter	Sacramento River	San Joaquin River	Delta
Bromide*			Water Drinking water intakes < 50 µg/L
Total organic carbon (TOC)*			Water Drinking water intakes < 3 mg/L
Chloride			Water Agricultural intakes For surface irrigation SAR < 3 For sprinkler irrigation < 3 mg/L Drinking water intakes 250 mg/L, 150 mg/L
Nutrients (nitrate)			Drinking water intakes 10 mg/L (no increase in nitrate levels)
Salinity (EC_w)		Agricultural intakes < 0.7 dS/m	Agricultural intakes < 0.7 dS/m or µmhos/cm
Salinity (EC)	Water Knights Landing above Colusa Drain ≥ 230 µmho/cm (50 percentile) or ≥ 235 µmho/cm (90 percentile) I Street Bridge ≥ 240 µmho/cm (50 percentile) or ≥ 340 µmho/cm (90 percentile)	Water Stuart Dutra to Grayson Ford ≥ 150 µmho/cm (90 percentile)	
SAR (EC_w relationship)*			Water Agricultural intakes SAR — EC_w 0 - 3 — > 0.7 3 - 6 — > 1.2 6 - 12 — > 1.9 12 - 20 — > 2.9 20 - 40 — > 5.0
Total dissolved solids (TDS)			Agricultural intakes < 450 mg/L Drinking water intakes < 220 mg/L (10-yr avg), < 440 mg/L (monthly avg)

Water Quality Targets for Parameters of Concern (Continued)

Parameter	Sacramento River	San Joaquin River	Delta
Dissolved oxygen	Water Keswick Dam to Hamilton City (June 1 to August 31) **9.0 mg/L**[a,1] Below I Street Bridge **7.0 mg/L**[1]	Water Between Turner Cut and Stockton (September 1 through November 30) **6.0 mg/L**[1]	Water[1] All Delta waters west of Antioch Bridge **7,000 µg/L (minimum)**[a,1] All Delta waters **5.0 mg/L**[a,1]
Pathogens			Water Drinking water intakes **no MCL standard**[b]; <1 oocyst/100L for *Giardia* and *Cryptosporidium*[b]
Temperature	Water Keswick Dam to Hamilton City **< 56°F**[a,1] Hamilton City to I Street Bridge **< 68°F**[a,1] I Street Bridge to Freeport **< 68°F**[a,1] I Street Bridge to Freeport (January 1 through March 31) **< 66°F**[a,1]	Water At Vernalis **< 68°F**[a,1]	Water West of Antioch Bridge < 5°C increase above for receiving water designated as cold or warm fresh-water habitat[1] Alteration of temperature shall not adversely affect beneficial uses[1]
Turbidity			Drinking water intakes **0.5 or 1.0 NTU**[b]**, 50 NTU**[b]
Toxicity of unknown origin[1]			Water The RWQCBs have toxicity criteria specific to waters within their regions. CALFED will be working to eliminate toxicity within the Delta as it is defined by the CVRWQCB and the SFBRWQCB.

NOTES:

Water quality targets have no regulatory meaning within the context of the CALFED Bay-Delta Program (CALFED).

The California Toxics Rule (CTR) (40 CFR, Part 131) was adopted on May 18, 2000. The CTR established numeric criteria for priority toxic pollutants for the State of California. The water quality targets and associated references have not been updated pursuant to this rule; therefore, differences may exist.

- On December 5, 1997, a meeting was held between the drinking water industry, U.S. Environmental Protection Agency (EPA), and CALFED, to identify source water quality targets for bromide and TOC. As a result of the discussion, urban water agencies are going to further analyze different levels of treatment for different levels of a constituent and report their findings to CALFED.

Water Quality Targets for Parameters of Concern (Continued)

NOTES (continued):

- Dissolved form
- Total recoverable form
- The effects of these concentrations were measured by exposing test organisms to dissolved aqueous solutions of 40 mg/L hardness that had been filtered through a 0.45-micron membrane filter. Where deviations from 40 mg/L of water hardness occur, the objectives shall be determined in mg/L using the following formulas:
  - $Cu = e^{[illegible]} \times 10^{-3}$
  - $Zn = e^{[illegible]} \times 10^{-3}$
  - $Cd = e^{[illegible]} \times 10^{-3}$
- Central Valley Regional Water Quality Control Board (CVRWQCB) Water Quality Control Plan
- General EPA Section 304(a) guideline
- Within the year, the State Water Resources Control Board (SWRCB) or EPA will promulgate/adopt objectives that depend on hardness. The adoption language likely will contain a clause stating that the most stringent objective applies. Sometimes the 10 µg/L objective will be more stringent, at other times, the new rule will be more stringent.
- Similar to the objectives for copper, we expect the SWRCB or EPA to promulgate new objectives within the year that will be more stringent than current objectives.
- The CVRWQCB expects to adopt an objective for carbofuran within the year. The objective probably will be very similar to the performance goal.
- Water quality-limited segments for mercury in fish tissue occur in the Sacramento River and Delta.
- Water quality-limited segments for selenium in the water column occur from Salt Slough to Vernalis on the San Joaquin River.
- The lower Sacramento River is a water quality-limited segment for carbofuran.
- California Department of Fish and Game (DFG) acute (1-hour) and chronic (4-day) hazard assessment criteria.
- The Sacramento River, San Joaquin River, and Delta are water quality-limited segments for chlorpyrifos.
- The Sacramento River, San Joaquin River, and Delta are water quality-limited segments for diazinon.
- The San Joaquin River is a water quality-limited segment for DDT in tissue.
- Values are a function of pH, temperature, and designation of water body as cold- or warm-water fish beneficial use.
- When natural conditions lower dissolved oxygen (DO) below this level, the concentrations shall be maintained at or above 95% of saturation.
- Except those water bodies that are constructed for special purposes and from which fish have been excluded or where the fishery is not important and a beneficial use.
- The south Delta around Stockton is a water quality-limited segment for DO.
- Bioassay results or other special studies demonstrate toxicity. The Sacramento River, San Joaquin River, and Delta are water quality-limited segments for toxicity of unknown origin.
- The temperature shall not be elevated above 56°F in the reach from Keswick Dam to Hamilton City nor above 68°F in the reach from Hamilton City to the I Street Bridge when temperature increases will be detrimental to the fishery.
- The daily average water temperature shall not be elevated by controllable factors above 68°F from the I Street Bridge to Freeport on the Sacramento River, and at Vernalis on the San Joaquin River between April 1 through June 30 and between September 1 through November 30 in all water year types.
- The daily average water temperature shall not be elevated by controllable factors above 60°F from the I Street Bridge to Freeport on the Sacramento River between January 1 through March 31.
- San Francisco Bay Regional Water Quality Control Board objectives at 100 mg/L hardness. Formulas for calculating objectives for varying hardness levels are as follows:
  - $Cd = e^{[illegible]}$ (4-day average)
  - $\quad = e^{[illegible]}$ (1-hour average)
  - $Cu = e^{[illegible]}$ (4-day average)
  - $\quad = e^{[illegible]}$ (1-hour average)
  - $Zn = e^{[illegible]}$ (4-day average)
  - $\quad = e^{[illegible]}$ (1-hour average)
- National Academy of Sciences - National Academy of Engineers [illegible]
- Effects range-low (ERL) concentrations
- San Luis Drain Reuse Technical Advisory Committee selenium ecological risk guidelines
- For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salt tolerance in Ayers and Westcot as equivalent.
- SAR means sodium adsorption ratio. SAR sometimes is reported by the symbol RNa.

Water Quality Targets for Parameters of Concern (Continued)

For overhead sprinkler irrigation and low humidity (< 30%), sodium and chloride greater than 70 or 100 mg/L, respectively, have resulted in excessive leaf absorption and crop damage to sensitive crops; see Ayers and Westcot.

EC_w means electrical conductivity of irrigation water, reported in mmhos/cm or dS/m.

At a given SAR, the infiltration rate increases as salinity (EC_w) increases. To evaluate a potential permeability problem, examine SAR and EC_w together.

The objective is to provide source water meeting the target so that will provide an equivalent level of public health protection in treated drinking water.

Bromide value is predicated on the assumption that the maximum contaminant level (MCL) for bromate will be 5 µg/L in treated water.

EPA secondary MCL for treated water, 1995.

EPA current MCL for treated water, 1995.

EPA requires removal of 99.9% of *Giardia* and 99.99% of viruses during water treatment. Higher levels of removal are required for poor water quality source waters.

Target level based on the California Urban Water Agencies' (CUWA's) Expert Panel report recommendations (Bay-Delta Water Quality Criteria, December 1996). The Expert Panel assumed a future drinking water regulatory scenario for disinfection by-product (DBP) control and inactivation of *Giardia* and *Cryptosporidium*, based on the proposed Stage 2 D/DBP Rule and Proposed Enhanced Surface Water Treatment Rule (ESWTR). The bromide target level is constrained by the formation of bromate when using ozone to inactivate *Cryptosporidium*.

Nutrients are a critical reservoir management issue. Nutrient levels are a determining factor governing the growth of taste- and odor-producing algae in water storage reservoirs. State Water Project (SWP) supplies are nitrogen limited; however, phosphorous is present in great excess. This is a problem with respect to the growth of blue-green algae, which can fix their own nitrogen. Water quality impacts of nutrients are driven by reservoir management issues as opposed to human health effects; as a result, use of the MCL for nitrate (as N) of 10 mg/L is not appropriate.

Desirable target levels are based on likely future regulatory scenarios under the ESWTR that will base required levels of pathogen removal/inactivation treatment on pathogen density in source water. Future regulations may require removal requirements for *Cryptosporidium*. Increasing treatment for removal of pathogens makes it more difficult to control the formation of DBPs. To balance disinfection requirements for controlling pathogens with the production of DBPs, selection of a Bay-Delta alternative should not result in degraded water quality that necessitates increased removal requirements for pathogens.

Target levels for total dissolved solids (TDS) would allow compliance with the TDS objective established in Article 19 of the SWP Water Service Contract. The average TDS levels in SWP supplies over the last 10 years consistently have exceeded the 220-mg/L (10-year average) SWP objective. The 10-year averaging period for the 220-mg/L objective is too long to be sufficiently protective of source water quality. The Metropolitan Water District of Southern California (MWD) staff currently are exploring the development of appropriate alternative TDS objectives for shorter time frames (e.g., 1-year and 6-month averages) and will forward that information to CALFED when available. The SWP TDS objective of 440 mg/L (monthly average) is a problem for water resource management programs, especially in April and September, and there is a real need to reduce peaks in TDS in SWP supplies. Consistently low TDS levels are needed to minimize the following salinity-related impacts: (1) increased demand for Delta water supplies when such water is used for blending with other higher salinity water sources, and (2) adverse impacts on water recycling and groundwater replenishment programs, which depend on Delta water supplies to meet local resource program salinity objectives. Failure to develop local resource programs may result in increased demand on Delta exports and economic impacts on industrial, residential, and agricultural water users.

Target level based on the CUWA Expert Panel report recommendations (Bay-Delta Drinking Water Quality Criteria, December 1996). The Expert Panel assumed future drinking water regulatory scenario for DBP control and inactivation of *Giardia* and *Cryptosporidium* based on the proposed Stage 2 D/DBP Rule and proposed ESWTR. The proposed D/DBP Rule requires increased levels of TOC removal as TOC concentrations in source waters increase. The recommended TOC target level is constrained by the formation of total trihalomethanes when using enhanced coagulation for TOC removal and free chlorine to inactivate *Giardia*.

Reduced variability in turbidity is needed to improve treatment plant performance. When source water turbidity increases, water is more difficult and costly to treat. Also, increased turbidity reduces protection from pathogens because turbidity interferes with disinfection.

Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. May 1995. 95-1WR. SWRCB and Cal-EPA. According to the Water Quality Control Plan, this value applies from October to September during all water-year types for the Contra Costa Canal at Pumping Plant No. 1, West Canal at the mouth of Clifton Court Forebay, the Delta-Mendota Canal at the Tracy Pumping Plant, Barker Slough at the North Bay Aqueduct intake, and Cache Slough at the City of Vallejo intake.

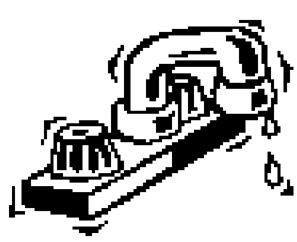
Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. May 1995. 95-1WR. SWRCB and Cal-EPA. According to the Water Quality Control Plan, this value applies to a certain number of days per year, depending on water-year type, to the Contra Costa Canal at Pumping Plant No. 1 and the San Joaquin River at Antioch Water Works intake.

Water Quality Targets for Parameters of Concern (Continued)

- * Recommendation of September 30, 1997, from Karen Schwinn, Water Division, EPA
- ** Recommendation of July 24, 1997, from Bruce Macler, Water Division, EPA
- ^ Changes in normal ambient pH levels shall not exceed 0.5 in fresh water with designated cold or warm water beneficial uses
- ^^ Alkalinity as $CaCO_3$
- ^ At 25 °C, CVRWQCB Water Quality Control Plan
- ^^ Based on the previous 10 years of record, CVRWQCB Water Quality Control Plan
- \# A Compilation of Water Quality Goals, March 1995 edition, plus December 1998 update, CVRWQCB
- \#\# From Water Quality for Agriculture, R. S. Ayers and D. W. Westcot, 1985, Food and Agriculture Organization of the United Nations, Rome

APPENDIX E

BAY-DELTA DRINKING WATER QUALITY: BROMIDE ION (Br^-) AND FORMATION OF BROMINATED DISINFECTION BY-PRODUCTS



Bay-Delta Drinking Water Quality: Bromide Ion (Br^-)

and Formation of Brominated Disinfection By-Products (DBPs)

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A Report Prepared for:

CALFED Bay-Delta Program

November, 1998

Summary

This report is an outgrowth of a meeting involving an expert panel on bromide ion (Br^-), convened by the CALFED Bay-Delta Program in Sacramento, California on September 8 – 9, 1998. Experts (the authors of this report) on water chemistry, drinking water treatment, health effects, drinking water regulations, and source assessment and management held a public meeting to exchange information with utility, government, and environmental representatives in the presence of CALFED staff. Panel members were provided background reports and unpublished data both before and after the meeting. The purpose of this report is to provide CALFED with input on controlling concentrations of bromide ion (Br^-) within regions of the Sacramento River Delta-San Francisco Bay (i.e., the *Bay-Delta*) used as a source for drinking water supply.

The Bay-Delta region is a complex, multi-use system comprised of two major freshwater inflows (the Sacramento and San Joaquin Rivers), San Francisco Bay, and transitional estuarine and Delta areas. The primary export facility for drinking water is the State Water Project (SWP), which originates in the southern reaches of the Delta; other export points include the North Bay Aqueduct (NBA), the South Bay Aqueduct (SBA), and the Contra Costa Canal (CCC). CALFED has proposed three alternatives for managing the flow of Sacramento River water through the Delta to points of drinking water export, each of these alternatives, embodying channel modifications, storage, and possibly a new conveyance channel, will have varying effects on Br^- levels in exported water.

It is well known that disinfection by-products (DBPs) are formed during water treatment disinfection/oxidation. The impetus for this report is that, in the presence of Br^- and natural organic matter (NOM, measured as total organic carbon (TOC)), various brominated DBPs are formed including: brominated trihalomethanes (THMs) and haloacetic acids (HAAs), formed upon chlorination; and bromate ion (BrO_3^-), formed upon ozonation.

The major source of Br^- within the Delta is seawater derived through tidal exchange with San Francisco Bay. The major incremental source of TOC (beyond that associated with inflows) are agricultural drains situated throughout the Delta.

There are major concerns about the public health (e.g., carcinogenic, mutagenic, or reproductive) effects of DBPs in drinking water. Brominated DBPs such as

bromodichloromethane (a THM species) and BrO_3^- may be of particular concern. The U.S. EPA intends to promulgate more stringent drinking water regulations in November of 1998, limiting the maximum contaminant levels of THMs (sum of four species), HAAs (sum of five species), and BrO_3^-. EPA is also considering further DBP regulation and more stringent disinfection regulations (e.g., *Cryptosporidium* inactivation) which could further influence changes in disinfection practice and create a potential conflict between minimizing chemical (DBPs) and microbial risk.

There are very limited treatment options (i.e., membranes) for removing Br^-. Conversely, there are both conventional (coagulation, sedimentation, filtration) and advanced (granular activated carbon, membranes) processes for effective removal of TOC; however, these processes increase the ratio of Br^-/TOC and may not proportionally reduce chemical risk to public health. Options exist for minimizing bromate formation during ozonation (e.g., low-pH ozonation), or for removing BrO_3^- after its formation (e.g., chemical reduction with ferrous salts); however, there are water quality and technology-development constraints to their implementation (e.g., low pH ozonation for high-alkalinity source waters, substitution of ferrous salts for traditional coagulants). Management of Br^- may be best realized through a combination of treatment and source control, with the three CALFED alternatives reflecting different options for managing the intermixing of seawater with freshwater as it is conveyed through the Delta. Given the synergistic behavior of Br^- and TOC in forming DBPs, the co-occurrence within the Delta and the fate through treatment of both Br^- and TOC are of importance. Similarly, the co-occurrence of fecal contamination with these parameters can exacerbate the control options for DBPs because of potentially higher disinfection levels needed to control pathogens.

