Salinity and Selenium Control Actions

CALFED Water Quality Program

Water Quality Technical Group

Final Report

By

Salinity and Selenium Team

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Salinity and Selenium Team Members

Name	Affiliation	Phone	E-mail
Manucher Alemi*	DWR/SJVDIP	(916) 327-1630	malemi@water.ca.gov
Elaine Archibald	Urban/AG	(916) 736-3713	awconsult@aol.com
Vashek Cervinka	DWR	(530) 759-0974	cervinka@dcn.davis.ca.us
Kevin Donhoff	MWDSC	(213) 217-6359	kdonhoff@mwd.dst.ca.us
Russ Grimes	USBR	(209) 487-5050	rgrimes@mp.usbr.gov
Les Grober	CVRWQCB	(916) 255-3105	lgrober@davis.com
Alex Hildebrand	SDWA	(209) 823-4166	hildfarm@gte.net
Bill Johnston	Modesto ID	(209) 526-7384	billj@mid.org
Gail Louis	EPA	(415) 744-2019	louis.gail@epamail.epa.gov
Don Marciochi	DWD	(209) 826-5188	DKwasny@aol.com
Tom Maurer	USFWS	(916) 979-2110	thomas_maurer@mail.fws.gov
Joe McGahan	GAF	(209) 582-9237	jmcgahan@cnetech.com
Eugenia McNaughton, EPA		(415) 744-1162	mcnaughton.eugenia@epamail.epa.gov
Nigel Quinn	LBL	(510) 486-7056	nquinn@mp.usbr.gov
Steve Shaffer	CDFA	(916) 653-5658	SShaffer@smtp1.cdfa.ca.gov
K.T. Shum	CCWD	(925) 688-8083	wrccwd@ccnet.com
Linda Smith	MWD-fax 444-6887,	Ph(916) 650-2632	lsmith@mwd.dst.ca.us
Lenore Thomas	USBR	(916) 978-5084	lthomas@mp.usbr.gov
Wayne Verrill	DWR/SJVDIP	(916) 327-1667	wverrill@water.ca.gov

*** Team lead person**

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I.1 Introduction

The March 1998 CALFED WQP Report proposed to address the following topics with respect to salinity and selenium:

- Reduce the impairment of environmental, agricultural and drinking water beneficial uses associated with salinity using water management techniques.
- Reduce impairment of agricultural beneficial uses in the South Delta associated with salinity through improved outflow pattern and water circulation in the Delta Region
- Reduce impairment of environmental, agricultural, municipal, and industrial beneficial uses in Delta region associated with salinity through source control and treatment of agricultural surface and subsurface drainage in the Sacramento and San Joaquin Rivers.
- Evaluate loading of salt from non-agricultural sources in the Delta and the Sacramento and San Joaquin Rivers and assess the need for source control measures to reduce impairment of environmental, agricultural, municipal, and industrial beneficial uses.
- Reduce impairment of environmental beneficial uses of water in the Lower San Joaquin River and the Delta associated with selenium loadings by controlling sources of selenium in agricultural subsurface drainage water.
- Reduce the impairment of environmental beneficial uses in the Delta region associated with selenium loadings through source control and treatment of industrial discharges to the Suisun Bay and Carquinez Strait.

This action item report proposes local and basin-wide actions to reduce water quality impairment due to selenium and salinity from various sources.

The salinity actions are organized in three categories: Local actions to reduce salinity from irrigated lands, basin-wide actions to manage salinity, and evaluation of sources of salinity other than irrigated agricultural lands.

The selenium actions are broken down into the two primary sources of selenium: subsurface agricultural drainage waters and refineries in the Delta.

1.2 Problem Statement

Portions of rivers and the Delta are impaired by discharges from agriculture, wetlands, mines, industries, and urban areas. Significant amounts of total dissolved solids enter the rivers and the Delta from these sources. Sea water intrusion is another source of salinity in the Delta. Salinity is primarily affecting agricultural and drinking beneficial use of water.

The water management actions are proposed to reduce salinity impairments in the San Joaquin River and in the South Delta Region. The objective is to reduce or manage salinity in the SJR and in the Delta Region by relocating point of drainage discharge, improved flow patterns using flow barriers, reducing and managing drainage water, reducing salts discharged to these water bodies, real-time management and utilizing assimilative capacity of the River through the Delta-Mendota Canal circulation. Currently the timing of the discharges of drainage from Grasslands area is not coordinated with reservoir releases consequently the assimilative capacity of the SJR is frequently exceeded at Vernalis.