There must be both a short-term (before implementation of an alternative) and a long-term (after alternative implementation) strategy for drinking water utilities using Delta water. In the short-term, more emphasis should be placed on treatment with some possibilities for source control (e.g., treatment or rerouting of agricultural drainage or storage (external to Delta) for dampening variations in Br^-, possibly also lowering TOC, and limiting fecal contamination); in the long-term, more substantial source management options are possible with implementation of an alternative for conveying water through the Delta.

1.0 Introduction and Background

1.1 Significance of Bromide (Br^-) in Drinking Water Sources

Bromide ion (Br^-) occurs ubiquitously in natural waters, ranging from < 5 ug/L in some freshwaters to 65 mg/L (65,000 ug/L) in seawater. While it is considered a trace contaminant in drinking water supplies (i.e., usually < 1 mg/L or < 1,000 ug/L), Br^- can have a significant impact on drinking water quality. Bromide itself is harmless; however, it reacts with water-treatment chemical disinfectants and oxidants (e.g., chlorine and ozone) to form potentially harmful disinfection by-products (DBPs). Chemical disinfection reduces microbial risk from pathogenic microorganisms (e.g., *Giardia* and *Cryptosporidium*); however, the formation of DBPs (e.g., bromodichloromethane and bromate) poses a chemical risk to public health. While Br^- serves as the inorganic DBP precursor, it interacts with natural organic matter (NOM), measured as total organic carbon (TOC), playing the role of the organic DBP precursor, which contributes to the formation of organic DBPs.

1.2 General Sources and National Occurrence of Br^- and TOC

Both natural sources of bromide in water (e.g., geochemical weathering, connate seawater, seawater intrusion) and anthropogenic sources (e.g., industrial and oil field brine discharges) exist. A nation-wide survey (Amy, et al., 1994) reported that the average drinking water source in the U.S. contains 62 ug/L of bromide, with a range from 5 to 430 ug/L observed for 88 randomly-sampled sources; the 90-percentile concentration was estimated to be about 300 ug/L. The average Br^- concentration in 17 targeted (known high Br^- levels) sources was 210 ug/L. (Bay-Delta water exported through the State Water Project (SWP) was included in this grouping).

Amy et al. (1994) reported a nation-wide average TOC concentration in 100 drinking water sources to be 2.7 mg/L, a finding consistent with other studies; the range of TOC concentrations was <0.2 to 21 mg/L. The co-occurrence of TOC with Br^- can be represented by a Br^-/TOC ratio; the average ratio reported by Amy et al. (1994) was 28 ug Br^-/mg TOC; no significant correlation was observed between Br^- and TOC occurrence.

1.3 Formation and Chemistry of Brominated Disinfection By-Products (DBPs)

The traditional chemical disinfectant, chlorine (Cl_2), as well as alternative disinfectants, ozone (O_3), chlorine dioxide (ClO_2), and chloramines (NH_2Cl, monochloramine), all form their own suite of DBPs. The following discussion will emphasize chlorination and ozonation DBPs because of the importance of Br^- in their formation. In contrast, the major chlorine-dioxide DBP is chlorite ion (ClO_2^-), a non-brominated DBP. When chloramine practice involves free chlorine followed by ammonia addition, lesser amounts of chlorination DBPs are formed; however, observations of enhanced formation of cyanogen chloride have raised concerns about a possible bromine analog, cyanogen bromide.

1.3.1 Trihalomethanes (THMs) and Haloacetic Acids (HAAs)

Bromide (Br^-) ion is itself harmless; however, through interaction with chemical disinfectants and oxidants, it can become incorporated into disinfection by-products (DBP). Br^- is oxidized by chlorine (Cl_2) to bromine (Br_2), more specifically hypobromous acid in equilibrium with hypobromite ($HOBr \leftrightarrow H^+ + OBr^-$). Cl_2 and Br_2 collectively react with natural organic matter (NOM), measured as total organic carbon (TOC), to form halogenated (chlorinated and/or brominated) organic DBPs that can be represented by organic-halogen (TOX) including organic-chlorine (TOCl) and organic-bromine (TOBr) components. Less than 50 % of the TOX pool has been identified as specific compounds/compound classes such as trihalomethanes (THMs) and haloacetic acids (HAAs). Of the four THM species, one is fully chlorinated (chloroform, $CHCl_3$), one is fully brominated (bromoform, $CHBr_3$), and two are mixed species (bromodichloromethane and dibromochloromethane). Of the nine HAA species, three are fully chlorinated (tri-, di-, and mono-chloroacetic acid), three are fully brominated (tri-, di-, and mono-bromoacetic acid), and three are mixed species (bromodichloro-, dibromochloro-, and bromochloro- acetic acid). The relevant chemistry is summarized below.

$$2\,Br^- + Cl_2 \rightarrow Br_2 + 2\,Cl^-$$

$$NOM + Cl_2 \rightarrow TOCl \qquad \text{(e.g., } CHCl_3\text{)}$$

$$NOM + Br_2 \rightarrow TOBr \qquad \text{(e.g., } CHBr_3\text{)}$$

$$NOM + Cl_2 + Br_2 \rightarrow TOCl + TOBr$$

The formation of total THMs (TTHM) is positively (+) influenced by temperature, pH, Cl_2 dose, Br^- concentration, TOC, and reaction time. The formation of total HAAs (THAA) is similarly influenced by the same parameters except for pH; pH has a significant inverse (-) effect on certain HAA species (e.g., trichloroacetic acid). The relative amounts of Br^- and TOC affect the species distribution of both TTHM and THAA, with a higher Br^-/TOC ratio driving the mixture toward greater bromination. NOM properties, as indicated by measurements of UV absorbance at 254 nm (UVA_{254}) and specific UV absorbance (SUVA = UVA_{254}/TOC), also affect TTHM and THAA formation. UVA_{254} and SUVA are indicative of the aromatic (non-polar) character of NOM. A positive correlation have been observed between TTHM and SUVA. Polar NOM has been shown to be more influential in THAA than TTHM formation. Higher bromination (THM-Br and HAA-Br) has been observed for polar NOM. It is important to note that Br has a molecular weight of 80 versus 35.5 for Cl; thus, because of weight-based (ug/L) standards, Br^- exacerbates TTHM and THAA formation. Another important observation is that brominated DBPs form more rapidly that chlorinated DBPs, a factor that may affect control strategies such as chloramination involving free-chlorine contact subsequently followed by ammonia addition.

1.3.2 Bromate (BrO_3^-) and Organic-Bromine (TOBr)

Br^- is also oxidized by ozone (O_3) to HOBr/OBr^- (Br_2); OBr^- serves as an important reaction intermediate to formation of bromate (BrO_3^-), an inorganic DBP. BrO_3^- can form through two potential pathways, a molecular ozone (O_3) and a hydroxyl radical ($OH^{\bullet}$) pathway. The molecular ozone pathway is summarized below:

$$Br^- + O_3 \rightarrow OBr^- + O_2$$

$$OBr^- + 2\ O_3 \rightarrow BrO_3^- + 2\ O_2$$

The $OH^{\bullet}$ pathway is represented below, in a simplified (unbalanced) format:

$$Br^- + OH^{\bullet} \rightarrow BrO_3^-$$

Bromate is positively (+) affected by temperature, pH, O_3 dose, and Br^- concentration. The radical pathway is more dominant under higher pH conditions and in the presence of NOM.

TOBr may also form during ozonation in the presence of Br^-, with an inverse (-) pH effect, through the reaction of NOM with the HOBr intermediate:

$$NOM + HOBr \rightarrow TOBr$$

1.3.3 Co-Occurrence of Br- and TOC, DBP Mixtures, and Balancing Risk

The above discussion shows the linkage between Br^-, the inorganic DBP precursor, and NOM (TOC), the organic precursor. Thus, their co-occurrence in Delta water and their relative removals during water treatment are of concern. As regulations drive practice toward use of multiple disinfectants/oxidants, a DBP mixture will result. From a risk perspective, there is a need to balance chemical risk to public health, associated with the resultant DBP mixture created by a disinfectant/oxidant or combinations thereof, with microbial risk posed by pathogenic microorganisms.

Another important consideration is the co-occurrence of Br^- and TOC with microbes (e.g., fecal coliforms); the co-occurrence of Br^- and *Cryptosporidium* creates a dilemma between effective inactivation by ozone versus bromate formation.

1.4 National Occurrence of Brominated DBPs

Krasner et al. (1989) reported the results of a 35-utility DBP survey. All four THM species and five HAA species (HAA_5) were measured prior to point of entry into the distribution system. Median values for chloroform, bromodichloromethane, dibromochloromethane, and bromoform were reported to be 15, 6.6, 3.4, and 0.6 ug/L, respectively; median values for trichloracetic acid, dichloroacetic acid, monochloroacetic acid, dibromoacetic acid, and monobromoacetic acid were reported to be 5.4, 6.4, 1.1, 1.2, and <0.5 ug/L, respectively. Recent work by Zhu (1994) has shown that, because of the concentration of bromochloroacetic acid (a sixth species), HAA_6 on average is about 10 % greater than HAA_5. Little is known about the occurrence of the remaining three HAA species. Krasner et al. (1993) found bromate levels ranging from < 5 ug/L to 60 ug/L in pilot studies and at operating ozonation facilities.

1.5 The Bay-Delta System as a Drinking Water Source

The Bay-Delta system is a region encompassing the confluence of the Sacramento and San Joaquin Rivers, San Francisco Bay, and the transitional estuarine and Delta areas (Figures 1 and 2). CALFED is charged with developing a consensus on potentially conflicting beneficial uses of the Bay-Delta, with drinking water supply identified as one important beneficial use. CALFED has articulated three alternatives to reconcile Bay-Delta issues. These three alternatives, summarized below, would have varying impacts on drinking water quality in general, and levels of bromide ion (Br^-) in particular:

- Alternative 1 (Figure 3) "proposes existing Delta channels, with some modifications for water conveyance and various storage options";
- Alternative 2 (Figure 4) "proposes significant modifications of Delta channels to increase water conveyance across the Delta combined with various storage options"; and
- Alternative 3 (Figure 5) "includes Delta channel modifications coupled with a conveyance channel that takes water around the Delta with various storage options". (This alternative will include an isolated conveyance facility with a capacity of 8,000 to 12,000 cfs, connecting the Sacramento River to drinking water export facilities).

The average annual freshwater inflow into the Delta is about 27 MAF/yr (million acre-feet/year), 62 % derived from the Sacramento River. This inflow, however, is volumetrically small in comparison to tidal exchange with San Francisco Bay. On average, about 5.9 MAF/yr are exported via the major drinking water aqueduct, the State Water Project (SWP, 3.6 MAF/yr); and the major agricultural water aqueduct, the Central Valley Project (CVP, 2.3 MAF/yr). On a much smaller scale, drinking water is exported via the North Bay Aqueduct (NBA, 35,000 acre-feet/year), the South Bay Aqueduct (SBA, 160,000 acre-feet/year), and the Contra Costa Canal (CCC, 100,000 acre-feet/year). Flow patterns throughout the Delta are influenced by tidal actions and export operations. There is a clear seasonality to inflow, lowest in the summer and highest in the winter; this is in contrast to variations in water demand which are highest in summer. Variations in inflow versus demand can be dampened by storage in the form of surface reservoirs or groundwater basins; presently, there are 30 reservoirs with a combined capacity of 25 MAF.

FIGURE 1

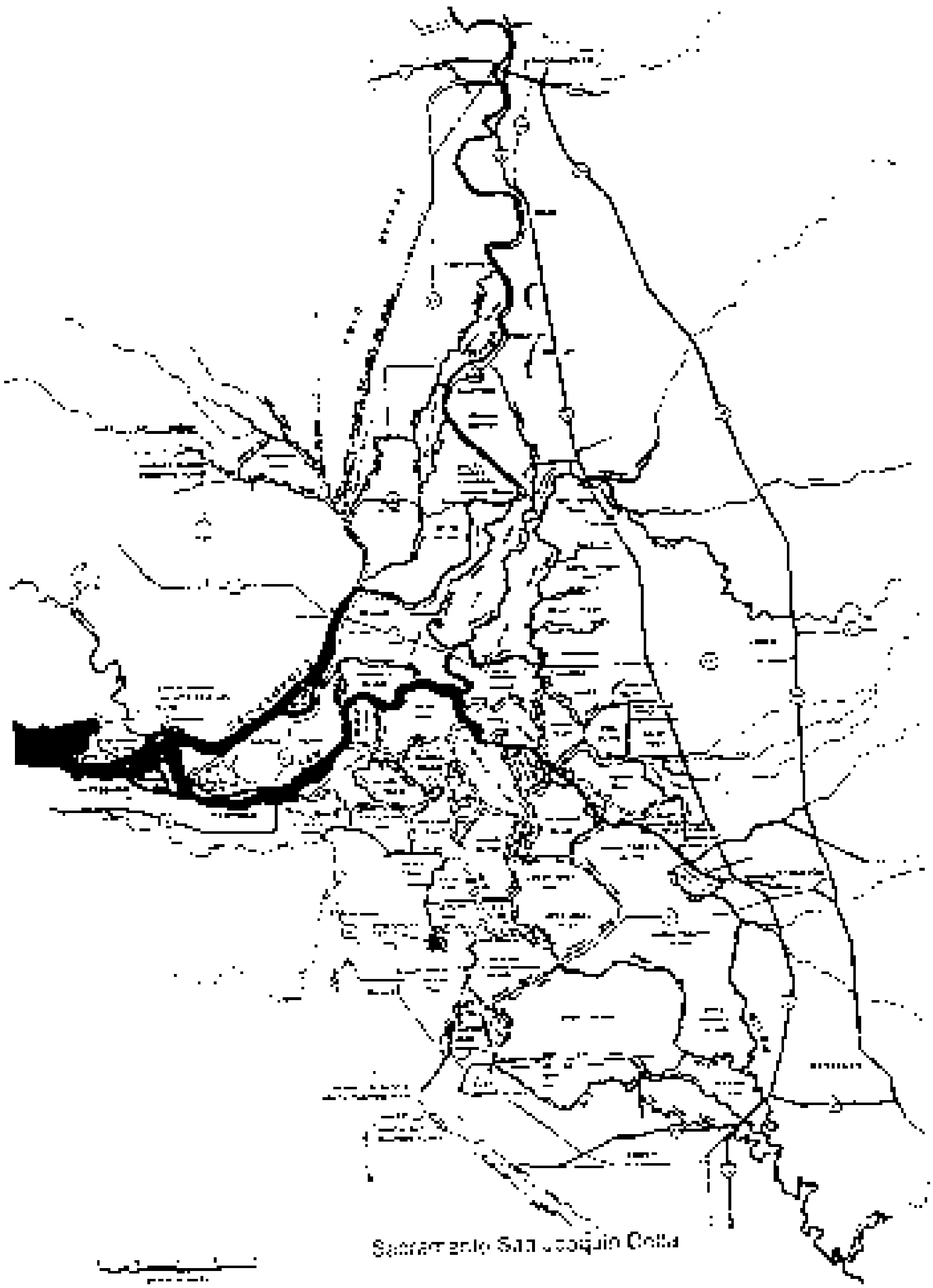
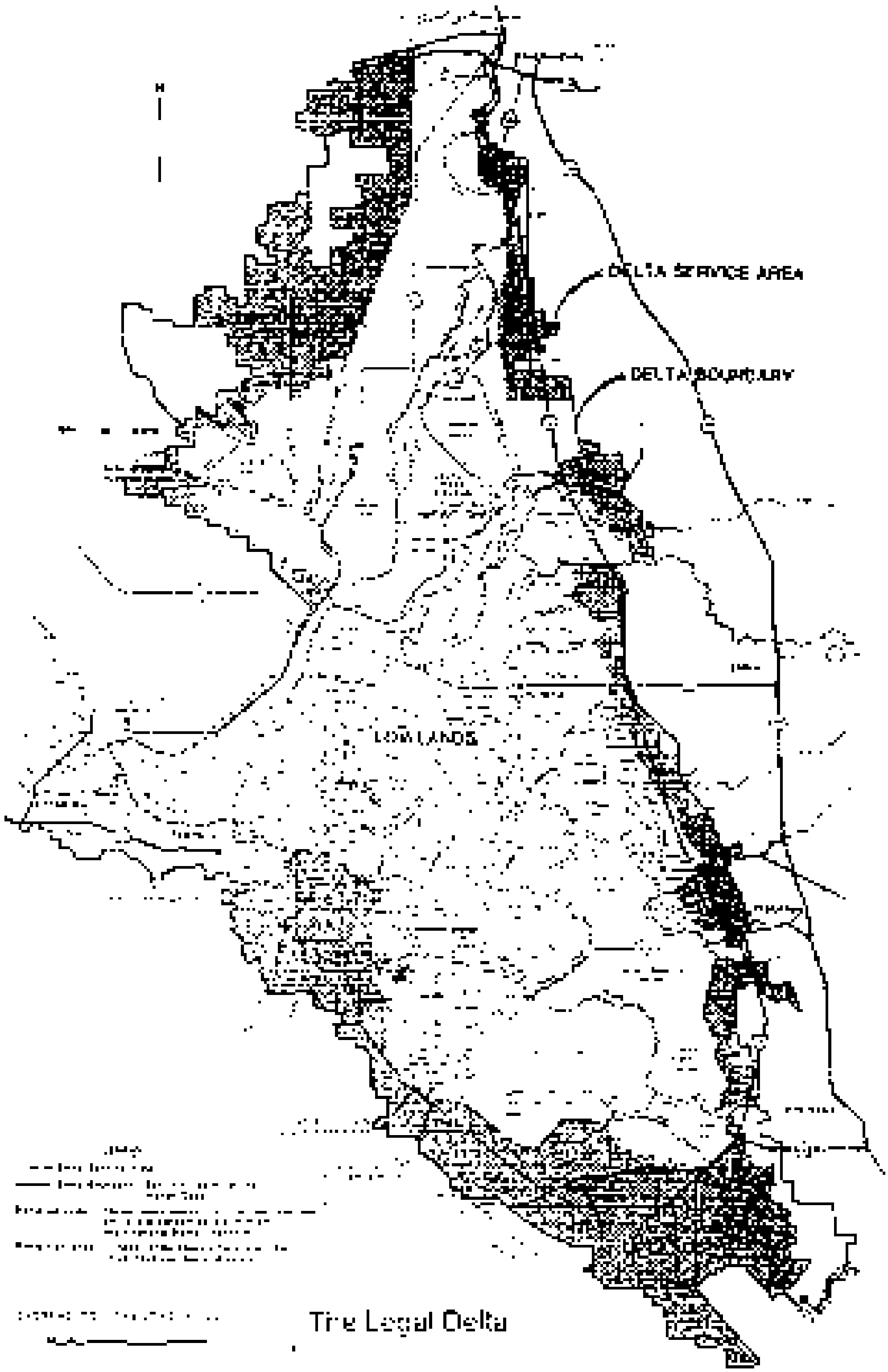


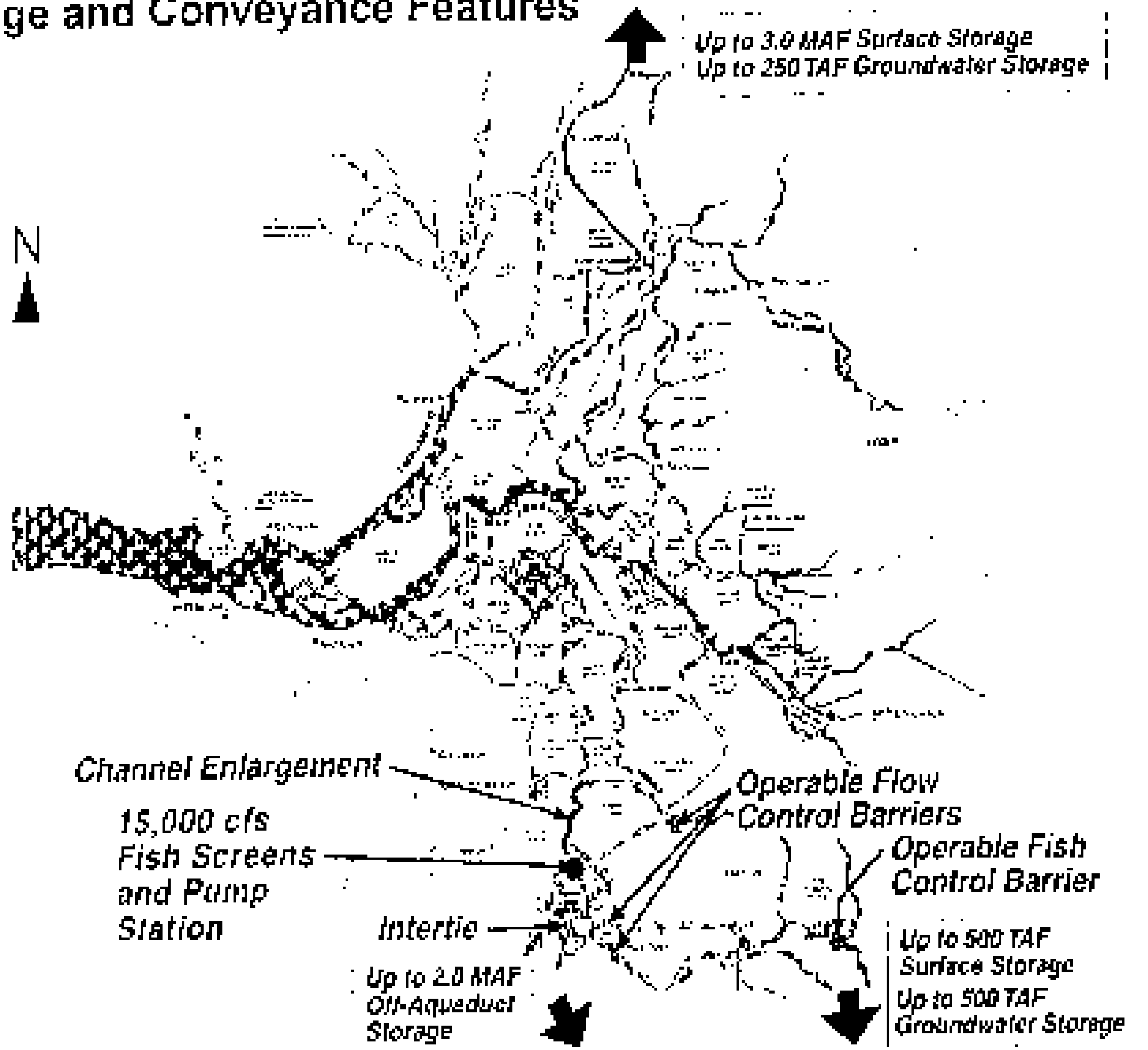
FIGURE 2

The Legal Sacramento/ San Joaquin Delta



Alternative 1

Storage and Conveyance Features

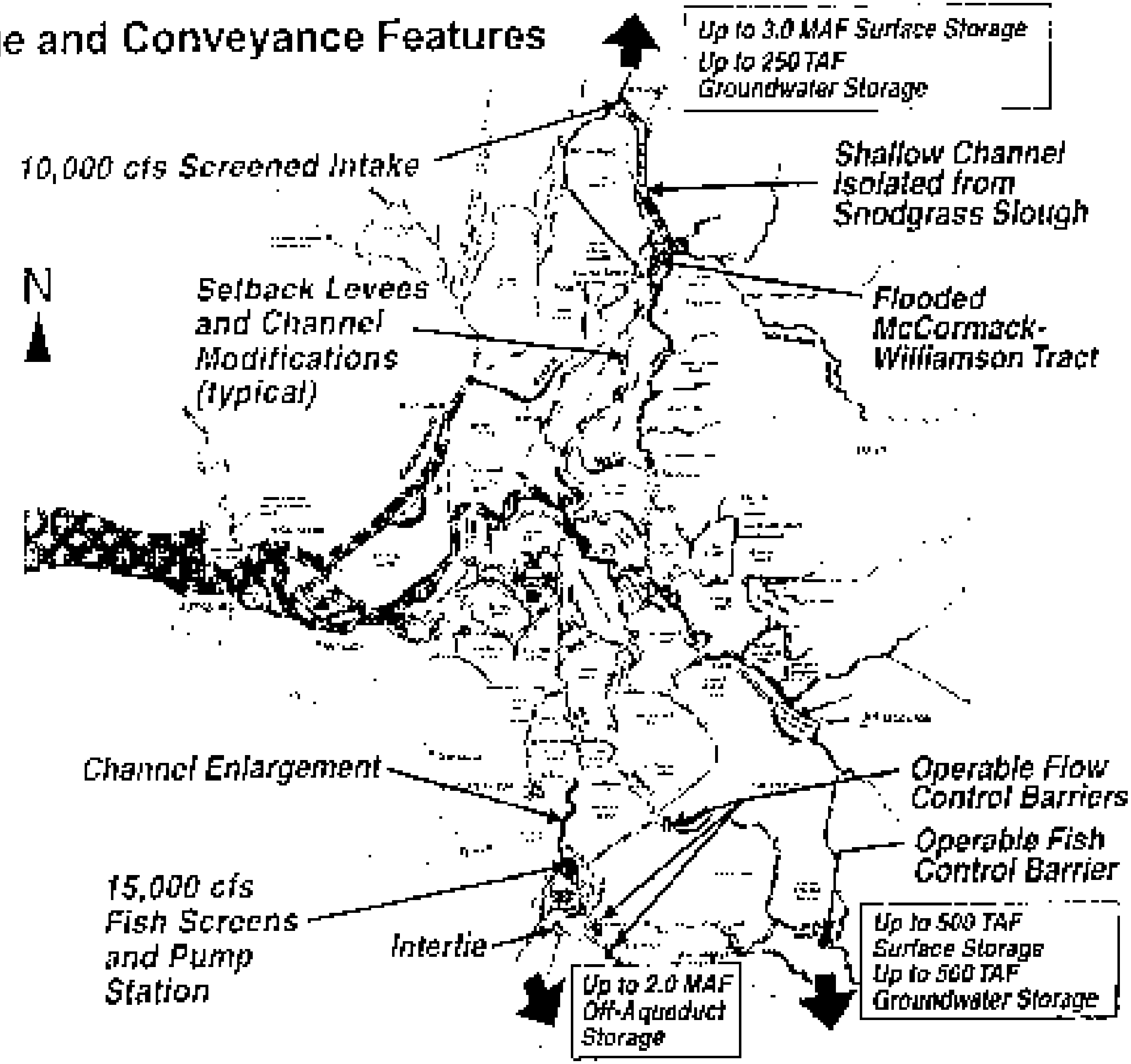


Alternative 1

FIGURE 3

Alternative 2

Storage and Conveyance Features

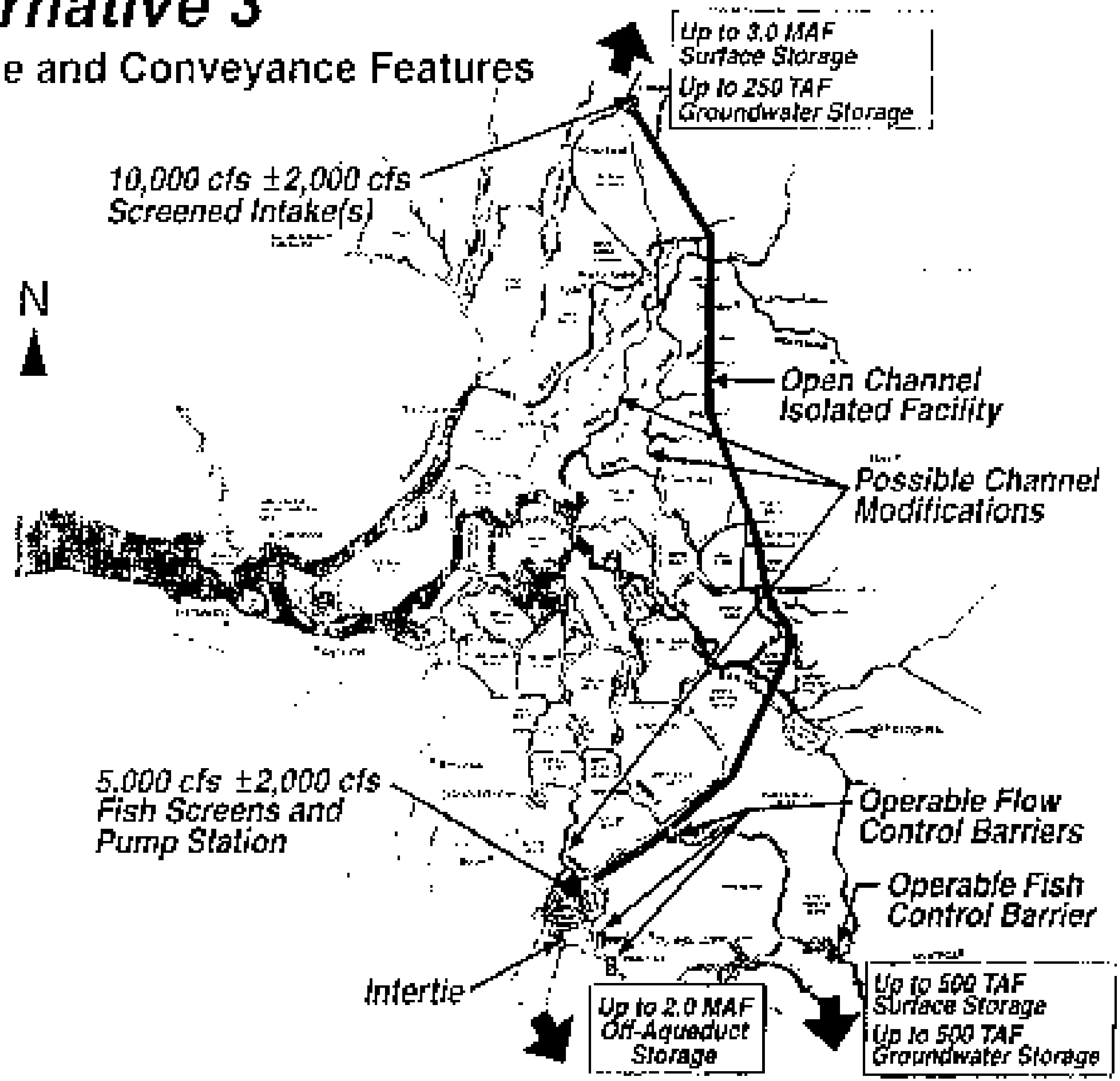


Alternative 2

FIGURE 4

Alternative 3

Storage and Conveyance Features



Alternative 3

FIGURE 5

There is presently a permit-based export limitation restricting the pumping rate to 6,680 cfs (cubic feet per second) of SWP and 4,600 cfs of CVP; the various CALFED alternatives will increase the permitted pumping rate of SWP to 10,300 cfs (14,900 CFS for combined SWP and CVP), with new storage reservoirs of up to 6 MAF.

From a drinking water perspective, the Sacramento River is a high quality source with low to moderate levels of various inorganic and organic constituents. The San Joaquin River exhibits lower water quality largely due to agricultural runoff within its watershed (its relatively high Br^- concentrations are largely attributed to "recycling" of high-Br^- water from the Delta). There are numerous "islands" within the Delta that are used for agricultural purposes; agricultural drainage from these peat-soil islands further degrades Delta water. The primary impact of agricultural drainage is an increase in organic matter as measured by TOC (total organic carbon), with greater impacts observed during winter when leaching activities are more intensive. The Sacramento River contains moderate TOC (≈ 2 mg/L), relatively low TDS (total dissolved salts, ≈ 100 mg/L), and little Br^- (≈ 20 ug/L); the primary impact of seawater interchange is an increase in TDS (seawater contains 35,000 mg/L of TDS) and, in particular, Br^- (seawater contains 65 mg/L of Br^-). The impact of seawater on Delta water quality has been corroborated by tracking the extent of tidal exchange through the ratio of Br^-/Cl^- in seawater. Seawater contains little TOC (≈ 0.5 mg/L).

The location of the major drinking water export facility (Figure 1) is near Clifton Court, which feeds into the H.O. Banks Delta Pumping Plant. Other major export facilities are Rock Slough (the origin of the Contra Costa Canal intake), Barker Slough/North Bay Pumping Plant (the origin of the North Bay Aqueduct), and California Aqueduct/South Bay Pumping Plant (the origin of the South Bay Aqueduct). Thus, these locations represent points of primary concern for drinking water quality.

1.6 Present Drinking Water Treatment Practice for Bay-Delta Water

There are presently over 40 water treatment plants that use Delta water exported through the SWP; a number of other plants use North Bay Aqueduct water, several plants use South Bay Aqueduct water, and several plants use Contra Costa Water District Aqueduct water. While conventional water treatment is widely practiced, there are some direct filtration facilities. Some of the conventional facilities are being modified or have been modified to implement enhanced coagulation for improved TOC removal; others are being modified to incorporate ozonation.

The Alameda County Water District (ACWD) operates two conventional plants: the first employs pre-ozonation, biofiltration, and free chlorine addition followed by ammonia addition (chloramination); because BrO_3^- levels are highly variable with instantaneous levels as high as 30 ug/L, acid-addition capabilities are presently being installed to permit low-pH ozonation. The second ACWD plant has the same chloramination practice but no ozonation; TTHM and HAA_5 levels range from about 60 to 100 ug/L and 30 to 60 ug/L, respectively. The Santa Clara Valley Water District operates three conventional plants, and is presently designing for intermediate (settled-water) ozonation. The Metropolitan Water District (MWD) operates 5 conventional or direct filtration plants which use SWP or combinations of SWP and Colorado River Water; MWD practices chloramination in the mode of free chlorine contact followed by ammonia addition (typical TTHM levels are 40 to 50 ug/L), and is designing for pre-ozonation and biologically active filters (biofiltration). MWD has done extensive demonstration-scale testing of low-pH ozonation; while BrO_3^- levels can be reduced significantly, acid costs are high and TDS increases (because of acid and subsequent base addition) are significant. The Contra Costa Water District (CCWD) operates two plants: the first is a conventional plant with intermediate ozonation that typically forms <5 to 10 ug/L of BrO_3^-, while the second is an unusual plant that includes GAC with both pre- and post-ozonation. CCWD has built an external storage reservoir to dampen variations in Delta-water Br^-. The Los Angeles Department of Water and Power (LADWP) operates a direct filtration facility with pre-ozonation that occasionally treats a mixture of SWP with Los Angeles Aqueduct water.

In summary, SWP treatment practice largely consists of conventional treatment and includes fairly widespread ozonation and chloramination, but there is little advanced treatment practice involving GAC and membranes. One CCWD facility uses GAC and some pilot testing of membranes has taken place at CCWD, MWD, and ACWD.

1.7 Objectives of Report

The objectives of this report are summarized below:

- Define the sources and occurrence of Br^- (present and projected) in the Delta, and articulate source management options,

- Summarize present drinking water regulations, and project future trends,
- Describe the health effects of Br^- in disinfected drinking water, and identify ongoing/future studies;
- Identify and compare drinking water treatment options for controlling brominated DBPs;
- Contrast treatment versus source management approaches; and
- Make recommendations on short-term and long-term treatment practice and source management, and identify information/research needs.

2.0 Sources and Occurrence of Bromide, and Source Management Options

2.1 Occurrence of Bromide in the Delta

Concentrations of bromide in Delta waters are summarized in Figure 6 (California Department of Water Resources, 1998a); this figure lists bromide concentrations in micrograms per liter (µg/L) for mean measurements and also mean plus or minus one standard deviation at the following monitoring locations: (i) Sacramento River at Greenes Landing; (ii) North Bay Pumping Plant (SWP); (iii) Sacramento River at Mallard Island; (iv) Rock Slough at Old River; (v) H.O. Banks Pumping Plant (SWP); (vi) Delta Mendota Canal at Lindemann Road (CVP); and (vii) San Joaquin River near Vernalis.

Figure 7 (California Department of Water Resources, 1998a) shows bromide concentrations in Delta channels from October 1994 through September 1997 and Figure 8 (California Department of Water Resources, 1998b) shows bromide concentrations in Delta agricultural drains for the same time period.

2.2 Sources of Bromide in the Delta

The sources of bromide in Delta waters include: (i) sea water intrusion, (ii) recycling of agricultural drain waters from the Delta, (iii) methyl bromide used for soil, commodity and structural fumigation, (iv) discharges from olive processing facilities, (v) discharges from municipal wastewater treatment plants, and (vi) disinfectants used in spas. Apparently, sources of bromide from olive processing facilities, municipal wastewater treatment plants, and disinfectants used in spas contribute minimal amounts of bromide to Delta waters. This statement is based on the fact that Sacramento River water above the Delta typically contains

FIGURE 6

Sources of Bromide and Levels at Diversion Points

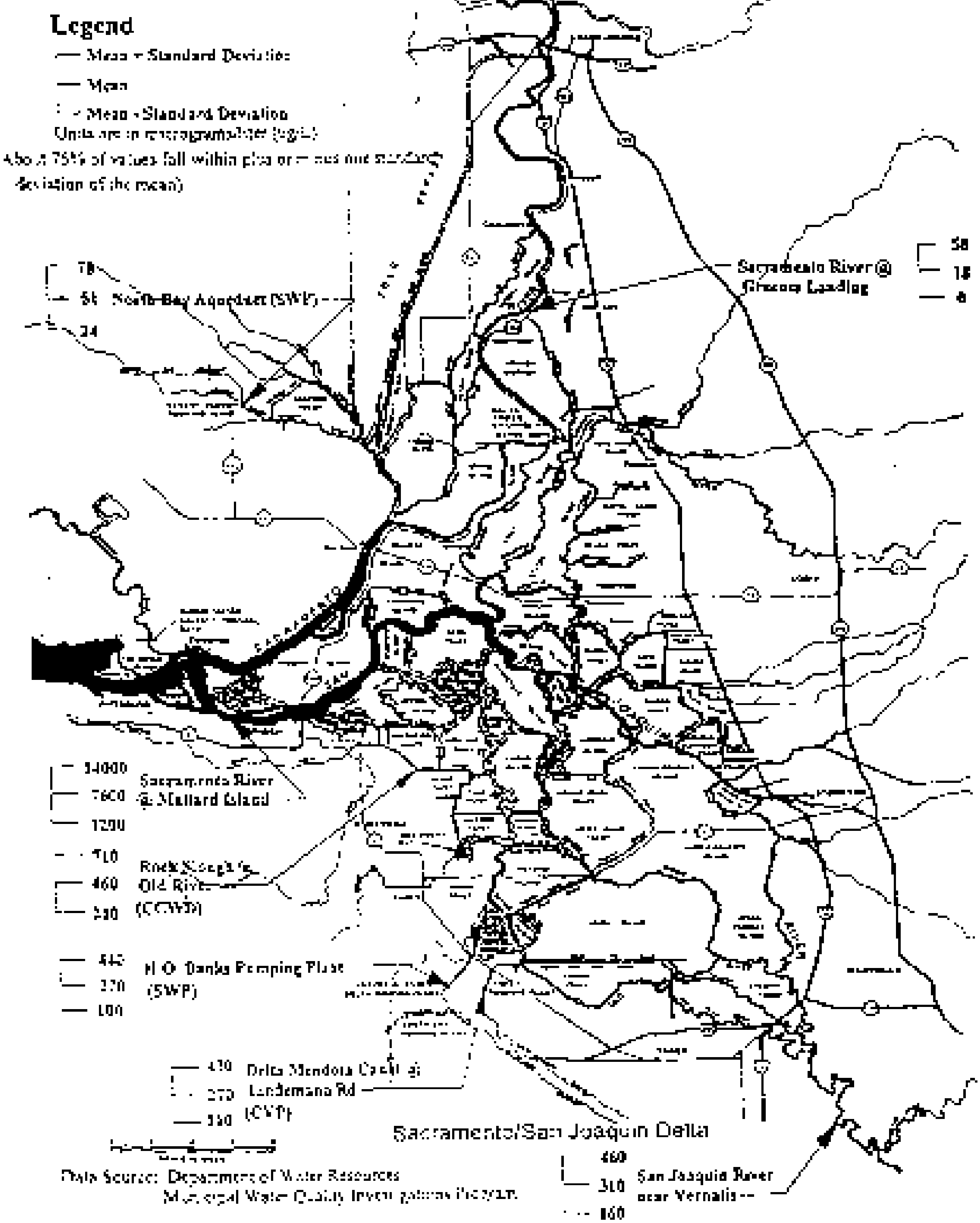


FIGURE 7

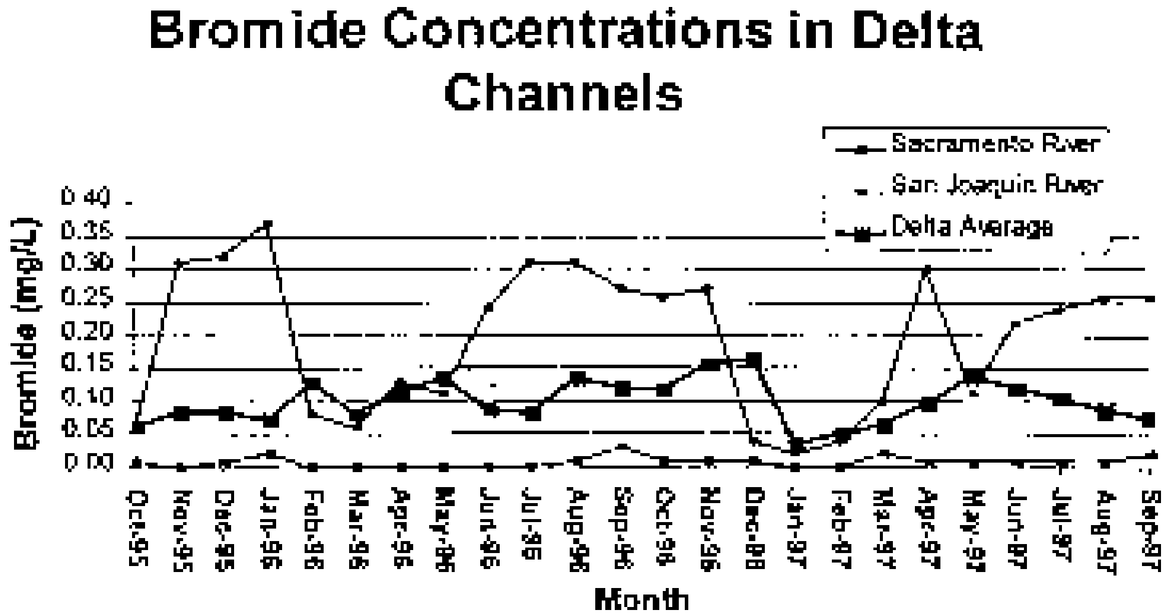
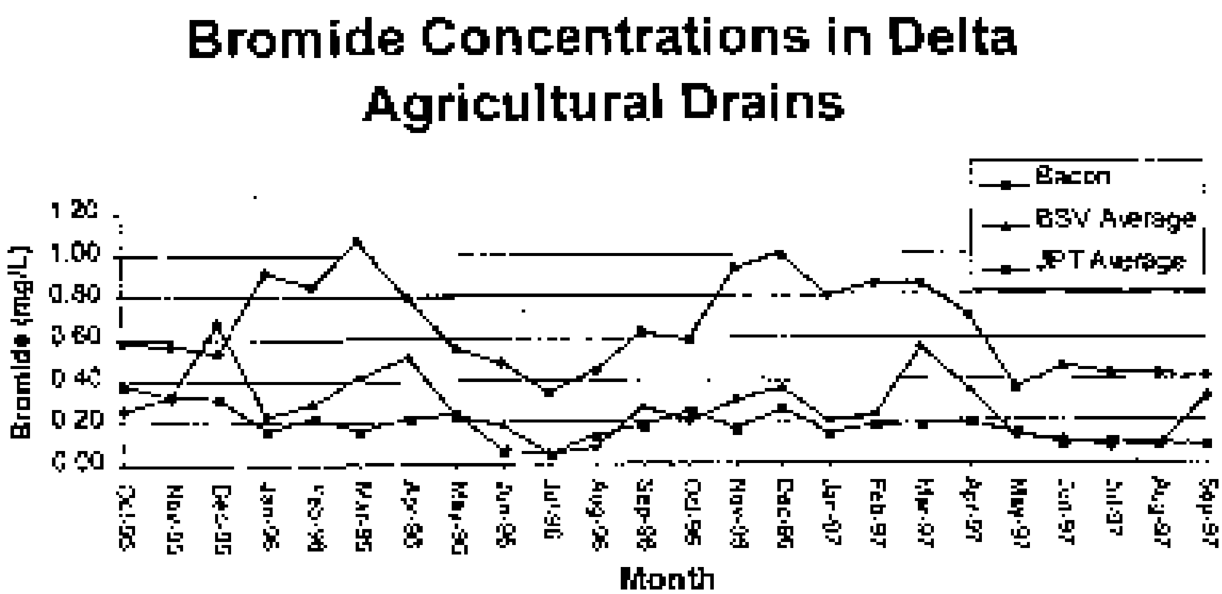

Bromide Concentrations in Delta Channels
Sacramento River
San Joaquin River
Delta Average
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Bromide (mg/L)
Oct-95
Nov-95
Dec-95
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Month

FIGURE 8


Bromide Concentrations in Delta Agricultural Drains
Bacon
BSV Average
JPT Average
Bromide (mg/L)
1.00
0.80
0.20
Month
Nov-95
Jan-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97

less than 20 micrograms per liter (µg/L) of bromide (California Department of Water Resources, 1998b).

A report prepared by the Department of Water Resources (California Department of Water Resources, 1998b) articulated the following points regarding the sources of bromide in Delta waters. The Delta has one major source of bromide, sea water that enters the western Delta from tidal excursions and mixes with Sacramento River water flowing through the Delta to the export facilities in the southern Delta. Bromide levels at Clifton Court Forebay and at the Contra Costa Canal intake are attributed to sea water intrusion. Another source of bromide may be the San Joaquin River; however, the primary source of bromide in the San Joaquin River is probably from agricultural return water which contains bromide and is exported from the Delta, so this may simply be a "recycling" of bromide from sea water intrusion. Another source of bromide is connate water beneath some Delta islands (e.g., Empire Tract) (California Department of Water Resources, 1994). Overall, the primary source of bromide in Delta waters is the result of sea water intrusion (Krasner et al., 1994).

Figure 9 (Metropolitan Water District of Southern California, 1998) show average bromide concentrations in ug/L and percentage of total respectively for (1) CCC (Contra Costa Canal) Intake, (2) H.O. Banks Intake, and (3) DMC (Delta Mendota Canal) Intake for baseline 1984-92, with sources of bromide from sea water, agricultural drainage, east sources, San Joaquin River and Sacramento River.

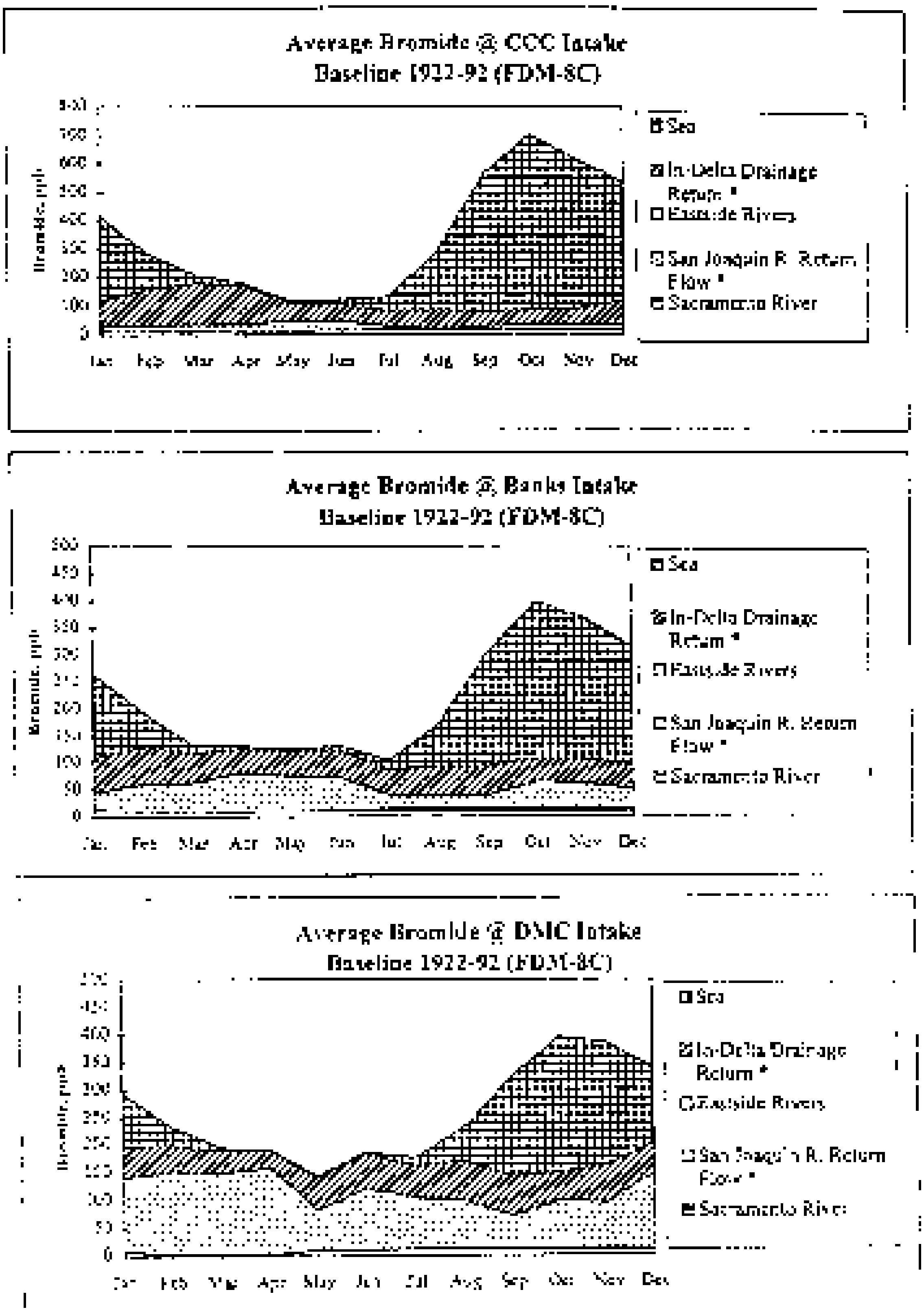
Figures 6 through 9 contain information on the magnitude of sources of bromide at points of diversion for drinking water supply and at other locations in the Delta. The magnitude of bromide in the Delta is near the upper 90^{th} to 95^{th} percentile, based on the nationwide bromide survey by Amy et al. (1994), suggesting that the bromide problem facing CalFed is more of a regional than national one.

A concern was expressed during the Bromide Panel meetings in Sacramento held on September 8 and 9, 1998, that some of the "recycled" bromide in the San Joaquin agricultural drain waters could come from agricultural applications of methyl bromide.

2.5 Management Options for Bromide Sources

Identification of sources of bromide from, (i) methyl bromide fumigation applications, (ii) olive processing facilities, (iii) municipal wastewater treatment plants, and (iv) disinfectants

FIGURE 9



* Past studies indicated that seawater intrusion is the primary source of bromide in the Delta; hence bromide in San Joaquin River return flows and in-Delta drainage returns primarily originated from the ocean.

Source: Metropolitan Water District of Southern California used in spas; will allow for management and control of these sources. Information on methyl bromide fumigation applications could be obtained from the Department of Pesticide Regulation. Regional water quality control boards could provide information on potential bromide discharges from municipal wastewater treatment plants and olive processing facilities. Merchants selling disinfectants for spas could indicate whether or not bromine is used as a disinfectant, how much is used, and its ultimate fate (as bromide) in the environment.

Considerable modeling has been performed by various agencies to forecast the effectiveness of various combinations of storage and conveyance features for Alternatives 1, 2 and 3.

The predicted effectiveness of these three alternatives for changing water quality concentrations of bromide are shown in Figure 10 (Clifton Court) and Figure 11 (Rock Slough) (California Department of Water Resources, 1998a). The figures show average predicted bromide concentrations as well as the upper and lower 95 percent bromide confidence limits. Projected TOC levels at the H. O. Banks Pumping Plant are 3.2, 3.1, 3.1, and 2.5 mg/L for no action, Alternative 1, Alternative 2, and Alternative 3, respectively.

Figures 12 and 13 (California Department of Water Resources, 1998a) illustrate the predicted monthly average bromide concentrations in ug/L at Clifton Court and the Contra Costa intake for Alternatives 1, 2 and 3 for the water year. It is evident that Alternative 3 has the most impact on Br^- levels at Clifton Court, whereas Alternative 2 provides lower Br^- levels at the Contra Costa intake; thus, there is no single alternative that provides lowest Br^- levels for all drinking-water export points.

<u>2.4 Additional Information Needed</u>

CalFed should assemble information on the monthly variations of bromide concentrations for key locations (Clifton Court, Contra Costa Intake) for each alternative (1, 2, 3). CalFed should perform a sensitivity analysis by estimating how much effort, cost, benefit and environmental impact would result if each alternative (1, 2, 3) were modified for both an incremental increase and decrease of bromide at key locations (Clifton Court, Contra Costa Intake). CalFed should assemble and analyze additional TOC occurrence data, particularly co-occurrence of TOC with Br^-.

FIGURE 10

Bromide Water Quality
Predicted Bromide at Clifton Court

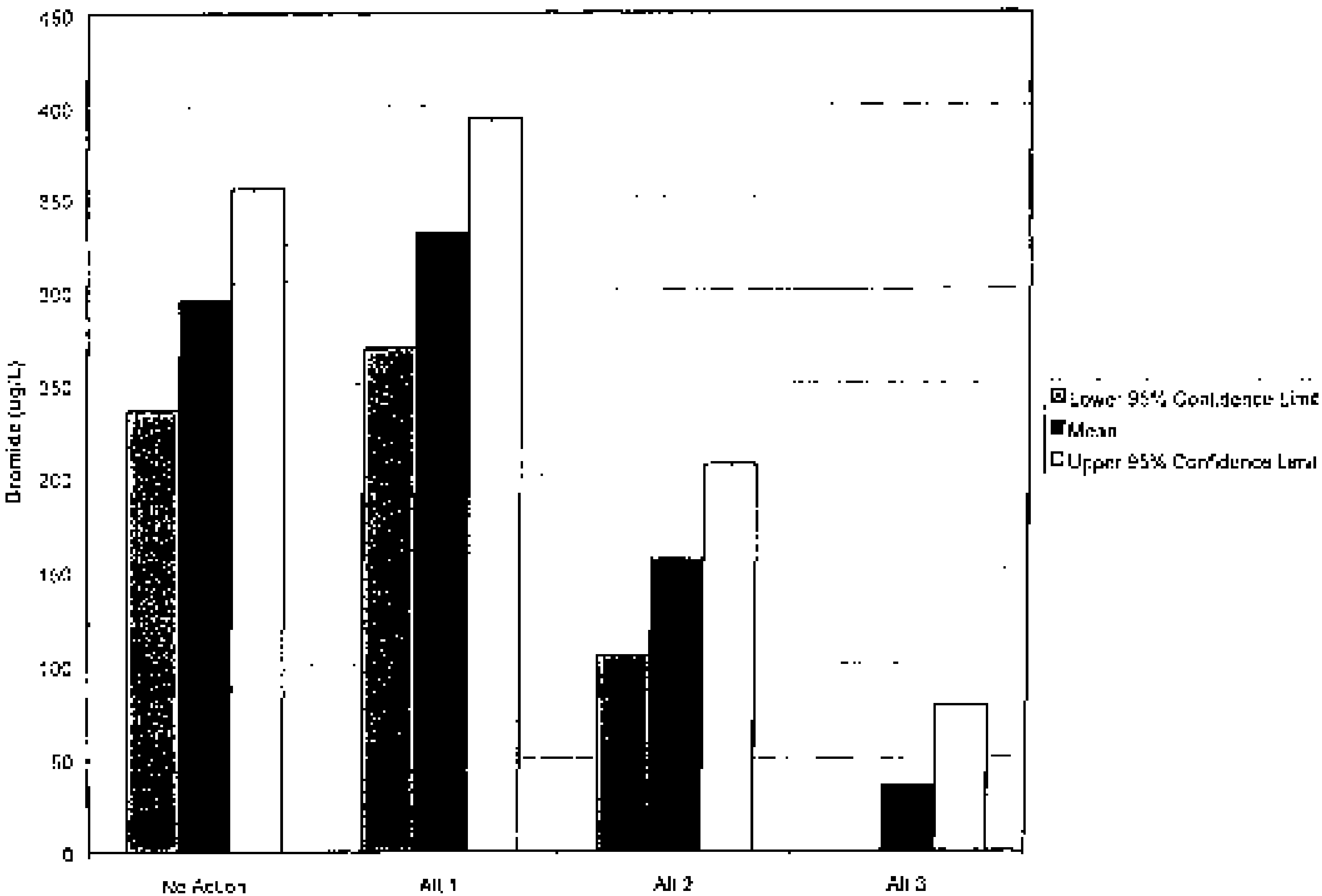


FIGURE 11

Bromide Water Quality
Predicted Bromide – Contra Costa Canal Intake at Rock Slough

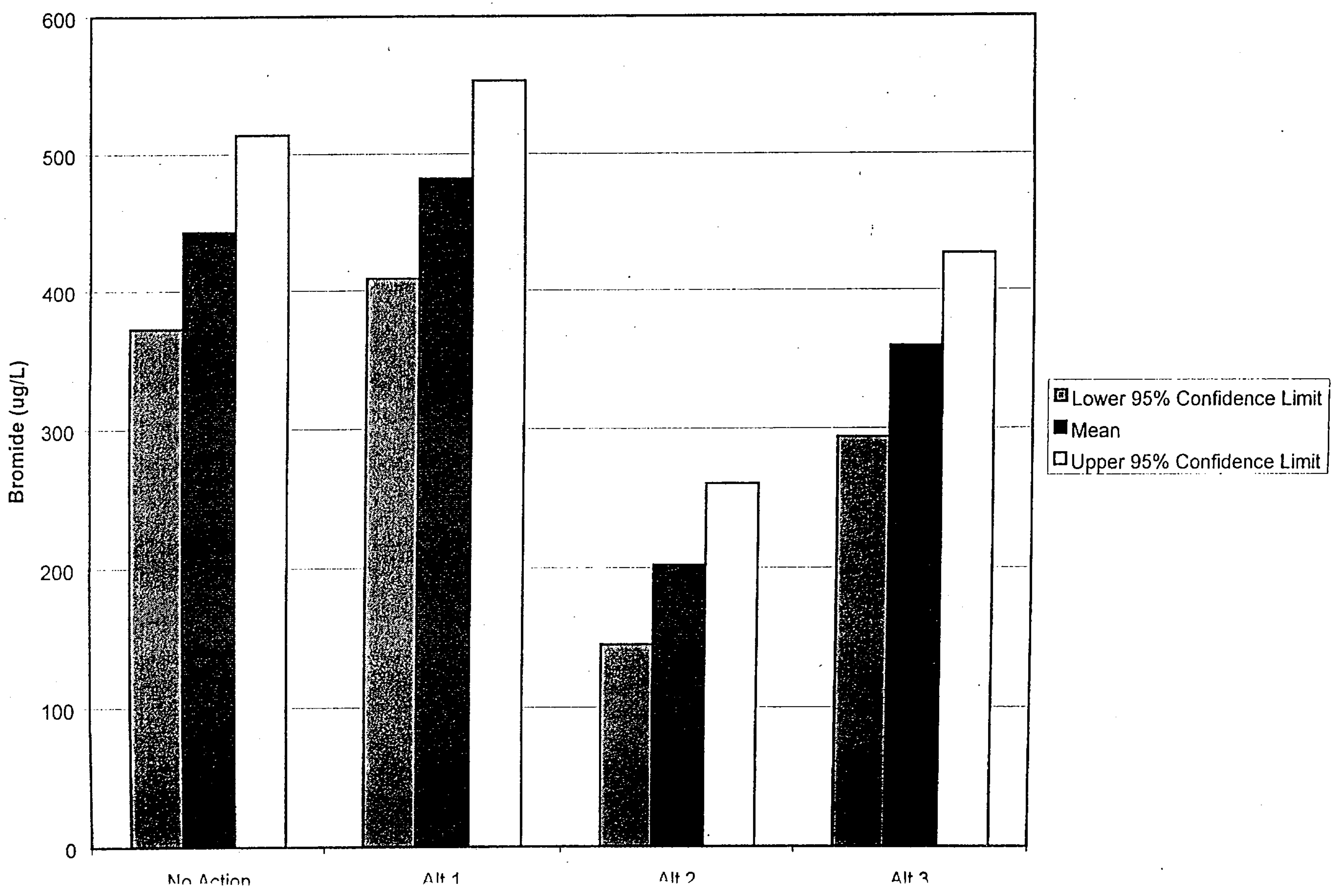
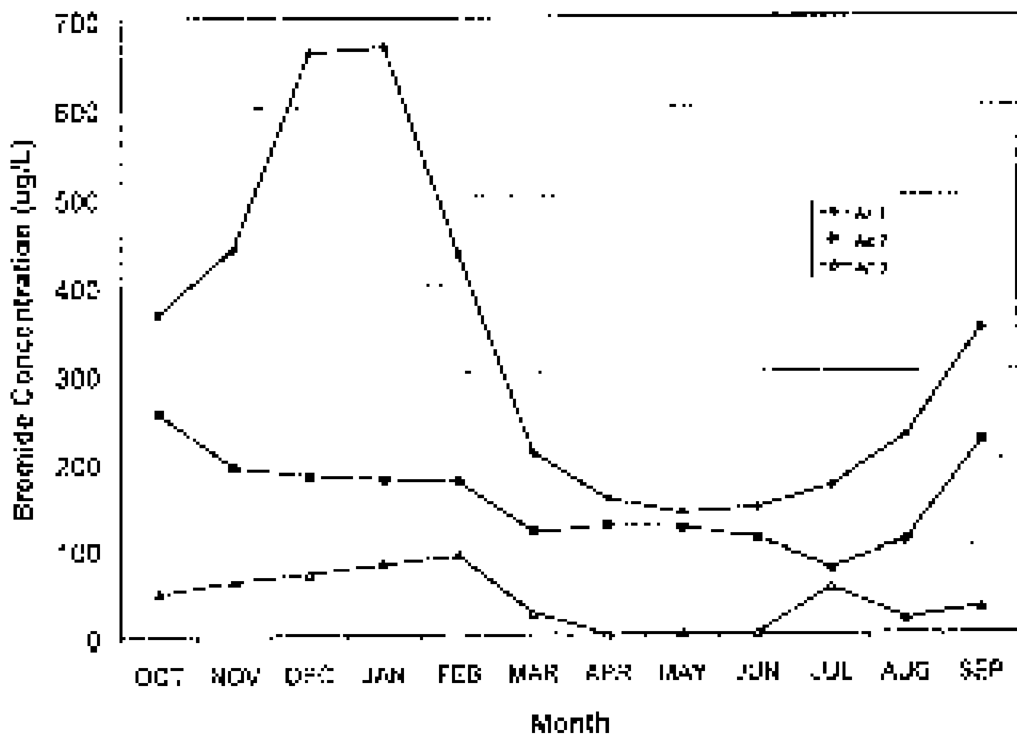
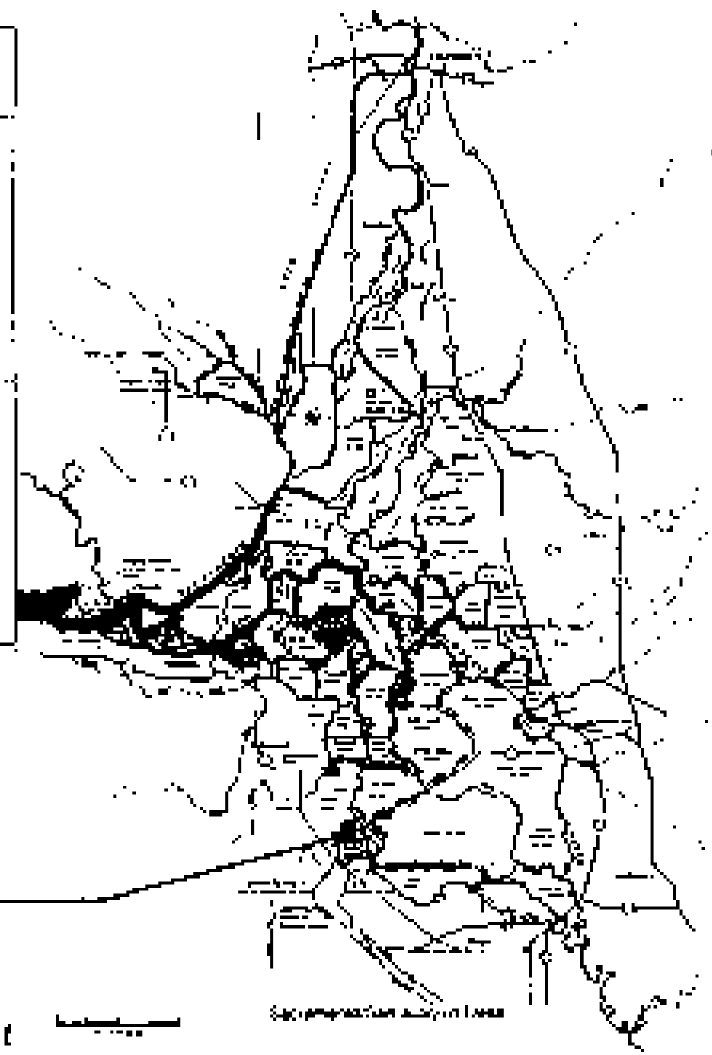


FIGURE 12

Predicted Average Monthly Bromide at Clifton Court Forebay

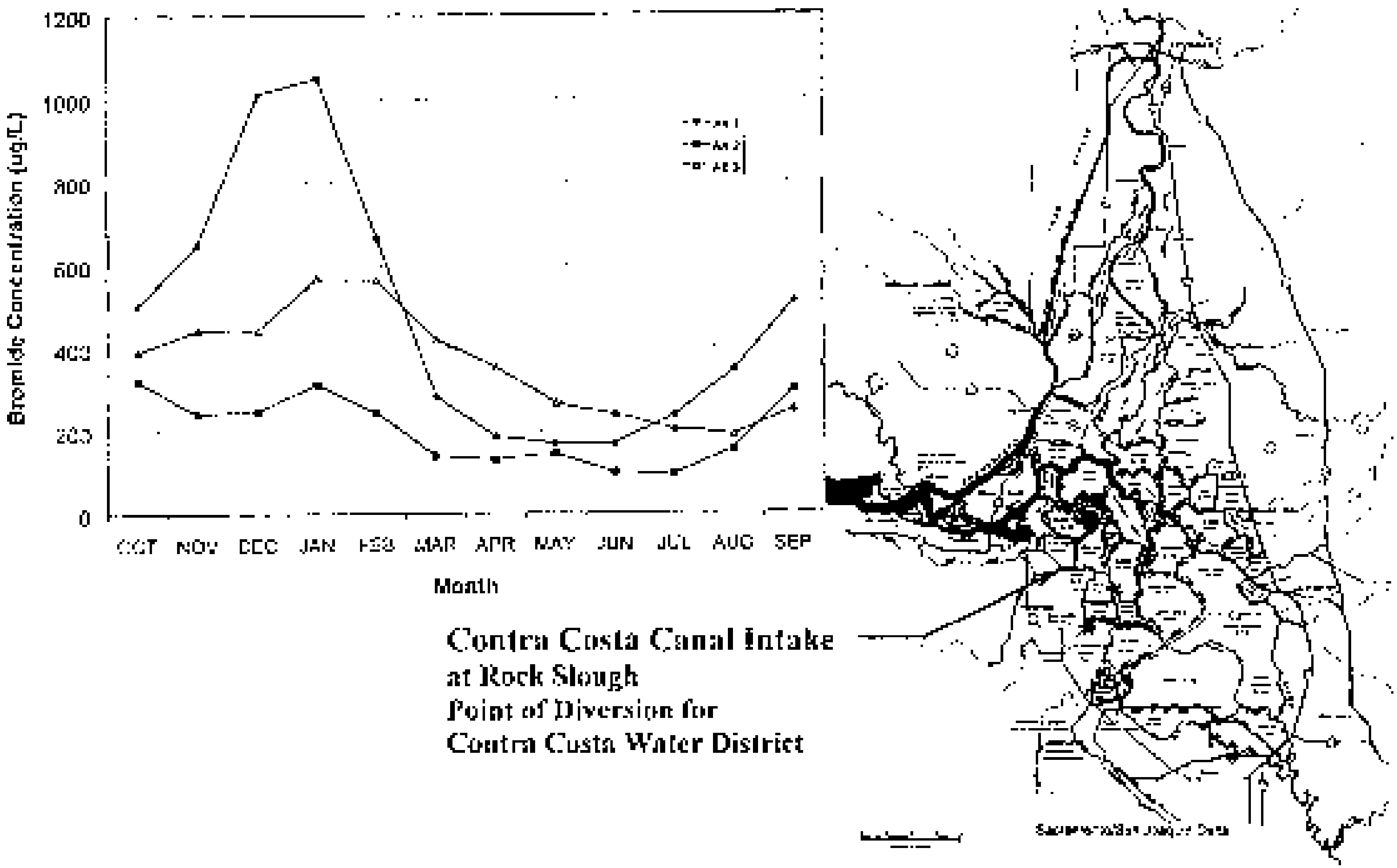




Clifton Court Forebay
Combined Point of Diversion
For State Water Project
And Federal Central Valley Project

FIGURE 13

Predicted Average Monthly Bromide at Contra Cost Canal Intake



2.5 Recommendations

CalFed should resolve concern regarding whether or not (or how much) of "recycled" bromide from agricultural return drains is actually "recycled" or is from agricultural fumigation activities using methyl bromide. CalFed should investigate options for immediate opportunities to enhance source controls of bromide. These options could include identification and control of all possible sources of bromide. Another option could be alternative means of managing storage and flows through the Delta. Potential short-term solutions/options should be implemented as soon as possible. CalFed should study the potential for using alternative sources of high quality water for drinking purposes and using lower quality waters to meet agricultural water supply demand.

3.0 Health Concerns Posed by Bromide in Source Waters Used for Drinking Water

High concentrations of bromide in source water are of little direct health concern. However, bromide serves as a precursor for the formation of a wide variety of organic by-products when chlorine or chloramines are used in disinfection. With the use of ozone, bromate becomes a major concern. A number of these by-products are carcinogenic, produce reproductive and developmental toxicities, and have other toxicological properties that would be of concern if produced at sufficient concentrations. The major focus of this section is to provide some basis for appreciating the reasons one might be more concerned about brominated by-products than their chlorinated analogs.

3.1 Epidemiology Suggests Different and Greater Hazards than Available Toxicological Data

It is difficult to gauge the actual magnitude of risks from disinfection by-products in drinking water. Epidemiological data has associated increases in bladder and colorectal cancer with the use of chlorine as a disinfectant. Meta analyses have been applied to these data that suggest that the attributable risk could be thousands of cases of cancer in the U.S. annually (Morris et al., 1992). It must be noted that the utilization of meta analyses in this case has been seriously questioned (Poole, 1997). However, *if the epidemiological results are actually valid, these are the levels of risk that would be derived from the positive studies*. If these estimates are real, risks of this magnitude may warrant significantly more stringent control of chlorinated

DBPs than anticipated under the Stage I DBP rule. However, proof of causality has been elusive (Poole et al., 1997; USEPA, 1998a). Many scientists in the area believe it to be premature for precipitous action based on available epidemiological data.

Toxicological studies have identified chemicals that can produce cancer in rodents, but the target organs most frequently identified are the liver and kidney. Two by-products have been shown capable of producing colon cancer in rats (bromodichloromethane and bromoform), but their activities are much too weak to account for the incidence seen in the epidemiology studies. To date, no bladder carcinogen has been identified. There are a number of reasons to explain both the quantitative and qualitative discrepancies between the epidemiological and toxicological data. The possible risks suggested by epidemiology studies may simply not be correct. On the other hand, the experimental animals used may simply be poor models for human susceptibilities to these disinfection by-products. The fact is that a very large fraction of disinfectant by-products have not actually been subjected to cancer bioassays. Brominated by-products are very underrepresented in the tested compounds. Moreover, the National Toxicology Program (NTP) noted that induction of colon cancer was a rare event in bioassays. However, this site was targeted by three other brominated compounds in the experience of NTP (Melnick et al., 1994). Therefore, one must consider the problem that is stated in Table 1.

The same type of problem of interpreting possible cancer risks from chlorinated DBPs pertains to understanding possible reproductive and developmental risks from chlorinated DBPs. There has been a single, well conducted epidemiology study associating disinfection by-products as a potential cause of spontaneous abortion (Waller et al., 1998); it is noteworthy that this study was performed in California, involved brominated THMs, and possibly some Delta water. Toxicological studies have identified a number of chemicals that have effects on male reproduction and new experiments are exploring other reproductive hazards. The most potent DBP found to affect male reproductive function is dibromoacetic acid (Linder et al., 1995) suggesting that brominated species may be the most likely group of chemicals to produce these effects. Still the potency of dibromoacetic acid is too low to account for the epidemiological results and the studies focused on different endpoints. However, if other short-chained chlorinated hydrocarbons are examined, the substitution of bromine for chlorine significantly increases the probability of adversely affecting male reproductive function (Lag et al., 1991).

Therefore, the issues identified in Table 3 are even more important for developmental and reproductive toxicities that might be associated with DBPs.

Table 3. Potential explanations for the discrepancy between epidemiological studies of chlorinated water and toxicological studies of disinfection by-products.

1. Chlorinated by-products have been the most thoroughly studied.
2. Concerns about major chlorinated by-products (chloroform, dichloroacetate and trichloroacetate) are fading at the low levels produced in drinking water based upon new toxicodynamic data. These by-products are the major liver and kidney carcinogens.
3. The majority of by-products produced from chlorination have not been subjected to toxicological testing.
4. Brominated by-products comprise a major portion of the untested compounds.

3.2 Brominated By-products – Reasons for Concern

As should be appreciated from the above discussion, the data available at this time are too sparse to raise alarms about brominated DBPs. However, relatively large investments are being considered to improve environmental conditions in the Bay-Delta system. These improvements are being viewed to an end point that is 25-30 years in the future. As some of the alternatives could potentially change bromide levels present in drinking water sources, it is necessary to consider the potential impacts of the resulting by-products on human health. Aside from the limited data on brominated by-products referenced above, there are several theoretical reasons why bromine containing disinfection by-products could become a serious problem over this time horizon. Anticipation of these potential problems should help avoid commitment to alternatives that could be untenable in the long-term

3.2.1 Direct and Indirect Effects of DBPs

Chemicals may exert their toxic effects as the parent compound or they may require metabolism to become active. Examples of both types are found with disinfection by-products. Dichloroacetic acid and trichloroacetic acid appear to act directly (i.e. do not require metabolism to be active) to produce liver cancer. It is likely that these chemicals bind through reversible hydrophobic and electrostatic interactions to proteins. The trihalomethanes can act directly at very high doses to produce anesthesia. However, their more severe toxicities are produced by being metabolized oxidatively to phosgene, reductively to a free radical, or reacting with glutathione to produce a third reactive intermediate. These reactive intermediates interact covalently with proteins and nucleic acids to produce toxicity and induce mutation, respectively. Oxidants can also produce damage by inducing oxidative stress. Generation of hydrogen peroxide, superoxide radical, and hydroxyl radical can produce damage to cell membranes and produce oxidative damage to purine and pyrimidine bases in DNA *in vivo*. Such reactions may occur spontaneously, but in some cases various enzymes that are present in the body accelerate them.

Impact of Bromine Substitution on Metabolism Leading to Reactive Intermediates. Halogen substitution on organic molecules provides an electronegative point of attack for either oxidative or reductive metabolism. In reductive dehalogenation reactions, free radicals are generated that lead to oxidative stress or to direct damage by the halogen radical. As halogens become larger, they become more electronegative and are more easily removed. Chlorine is a better leaving group than fluorine and bromine is better than chlorine. Therefore, toxicities that are the result of interactions of reactive metabolites are generally greater if bromine is substituted on a carbon instead of chlorine. To the extent that these metabolites can reach the DNA in the cell, they are frequently mutagenic.

The limited comparisons of toxic and carcinogenic effects of the relatively small numbers of brominated disinfection by-products are consistent with this hypothesis. The weight of evidence (induction of tumors in multiple species, multiple sites, and sites of relatively low incidence) of bromodichloromethane is much stronger than for chloroform. Moreover, the carcinogenic potency of bromodichloromethane is approximately 10-times that of chloroform using the linearized multistage model for comparisons at low doses (Bull and Kopfler, 1991).

Mutagenicity as a Major Determinant for Using Linear Approaches to Low-dose Extrapolation. The mutagenic activity of a chemical is a major determinant of whether linear methods are to be used for low dose extrapolation (USEPA, 1996). Within the THM and haloacetic acid groups of DBPs that have been investigated, the chlorinated members of the group are very inconsistently active in mutagenesis assays. There are three different pathways for metabolizing the THMs to reactive metabolites. In the two of the three pathways that have been investigated, substitution of bromine increases the mutagenic activity significantly above that seen with the chlorinated analogs (Zieger, 1990; Pegram et al., 1997). Dichloroacetic acid and trichloroacetic acid are very weak mutagens, requiring greater than millimolar concentrations to product modest responses (Harrington-Brock et al., 1998; Giller et al., 1997). Dibromoacetic acid and tribromoacetic acid are at least an order of magnitude more potent as mutagens in the Salmonella fluctuation assay (Giller et al., 1997).

Mutagenic activity of a compound assumes this importance based on the assumption that mutagenic events are cumulative with dose. Mutations are essentially irreversible events to the extent that the mutated cell and its progeny survive.

Based on the relative lack of data implicating a mutagenic mechanism for chloroform, an MCLG (maximum contaminant level goal) of 300 µg/L was recommended by the USEPA in a Notice of Data Availability (USEPA, 1998b). However, it is highly improbable that bromodichloromethane would be treated in the same way. In all probability, an MCLG = 0 will be maintained for bromodichloromethane because of its mutagenic activity and because of its more robust activity as a carcinogen. It is also improbable that dichloroacetic acid and trichloroacetic acid will be treated with linear-low dose extrapolation. As with bromodichloromethane, the mutagenic activity associated with the brominated haloacetic acids may also be used to rationalize linear low-dose extrapolation for these chemicals. In addition, the brominated haloacetic acids have been shown to produce a sustained elevation of oxidatively damaged DNA in the liver of chronically treated mice (Parrish et al., 1996), an effect not observed with dichloroacetic acid and trichloroacetic acid. As a result, the MCLGs proposed for the chlorinated vs. the brominated haloacetic acids could vary widely even though they have approximately the same carcinogenic potency in animal studies (Bull, unpublished data).

3.2.2 *Bromate*

When ozone is used in the disinfection of water containing significant amounts of bromide, the formation of bromate will result. When the concentrations of bromate produced in these circumstances are compared to those which induce cancer in rats (Kurokawa et al., 1986), the margin of safety is significantly lower than for disinfectant by-products that are produced with chlorination.

Estimated Cancer Risk. Applying the linearized multistage model to data obtained in cancer bioassays in rats, the concentrations of bromate associated with the 1 in a million additional lifetime risk is 0.05 μg/L (Bull and Kopfler, 1991). The 1 in 10,000 added risk is estimated at 5 μg/L which approximates the practical quantitation limit (PQL) in water.

Lack of Toxicokinetic and Toxicodynamic Data. The risk that bromate represents as a cancer hazard in humans may not be accurately reflected by the linearized multistage model. Unlike chlorination, no epidemiological studies have been conducted to suggest that ozonation of water carries a cancer risk for humans. Available data, however, suggest a relationship with oxidative damage to DNA in the induction of renal tumors (Umemura et al., 1993). The actual mechanisms involved are somewhat controversial. *In vitro* studies of bromate-induced DNA damage suggest that the process requires glutathione and produces a damage more consistent with the generation of bromide radicals than reactive oxygen species (Ballmaier and Epe, 1995). Conversely, Chipman et al. (1998) found little dependence upon glutathione *in vivo*, but indirect methods (i.e. glutathione depletion) were used to investigate glutathione dependence. On the other hand, these investigators did find evidence of lipid peroxidation in the kidney of rats following 100 mg/kg dose of potassium bromate, but not at 20 mg/kg. Neither case provided a rationale for why these effects were observed in the kidney and not other organs like the liver (Cho et al., 1993, Lee et al., 1996). The oxidative damage to DNA is also produced at very high rates by the normal energy metabolism of the body. The repair mechanisms for this type of damage are very rapid and efficient (Lee et al., 1996). At low doses, the amount of oxidative damage anticipated from bromate would be very small compared to the damage induced by normal metabolism. Consequently, it is likely that cancer risk would be low at the concentrations of bromate that might be anticipated in ozonated drinking water. Irrespective of a detailed mechanism, however, it will be necessary to obtain a much clearer and quantitative model of the toxicokinetics and toxicodynamic nature of bromate-induced cancer. The research of Lee et al. (1996) provides an excellent start by identifying a critical biomarker for kidney cancer, but has yet to be coupled with biological responses in a quantitative way. Thus, detailed toxicokinetic and toxicodynamic data appear necessary to provide evidence that non-linear extrapolation is appropriate for bromate-induced cancer.

3.3 Variations in sensitivity in the human population.

It is important to acknowledge that the differences in epidemiological and toxicological studies of disinfection by-products could be that rodents are a poor representation of the distribution of human sensitivities to toxic chemicals. In general rodents used in toxicological tests are inbred strains. Frequently, these strains are chosen because they are sensitive models for certain types of toxic effects. While this may be generally true, it does not always hold true in particular cases. The factors that influence sensitivities to toxic chemicals frequently have a very specific basis that is not necessarily reflected by so-called "sensitive experimental animal models". It is beyond the scope of this report to cover this subject in a comprehensive way. However, there are two types of interaction that need to be identified and discussed in an illustrative way. Once the mechanisms involved in these two general processes are identified, the identification of traits that characterize sensitive populations can be done rationally in a chemical-specific way.

3.3.1 Enzymes involved in metabolism of disinfection by-products.

Several types of metabolic processes are involved in the toxicology of disinfection by-products. However, a broad class of enzymes, glutathione-S-transferases, have been implicated in the toxicities of the trihalomethanes, the haloacetic acids, and the haloacetonitriles. In the case of the THMs, the theta isoform appears to be capable of producing a mutagenic metabolite (Pegram et al., 1997). This isoform is not expressed by approximately 40% of the U.S. population. Therefore, the sensitive population may be only 60% of the human population. Conversely, evidence has been gathered that demonstrates that a new glutathione-S-transferase, the zeta isoform, acts to detoxify dichloroacetic acid (Tong and Anders, 1998). If there is a significant fraction of the population that did not express this enzyme, that fraction of the population could be extremely sensitive to this disinfection by-product.

3.3.2 Susceptibility to effects of DBPs

Other host-related factors that could be the basis for higher sensitivity of humans to disinfection by-products are more difficult to identify, but may be more important than variations in enzymes involved in the metabolism of DBPs. Broad examples can be provided, however. If a disinfection by-product acts through damaging DNA, lack of the enzymes that recognize and repair those lesions could make an individual much more sensitive. Some disinfection by-products (e.g. the haloacetic acids) appear to act by interfering with cellular signaling systems that are activated by insulin and related growth factors. Diabetics are much more prone to the development of liver cancer than the rest of the population. Consequently, if epidemiological studies had focused on this subpopulation, a risk of liver cancer may have been identified.

3.4 Summary

From the health effects standpoint, there are issues that surround bromide and brominated by-products that can be resolved in the next 5-10 years, but others that will require decades to solve. Properly directed toxicological screening studies and mechanistic studies could provide much better perspective on the actual risks associated with disinfection by-products in the shorter time frame. Without specific and detailed knowledge of the mechanisms by which disinfection by-product toxicity is induced, it is very difficult to identify those variables that would affect the distribution of human sensitivities to these chemicals that could be applied in a meaningful way in epidemiological studies.

The importance of establishing the mode of action by which chemicals induce toxicity, particularly in carcinogenesis, cannot be overstated. Nowhere is this more apparent than when considering the potential differences in risk that may exist between chlorinated and brominated by-products. Clearly, these molecules will share some aspect of their mechanism of action. As bromine substitution increases, however, multiple mechanisms are likely to become apparent. The non-genotoxic mechanism found with the corresponding chlorinated DBP will undoubtedly still be represented, but the brominated analogs are significantly more likely to add mechanisms of carcinogenesis involving mutagenesis. Thus, not only will the mechanisms contributing to the adverse response become more diverse, but they will also require linear extrapolation. In some cases, the mechanism responsible for the effect induced by the chlorinated analogs may actually disappear as the degree of bromine substitution increases. The permission from one mechanism to another could lead to some complex structure-activity relationships that might have to be resolved before the relative impact at concentrations found in drinking water can be estimated with confidence.

4.0 Regulatory Background

The purpose of this section is to provide a perspective on possible regulatory criteria that may influence treatment and associated cost impacts on public drinking water drinking systems using the Bay-Delta as their source water.

4.1 Overview of 1996 SDWA Amendments as they Pertain to DBPs/Microbes

In 1996, Congress issued amendments to the Safe Drinking Water Act requiring EPA to develop regulations within a specified time. These include promulgation of the Interim Enhanced Surface Water Treatment Rule (IESWTR) and Stage 1 Disinfectants and Disinfection By-Products Rule (DBPR1) by November 1998, a Long Term Enhanced Surface Water Treatment Rule (LT1ESWTR) by November 2000, and a Stage 2 Disinfectants and Disinfection By-Products Rule (DBPR2) by May 2002. As part of the 1996 amendments, Congress also requires EPA to consider risk from contaminants that might be indirectly affected by regulation. In this regard, EPA intends to propose and promulgate a Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) concurrently with the DBPR2.

4.2 Overview of DBPR1/IESWTR/LT1ESWTR

The purpose of the DBPR1 is to reduce risks from disinfectants and DBPs in public water systems which disinfect. Unlike the Maximum Contaminant Level (MCL) of 100 ug/l for total trihalomethanes (TTHMs), which only pertains to systems serving 10,000 people or more, the DBPR1 will apply to all system sizes. The purpose of the IESWTR is to reduce risks from pathogens, especially *Cryptosporidium*, and to prevent increases in microbial risk while systems comply with the DBPR1. With the exception of sanitary survey requirements (which will pertain to all system sizes), the IESWTR will pertain to systems serving 10,000 or more people. In November 1997, EPA issued two Notices of Data Availability in the Federal Register indicating the rationale supporting the criteria intended for promulgation in the DBPR1 and the IESWTR.

Criteria under consideration for the final DBPR1 include: (i) MCLs for TTHMs (0.080 mg/L = 80 ug/L), the sum total of 5 haloacetic acid concentrations otherwise known as HAA_5 (0.060 mg/L = 60 ug/L), bromate/BrO_3^- (0.01 mg/L = 10 ug/L), and chlorite/ClO_2^- (1.0 mg/L = 1,000 ug/L); (ii) maximum residual disinfectant levels for chlorine (4.0 mg/L), chloramines (4.0 mg/L), and chlorine dioxide (0.8 mg/L); and (iii) enhanced coagulation requirements for systems using conventional treatment or softening to remove DBP precursors (measured as percent reductions of total organic carbon (TOC)).

Criteria under consideration for the final IESWTR include: (i) tightening the combined filter turbidity performance criteria for systems using rapid sand filtration to less than 0.3 NTU in at least 95% of turbidity measurements taken each month; (ii) continuous turbidity monitoring requirements for individual filters and reporting of results to States depending upon individual filter performance; (iii) a provision that would not allow systems to lower existing levels of inactivation to comply with the Stage 1 DBPR MCLs without first consulting with the responsible State officials; and (iv) provisions that would require the responsible State agencies to conduct sanitary surveys of all surface water systems (including those serving <10,000 persons), and for systems to implement remedial action if problems are identified by State agencies. A sanitary survey incorporates not only an inspection of the treatment plant, but examination of a wider range of factors that influence the quality of drinking water, including the watershed and the distribution and storage system.

EPA envisions similar requirements to the IESWTR being issued for systems serving fewer than 10,000 persons in the LT1ESWTR scheduled for proposal in November 1999, and for promulgation in November 2000.

EPA intends to set compliance dates for the DBPR1 that will coincide with compliance dates for the IESWTR (November 2001 for systems serving 10,000 or more people) and the LT1ESWTR (November 2003 for systems serving less than 10,000 people).

EPA is planning to conduct stakeholder meetings beginning in December 1998 to discuss information and the process to support the development of the DBPR2 and LT2ESWTR. Major issues related to these rules are discussed below.

4.3 DBPR2 Issues

Major issues with developing the DBPR2 include: interpretation of cancer, developmental, and reproductive risk associated with DBPs from limited toxicological and epidemiological data; assessing the feasibility and costs of using various treatment technologies to reduce DBP concentration levels; and assessing the potential changes in microbial risk that might result from treatment changes to control for DBPs. Addressing the above issues will help determine the extent to which additional regulation may be appropriate such as whether to set

MCLs for DBP groups, individual DBPs, or treatment technique requirements (e.g., limits for total organic halides (TOX), or TOC removal requirements). Another issue may be whether MCLs should be set based on a running annual average as is currently the case, or on maximum single event concentration levels. MCLs based on maximum values within a distribution system would prevent all people from being exposed above a certain level. Such a strategy could become important if developmental or reproductive effects from exposure to DBPs are determined to be of concern.

Several specific issues relative to the broad generic issues discussed above may have particular significance for utilities using the Bay Delta as their source water. These include: (i) the risk associated with brominated DBP species versus the risks from the complete mixture of chlorinated DBPs; and (ii) if the risks from brominated species are deemed substantially more significant than those from the chlorinated species, the extent to which brominated species formed primarily through chlorination (e.g., bromodichloromethane or bromochloroacetic acid) or ozonation (e.g., bromate) can be controlled.

The setting of any new MCLs or treatment technique requirements will consider potential exposures (and associated risks) able to be avoided, and the technical feasibility and costs for reducing exposures on a national level. In considering this type of analysis, it becomes important to understand the national distribution of source water quality parameters (e.g., bromide, TOC, UVA_{254}) that most significantly affect the treatability of the water. Systems using the Bay-Delta as their source water (primarily because of the high bromide content), may have greater difficulty than the average utility in the U.S. in meeting a particular regulatory endpoint; another important consideration is the character of the TOC in Bay-Delta water. This regional consideration is also relevant to the national standard-setting provision that treatment must be affordable for large systems. The significance of this issue may also be largely influenced by the co-occurrence of pathogens (particularly *Cryptosporidium*) and DBP precursors. Depending upon the requirements of the LT2ESWTR, the level of inactivation required to control microbial risks could make it more difficult for systems to comply with the DBPR2 criteria. For example, a system with high levels of *Cryptosporidium* and DBP precursors (bromide and TOC) in their source water may have greater difficulty in complying with the DBPR2 and LT2ESWTR than systems with average source water quality. Each rule will have to consider and appropriately address the factors of affordability and availability of treatment raised by compliance with the other rule

4.4 LT2ESWTR Issues

Major issues with developing the LT2ESWTR include: estimating the microbial risk likely to remain after implementation of the IESWTR and LT1ESWTR, given limitations of data; determining appropriate risk goals (e.g., EPA's 1994 proposed 10^{-4} annual risk goal for *Giardia* or *Cryptosporidium*), and determining the appropriate regulatory framework and target organism(s). Several regulatory frameworks were considered under the 1994 proposed IESWTR and are likely to be revisited under the development of the LT2ESWTR. These include: a proportional treatment requirement, (where systems might be required to achieve at all times a minimum level of total removal/inactivation for *Cryptosporidium*, depending upon an estimated reasonable worst case pathogen occurrence in the source water); and a fixed level treatment requirement (where all systems would be required to achieve at least the same minimum level of treatment, with exceptions allowed, depending upon site specific characteristics)

Major constraints with developing the IESWTR included: lack of available methods for adequately measuring *Giardia* or *Cryptosporidium* in the source water, and limitations by which treatment efficiencies (physical removal and chemical inactivation) for these organisms could be practically determined. The extent to which these issues can be resolved may largely influence criteria to be included in the LT2ESWTR.

Although LT2ESWTR criteria will not become apparent for quite some time, factors which could significantly influence the impact of this rule on a particular utility include the magnitude and variability of *Cryptosporidium* in the source water, physical removal efficiencies for *Cryptosporidium*, and the feasibility of inactivating *Cryptosporidium* while also meeting new regulations for DBPs (as discussed above under DBPR2 issues). Systems with low pathogen loadings in their source water and/or high physical removal efficiencies are likely to be less affected by any inactivation requirements that might be specified for *Cryptosporidium*.

4.5 Recommendation

The CALFED program should strive to deliver the highest possible raw-water quality to the sources used for drinking water supply. This effort will minimize treatment costs and the threat to public health from drinking water.

5.0 Treatment Considerations

5.1 Overview of Treatment Considerations

A variety of treatment technologies are available for the disinfection of water. A number of these (e.g. chlorination, ozonation) produce potentially harmful disinfection by-products (e.g. trihalomethanes, haloacetic acids, bromate). The incorporation of bromine into these disinfection by-products increases as the bromide concentration in the water being treated increases. For example, the speciation of THMs shifts away from chloroform and toward bromodichloromethane, dibromochloromethane, and bromoform, respectively, as the concentration of bromide increases. Likewise, the speciation of haloacetic acids shifts away from di- and trichloroacetic acid towards bromochloroacetic acid and bromodichloroacetic acid, respectively, with increasing bromide concentrations. In the case of ozonation, bromate formation increases with increasing bromide concentrations. If disinfection requirements become more stringent with future regulations, greater concentrations of disinfectants may need to be applied, resulting in greater concentrations of disinfection by-products unless there is a shift toward higher quality source water or greater degrees of pretreatment prior to disinfection.

To control the formation of these potentially harmful disinfection by-products, several treatment strategies can be employed.

(a) removal of the organic precursors with which the disinfectant reacts prior to the application of the disinfectant;
(b) removal of the bromide prior to disinfection;
(c) removal of the disinfection by-products after they are formed;
(d) modification of treatment conditions to limit the formation of specific DBPs; or
(e) use of alternative disinfectants which do not produce DBPs of health concern.

Processes that can be used for the removal of organic precursors (TOC) include enhanced coagulation, granular activated carbon adsorption (GAC), membrane filtration, and chemical oxidation coupled with biofiltration. The only practical process that has been demonstrated to be applicable for the removal of bromide is membrane treatment (i.e. reverse osmosis, and to a lesser extent nanofiltration). The removal of disinfection by-products after they are formed is difficult, primarily because of the wide array of DBPs with their very different physical-chemical properties. An exception is bromate, where several technologies have been examined for its removal. Treatment conditions which can be modified to minimize bromate include decreasing the pH of ozonation to lower the formation of bromate. Disinfectant options include the use of ozone, chloramines, chlorine dioxide, ultraviolet (UV) irradiation, and membrane filtration to partially or fully offset the use of free chlorine.

5.2 Disinfection Practice

The most common chemical disinfectants for the treatment of drinking water are chlorine, ozone and chlorine dioxide. All are capable of inactivating viruses and *Giardia* cysts, at reasonable doses and contact times, in accordance with specifications of the Surface Water Treatment Rule. However, the LT2ESWTR may require greater removal and/or inactivation of Cryptosporidium oocysts. Ozone, and to a lesser extent, chlorine dioxide, appear to be the only chemical disinfectants capable of inactivating Cryptosporidium oocysts, although disinfectant combinations (e.g. free chlorine and chloramines) have been reported to be moderately effective as well. Because of this relationship, the waterworks industry has been moving toward ozonation in place of chlorination for primary disinfection, and many utilities in California that use Delta water have adopted ozonation for primary disinfection and for taste and odor control; ozone is also one of the more effective agents, along with activated carbon, for removing taste and odor-causing organic substances from water. Depending upon criteria developed under the LT2ESWTR, many more utilities may consider ozonation. A major limitation to more widespread practice of ozonation, however, is the fact that ozonation of bromide-containing waters produces bromate. A number of water systems that currently ozonate Delta water experience levels of bromate in excess of the proposed Stage 1 maximum contaminant level for bromate at certain times of the year and many are investigating techniques to limit bromate formation or to remove bromate after it is formed.

Other non-chemical or physical options for achieving the *Giardia* and virus removal/inactivation requirements of the Surface Water Treatment Rule and possible Cryptosporidium removal/inactivation requirements include UV-disinfection and membrane filtration. UV-disinfection for cyst inactivation has yet to be demonstrated on a practical, full-scale level, but a number of promising new technologies are under development. The next several years will determine whether or not these new technologies will be practical, and the type of pre-treatment requirements that will be necessary to allow them to function effectively. In contrast, microfiltration has already been demonstrated to be an effective technology for the "absolute" removal of *Giardia* cysts and Cryptosporidium oocysts. Microfiltration will not remove viruses, but tighter membranes, such as nanofiltration or ultrafiltration membranes, can be employed for this purpose. Alternatively, post-treatment of micro-filtered water with free chlorine for only a short contact time can achieve virus inactivation, but in some cases, excessive levels of halogenated disinfection by-products can still be formed, especially in bromide-enriched waters. Two major limitations of membrane filtration processes, particularly nanofiltration and ultrafiltration, are their relatively high costs compared to the more conventional processes, and the fact that they have a product recovery of only about 80% (somewhat greater for ultrafiltration); i.e. a significant amount of the influent water must be wasted, a particularly troublesome limitation for a water-short region like California.

5.3 Removal of Bromide

Bromide occurs as a dissolved species in water and cannot be readily removed by precipitation. It is also not readily removed by coagulation and associated solid-liquid separation processes and tends to pass conservatively through conventional treatment processes. It can be removed by ion exchange, but most resins available today are not very selective for bromide and therefore the process is not very practical for this application. The only processes available at this time for the removal of bromide are reverse osmosis and nanofiltration; bromide rejections of about 90 % and 50 % have been reported, respectively, for these membrane processes. These membrane processes, however, are the most costly of the membrane processes, require the use of conventional treatment (coagulation, clarification, filtration) prior to their use, and have the lowest recovery, making them relatively impractical for applications in California

5.4 Removal of Organic Precursors

The most widely studied and demonstrated approach for controlling the formation of disinfection by-products is removal of the organic precursors prior to disinfectant addition. The rationale is that, with lower levels of precursors in the water, the disinfectant demand of the water decreases and lower doses of disinfectants can be applied to achieve the desired level of disinfection, thereby lowering the formation of DBP's. In order of increasing cost and effectiveness, the most viable processes are enhanced coagulation, granular activated carbon adsorption, and membrane filtration. The success of these processes depends significantly upon the nature of the organic material in the water, i.e. whether it is hydrophobic or hydrophilic organic material. Generally, the organic material is characterized in terms of its total organic carbon (TOC) concentration, its ultraviolet (UV) absorbance at 254 nm, or a composite of the two parameters, its specific UV absorbance (SUVA).

Enhanced coagulation involves adding sufficient amounts of coagulant, often more than is typically used for turbidity (particle) removal, to achieve specific TOC removal requirements specified in the proposed Disinfectants/Disinfection By-Products Rule. Given the typical alkalinity and TOC concentration of Delta water, these requirements range from 15 to 40%. SUVA values at exports points are generally in the range of 3 to 4 m^{-1}/(mg C/L). These values indicate that the water likely contains a mixture of non-polar and higher MW versus and polar and lower MW NOM. The water is moderately amenable to coagulation and GAC; membranes would provide the most effective NOM removal. Limitations of practicing enhanced coagulation on Delta water are: the relatively large doses of coagulant required to remove the organic DBP precursors; the corresponding larger amount of sludge that is generated and must be disposed of; the possible need for relatively large amounts of acid to lower the pH in this relatively high alkalinity water to a level where coagulation of organic material is more effective; and the corresponding need for high levels of base to be added to bring the pH back up to acceptable distribution system levels for corrosion control. It should be noted that enhanced coagulation will not remove bromide from the water.

The effectiveness of granular activated carbon (GAC) adsorption for removal of DBP precursors depends upon the empty bed contact time (EBCT) of the carbon bed. Typically, EBCT's in excess of 15-20 minutes are needed for this particular objective. GAC can be used either in a filter-adsorber mode, in which the GAC is added to the conventional filter bed in place of the anthracite and/or sand media, or in a post-filter adsorber, in which a separate GAC adsorption bed is installed. The former approach, because of the relatively low EBCT's in conventional filter beds (5-10 min), is not very effective for precursor removal. Post-filter adsorbers can be designed and operated at any target EBCT, but the cost increases with increasing EBCT. Additionally, the GAC must be regenerated when its adsorptive capacity is reached. The frequency of regeneration ranges from about 3 to 6 months, depending upon the TOC concentration of the water. The cost of GAC increases with increasing frequency of regeneration. GAC will not remove bromide from the water.

A variety of membrane processes are available for water treatment practice, including, in order of increasing relative cost, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). The effectiveness of these processes for the removal of organic precursors depends on the size of the pores of the membranes, or more precisely, their molecular weight cutoff (MWCO). MWCO's of 200-500 Daltons are required for effective TOC removal, indicating that NF or RO must be used, although some modest removal can be realized with UF. While microfiltration is effective for the removal of particulate material (e.g. protozoan cysts), it is not fine enough for the removal of TOC, although it can be combined with some powdered activated carbon or coagulant addition to achieve some modest levels of TOC removal. Membrane elements that come in a spiral wound as opposed to a hollow fiber configuration (RO, most NF, some UF) require a substantial degree of pre-treatment to remove particulate material that can cause membrane fouling problems. As noted above, these processes have recoveries on the order of 80% (somewhat higher for NF and UF), making them of dubious practicality for a water-short region like California. Also, as noted above, only reverse osmosis has the ability to reject (remove) bromide.

A number of the larger utilities in California, some of which use Delta water, are currently running bench-scale and pilot-scale studies of GAC adsorption and membrane filtration as part of the EPA's Information Collection Rule to evaluate the effectiveness of these processes for TOC removal and DBP control.

The fact that the majority of these TOC removal processes do not remove bromide means that the bromide/TOC ratio will increase after treatment. As a result, although overall formation of DBPs will be reduced because of the reduced disinfectant requirements, the speciation of the DBPs will shift toward the bromine-containing species such as bromodichloromethane, bromochloroacetic acid, and bromodichloroacetic acid.

One additional treatment approach for removing organic DBP precursors is chemical oxidation and biofiltration. Ozone or advanced oxidation processes involving some combination of ozone, hydrogen peroxide, and UV irradiation, can be employed for this purpose. While these processes do not reduce the TOC concentration appreciably, i.e. they do not convert much of the organic carbon to carbon dioxide, they do alter the nature of the organic material. The oxidation by-products, consisting of aldehydes, organic acids, and other lower molecular weight more oxygenated compounds, are generally more biodegradable than the parent material. Passage of the oxidized water through a biologically acclimatized bed of filter media, e.g. granular activated carbon, anthracite, and/or sand, results in the biological removal of many of these by-products, producing a water with a lower DBP formation potential than the untreated water. Many of the water systems currently using ozone to treat Delta water also employ biological filtration. The effluent from the filters, however, must be treated with a disinfectant such as free chlorine or UV irradiation to inactivate heterotrophic bacteria that are sheared off the filter media. If free chlorine is used for this purpose and the residual precursor concentration in the filter effluent is still significant, appreciable concentrations of DBPs can still be produced, even if the chlorination contact time is relatively short, i.e. on the order of 15 min. This is because the kinetics of DBP formation are more rapid in the presence of bromide. Oxidation coupled with biofiltration is effective only when the water temperature is reasonably warm, e.g. above 10°C. During colder temperatures, the kinetics of microbial degradation are much slower and biofiltration is not as effective. Additionally, if the raw water contains bromide and ozone is the oxidant, bromate formation will occur. Biodegradation of bromate does not occur, except under anoxic conditions which are typically not desirable in water treatment.

5.5. Removal of DBPs

A number of the halogenated organic disinfection by-products produced from chlorination can be removed from the treated water after they have been formed. The trihalomethanes are volatile compounds, i.e. they have low vapor pressures, and can be removed by air stripping. The effectiveness of stripping decreases in the order chloroform, bromodichloromethane, dibromochloromethane, bromoform. These, however, are the only volatile species among the halogenated DBPs and therefore the only ones that can be removed by air stripping. A number of the haloacetic acids have been shown to be biodegradable under aerobic conditions and, accordingly, can be removed by passing, for example, pre-chlorinated water through a biologically active filter bed. The trihalomethanes, however, are biologically stable under aerobic conditions. They can be biodegraded anaerobically, but anoxic treatment is undesirable in water treatment. The haloacetonitriles have been shown to be unstable under elevated pH conditions, undergoing alkaline hydrolysis. Such conditions, however, promote THM formation. The DBP species all have different physical, chemical, and biological properties, hence there is no single treatment process that can be employed to remove them all. Removal of the halogenated organic DBPs after they are formed is therefore not practical; it is a more prudent strategy to try to control their formation by the techniques described above.

Bromate removal, however, may be an effective treatment strategy for controlling bromate levels following its formation by ozonation. Three strategies have been suggested: the use of ferrous iron salts, granular activated carbon adsorption, or UV irradiation. Ferrous iron can chemically reduce bromate to bromide; a ferric hydroxide precipitate is produced that must be removed by subsequent clarification and filtration processes. Hence, such treatment must occur early in the treatment train. pH control is critical to prevent the added ferrous iron from being initially oxidized by dissolved oxygen in the water, although eventual oxidation to ferric hydroxide allows it to function as an iron coagulant. Granular activated carbon can adsorb bromate, but its capacity for doing so is limited, leading to short effective lifetimes for this application of GAC. UV irradiation decomposes BrO_3^- to Br^-, with medium-pressure lamps being more effective than low-pressure lamps. RO and NF membranes can also remove BrO_3^-, but suffer from the same limitation described for Br^- removal. Of these processes, bromate reduction by ferrous iron appears to be most attractive, but more research and demonstration of this technique needs to be conducted before it can be reliably implemented on a full-scale basis.

5.6 Control of Bromate Formation

A final option for controlling bromate levels in finished drinking water is to minimize its formation in the first place. For example, the extent of bromate formation increases with increasing pH. Hence, pH adjustment to values below 6.5-7.0 prior to ozonation can reduce the formation of bromate. However, as in the case of enhanced coagulation, pH depression requires significant the addition of acid to high-alkalinity waters (Delta water exhibit medium-levels of alkalinity). Additionally, it has been demonstrated that splitting the application of ozone between several of the stages in a multi-stage ozone contactor produces lower levels of bromate than if all of the ozone is applied in the first stage. The judicious use of hydrogen peroxide and ammonia have also been shown to be potentially effective methods for limiting the formation of bromate. Whether or not such modifications can maintain bromate levels below the proposed and potential future MCLs for bromate in waters with elevated bromide levels such as those found in the Delta remains to be demonstrated. Most work to date has focused on the 10 ug/L proposed standard; the efficacy of bromate minimization approaches for a significantly lower MCL has not been studied.

5.7 Matching Treatment to Regulatory Options for Various Source Water Qualities

The national average of Br^- in drinking water sources is significantly less than 100 ug/L. Water exported from the Delta and intended for drinking water has Br^- at levels that are at least the 90th percentile on a national basis. It is noteworthy that BrO_3^- is 63 % Br by weight; this suggests that exceeding the 10 ug/L MCL for BrO_3^- requires only 6.3 ug/L of incorporated Br^-. Br^- is efficiently converted into THM and HAA species, with THM-Br ≈ 20 % and HAA_9-Br ≈ 10%.

One general approach to examining treatment options to meet various future regulatory objectives is to determine source water quality characteristics in terms of bromide and TOC concentrations that would allow Delta water users to meet these regulations using existing or future water treatment technologies. DBP prediction models; e.g., BrO_3^- = f(Br^-, etc.) or TTHM

= f(Br^-, etc.); can be used to predict a *limiting* value of Br^-; e.g., Br^-_{LIMIT} = f ($(BrO_3^-)_{MCL}$) or Br^-_{LIMIT} = f($TTHM_{MCL}$); to meet a MCL under a given set of water quality (e.g., temperature or pH) and treatment (e.g., O_3 or Cl_2 dose) conditions. Such an exercise was performed by Owen et al. (1998) in assessing potential compliance of Delta water to Stage 1 MCLs for TTHM, HAA_5, and BrO_3^- as well as SWTR disinfection requirements by considering coagulation, ozonation, GAC, and membranes. Their conclusion was that TOC and Br^- would be contrained to < 3 mg/L and < 50 ug/L, respectively, for utilities incorporating either enhanced coagulation or ozone disinfection; < 5 mg/L and < 50 –100 ug/L for GAC; and < 7 mg/L and < 300 ug/L for (NF) membranes. While Br^- and TOC are inter-related, it is Br^- that is the limiting factor; since the analysis by Owen et al. (1998) did not consider low-pH ozonation, it would be reasonable to stipulate an upper Br^- constraint of 100 ug/L for present SWP treatment practice (conventional treatment with movement toward implementing ozonation and enhanced coagulation). The most flexible treatment approach is membrane treatment, but brine disposal and associated water loss (up to 20 %), as well as cost are serious constraints. It is noteworthy that the models used by Owen et al. (1998) have limitations: the BrO_3^- model used is only applicable to pre-O_3 and the Cl_2 models used do not account for HAA formation nor the reduction in NOM reactivity with treatment.

Krasner (CALFED, 1998) performed bench-scale tests of "synthetic" Delta water (agricultural-drain water diluted with Milli-Q water and spiked with Br^-) under SDS-chlorination conditions (target Cl_2 residual of 0.5 – 1.5 mg/L, incubation time of 3 hours, pH 8.2, 25°C) and bromate formation potential conditions (O_3/TOC = 2 mg/mg, pH 8.0, 20 °C). These results are summarized in Tables 2 and 3, portraying potential Br^- and/or TOC constraints to chlorination and ozonation.

5.8 Summary

Table 4 summarizes the various treatment technologies and their relevance to disinfection and disinfection by-product control in Delta water.

Based on the previous summary, Table 5 matches potential approaches for the treatment of Delta water to meet various possible regulatory options. The approaches may depend significantly on the bromide, organic carbon content, and the level of fecal contamination in the Delta water.

Table 2. SDS-THM Results Portraying Potential Br^- and TOC Constraints.

Br^- (ug/L)	TOC (mg/L)				
	1.1	1.4	2.0	3.3	4.2
<10	24	31	38	64	78
100	43	51	60	80	91
200	60	75	83	103	113
400	75	113	128	142	159
800	88	137	182	241	243

Table 3. BrO_3^- (ug/L) Formations Results Portraying Potential Br^- and TOC Constraints.

Br^- (ug/L)	TOC (mg/L)				
	1.2	1.6	2.2	2.9	3.7
<10	<3	<3	4	<3	7
100	6	7	11	12	19
200	11	12	19	25	27
400 - 500	25	23	36	39	49
700 - 900	29	40	53	57	65

Table 4. Matrix of Treatment Processes: Advantages, Disadvantages, Additional Considerations, and Costs.

PROCESS	ADVANTAGES	DISADVANTAGES	ADDITIONAL CONSIDERATIONS	RELATIVE COST*
Chlorination	Effective primary disinfectant for *Giardia*, viruses; good secondary disinfectant	Produces halogenated DBPs (THMs, HAAs); ineffective for inactivation of Cryptosporidium	May be effective for Cryptosporidium inactivation when coupled with chloramines	+
Ozonation	Most effective chemical disinfectant for Cryptosporidium; does not produce chlorinated organic DBPs; can be coupled with biofiltration to limit formation of overall organic DBP formation	Produces bromate; can produce brominated organic DBPs; primary disinfectant only; must be coupled with secondary disinfectant such as chlorine or chloramine	Bromate formation can be controlled to some degree by pH adjustment, method of ozone addition; bromate removal possible but requires study	++
Chloramination	Does not produce appreciable THMs or HAAs; good secondary disinfectant for distribution system	Poor primary disinfectant, must be used with free chlorine or ozone as primary disinfectant; does produce unidentified halogenated organic material (TOX) but at lower levels than free chlorine		+
Chlorine Dioxide	Effective primary disinfectant for *Giardia*, viruses; does not produce halogenated DBPs; also inactivates Crypto but not as effectively as ozone	By-product chlorite exhibits acute toxicity; proposed MCL for chlorite of 1.0 mg/L limits use	Chlorite removal may be possible but requires study	+
UV Irradiation	Effective primary disinfectant for viruses; new emerging UV technologies for inactivation of cysts, but not yet demonstrated; does not produce DBPs	Requires use of secondary disinfectant for distribution system	Emerging new UV technologies being evaluated/demonstrated on plant-scale	+-

Enhanced Coagulation	Useful for removal of organic DBP precursors	TOC in Delta water not very amenable to coagulation; does not remove bromide		+
Granular Activated Carbon Adsorption	Useful for removal of organic DBP precursors	Requires EBCT in excess of 15-20 min, does not remove bromide; limited usefulness for bromate removal	Requires regeneration at 3-6 mos. frequency	++
Microfiltration	Effective for *Giardia*, Cryptosporidium cyst removal	Ineffective for virus removal but can be coupled with post-chlorination for virus inactivation; ineffective for TOC removal but can be coupled with powdered carbon or coagulant for partial TOC removal; will not remove bromide; waste stream needs to be disposed of	Membrane process technology undergoing rapid changes, becoming more practical and less expensive	+++
Nanofiltration And Ultrafiltration	Effective for *Giardia*, Cryptosporidium cyst removal and virus removal; NF effective for TOC removal at MWCO less than 200-500 Daltons; NF provides some bromide removal	UF will not remove bromide; requires pre-treatment to prevent membrane fouling; relatively low product recovery; waste stream needs to be disposed of	Membrane process technology undergoing rapid changes, becoming more practical and less expensive	++++
Reverse Osmosis	Effective for *Giardia*, Cryptosporidium cyst removal and virus removal; effective for removal of TOC and bromide	Requires pre-treatment to prevent membrane fouling; relatively low product recovery; waste stream needs to be disposed of	Membrane process technology undergoing rapid changes, becoming more practical and less expensive	+++++

* Relative costs are indicated by number of + entries

Table 5. Possible Treatment Options for Meeting Proposed or Future Rules.

PROPOSED OR FUTURE RULE	POSSIBLE TREATMENT OPTIONS
Interim Enhanced Surface Water Treatment Rule	No change in disinfection practice
LT2ESWTR	Treatment may depend on level of fecal contamination in source water; Ozonation; Chlorine Dioxide, Microfiltration; Possibly Emerging UV Disinfection
Stage 1 D/DBP Rule, with 10 ug/L bromate MCL	Chlorination with secondary chloramination; ozonation with/without biofiltration coupled with secondary chloramination with need for bromate control
Stage 2 D/DBP Rule (as proposed in 1994), with 5 ug/l bromate MCL. Stage 2 will be reproposed and these criteria may differ significantly from 1994 proposed criteria. .	Ozonation with/without biofiltration coupled with secondary chloramination with need for bromate control; nanofiltration with post-chloramination; microfiltration with chlorine and chloramines; and possibly emerging UV disinfection with post-chloramination

In summary, treatment processes are available to treat Delta water that will produce safe drinking water and minimize the risks to public health, although treatment costs may significantly increase with implementation of advanced treatment.

6.0 Treatment versus Source Control

General source control options for Br^- are largely limited to segregation of Delta water intended for export from saltwater intrusion. Another course of action is represented by storage intended to dampen seasonal variations in Br^-. Of course, within this general approach are many specific options that are largely embodied within the CALFED alternatives. Source control options for NOM include (on-site) treatment or diversion of agricultural drainage (or modified drainage practices) and algae control.

Even with selection of a CALFED alternative, there will still need to be a short-term strategy for utilities to meet Stage 1 and Stage 2 DBP regulations before alternative implementation. Much will depend on differences between the Stage 1 versus Stage 2 MCLs, and the Cryptosporidium-based disinfection requirements that will evolve through the ESWTR. During this same time period, additional health effects data will be forthcoming on HAA species and BrO_3^-, which may lead to either a relaxation or further restriction of current MCLs.

Enhanced coagulation, low-pH ozonation, and optimal use of multiple disinfectants will likely be the minimum technology required. Given that ozonation presently appears to be the only viable inactivation option for Cryptosporidium, it is likely that ozone use will continue to increase. Finally, there are exciting new developments in membrane and UV technology that may play a role in Delta-water treatment in the area of selective membranes (e.g., UF) that are less prone to fouling, capable of physical removal of microbes, and provide high (> 90 %) water recoveries.

7.0 Recommendations and Research Needs

7.1 Recommendations

The Cal-Fed program must examine issues as they are likely to develop over a 20 to 30 year horizon. The problems in the Delta are immense and will require a very large reliance on research that involves many disciplines. Short-term decisions will have to be geared toward meeting regulations that should be largely anticipated from stage II of the M/DBP rule. However, as the program develops its research agenda, its short-term research agenda must be consistent with providing more definition for decisions that impact water quality 20 to 30 years from now.

It is recommended that CALFED articulate a clear, short-term plan, comprised of both treatment and source control approaches, to deal with bromide-related drinking water issues before and during implementation of the various CALFED alternatives. It is not the charge of the expert panel to make an unqualified recommendation to CALFED on an alternative; however, considering *only* drinking water quality, it is clear that Alternative 3 would provide the most benefit with regard to the beneficial use of Delta water for drinking water supply, although Alternative 2 would provide more benefit at certain export points (e.g., CCC). Other hydraulic management options not included in the three Alternatives might also provide improvement in source water quality over that currently obtainable from the Delta. While it is not in the charge of this panel to identify such options, CALFED may wish to develop and consider such options within the phased process now under consideration for the CALFED long-term plan.

7.2 Research Needs

The panel recommends that a) CALFED follow and promote important health effects research that is ongoing/planned to focus on brominated DBPs, b) source-specific (e.g., SWP) DBP models be developed to assess various treatment and source control options, and c) given the importance of NOM, a NOM inventory of Delta water be performed to elucidate the spatial and seasonal distribution of NOM, both amount (TOC) and properties (e.g., UVA_{254}, DBP formation potential), followed by development of a model to predict TOC concentrations throughout the Delta.

Given that co-occurrence of pathogens and DBP precursors may significantly influence the feasibility of simultaneously controlling for both DBPs and pathogens under future drinking water regulations, the panel also recommends that CALFED a) obtain information indicating the level and variability of fecal contamination (including measurement of *Cryptosporidium* and *Giardia* [using best available methods] and *E. coli*) in source waters, b) obtain information on the co-occurrence of bromide, TOC, UVA_{254}, and microbes in source waters, and c) determine the extent to which pathogens and DBP precursors can feasibly be reduced in source waters of utilities.

Given the potential for membrane technology, it is recommended that NF and UF membrane processes be assessed for their collective ability to remove Br^-, TOC, and microbes from Delta water. Given the potential constraint of bromate formation, CalFed should evaluate BrO_3^- control strategies to meet a range of potentially more restrictive MCLs.

CALFED should resolve the concern regarding whether or not (or how much of) "recycled bromide from agricultural return drains is actually "recycled" or is from agricultural fumigation activities using methyl bromide.

CALFED should encourage and cooperate with epidemiological investigations of cancer, reproductive and developmental toxicities that may be associated with disinfectant by-products. This cooperation should focus on adding bromide to established studies that have been conducted on a national scale rather than trying to initiate new epidemiological studies that focus only on the Bay-Delta area. It is important to pursue reproductive and developmental toxicity issues as well as carcinogenic effects of disinfectant by-products in any research program. The low-dose carcinogenic risk of bromate is a critical issue if bromide-containing waters are to be ozonated. Investment in careful studies of the type that have been done for chloroform, dichloroacetate and trichloroacetate, but following hypotheses more appropriate for bromate induced tumorigenesis, could possibly raise the MCL.

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APPENDIX F

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