Surface agricultural 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 SJR and Delta Region. Processes that affect salinity of water in a basin occur over short and long time periods because of the interactions of surface and subsurface water and soil salinity. One of the fundamental principles that guides the CALFED Bay-Delta program is that solutions be durable. For this reason, the technical discussion and solution approaches presented here will refer to the relative time period over which a particular process is likely to occur. Some processes, and therefore related solution approaches may only be viable over a short time period, compared to other processes or approaches which may be more durable. For the sake of this discussion, short- term processes are defined as those occurring over a period of months to less than five years. Moderate term processes occur over a period of five to ten years and long-term processes over ten years. The exact time period over which a specific process may occur is arguable, particularly when other related processes may have a synergistic effect. It is the relative time periods that most importantly need to be considered, particularly when durable solution approaches are mandated by the fundamental principles guiding the CALFED program.

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 can also be impacted by locally and seasonally elevated salinity but can there be even more sensitivity due to specific ion toxicity. Seasonal and site specific objectives for salt (EPA, SWRCB, CRWQCB table of beneficial uses) are routinely exceeded in some regions.

Water quality of supply water 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 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. The incremental addition of salts from processes such as water softening may, however, be constant between basins. For some sources there may be significant discharges to land. Although such discharges will not have an immediate effect on surface water quality, salt loading of groundwater may have significant future effects.

Water in lower SJR and southern Delta frequently has salt concentrations that exceed desirable levels for agricultural beneficial uses (figure 1). The 700 µs/cm thirty day running average electrical conductivity water quality objective for the SJR near Vernalis for the April to August period has been exceeded 54 percent of the time from 1986 through 1997. The 1000 µs/cm water quality objective for the September to March period has been exceeded 13 percent of the time. These rates of accedence 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.

Though agricultural drainage can be a major source of waste water 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 (figure 2) compared to the San Joaquin River (near Vernalis). The 340 µs/cm CRWQCB objective for the Sacramento River at the I Street Bridge was not exceeded between water years 1986 and 1997.

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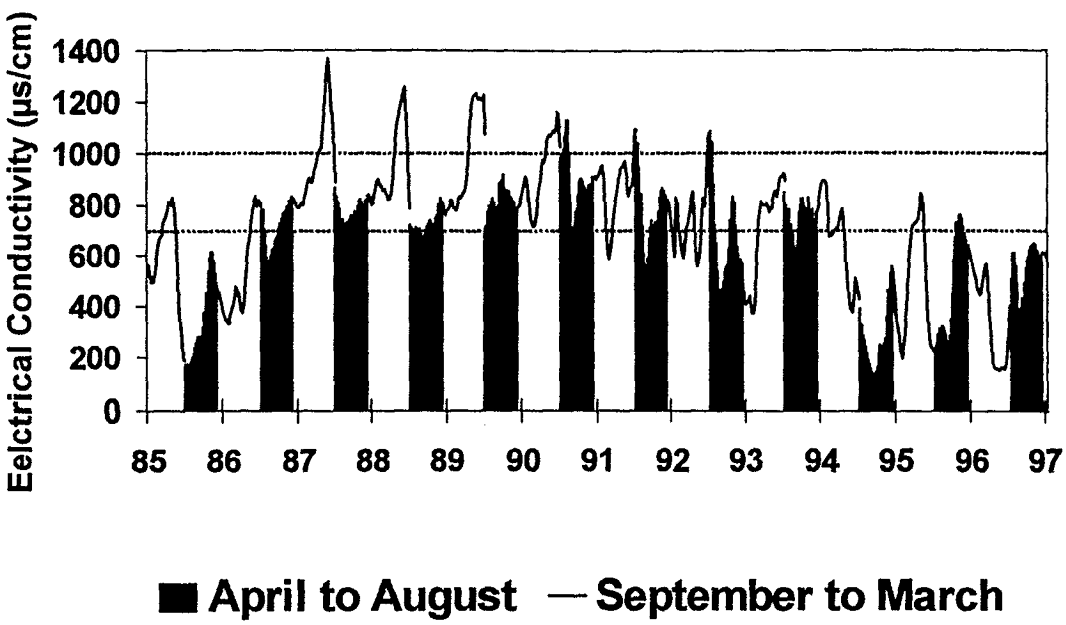

Figure 1. San Joaquin River near Vernalis 30 day Running Average Electrical Conductivity (from CVRWQCB, 1997)

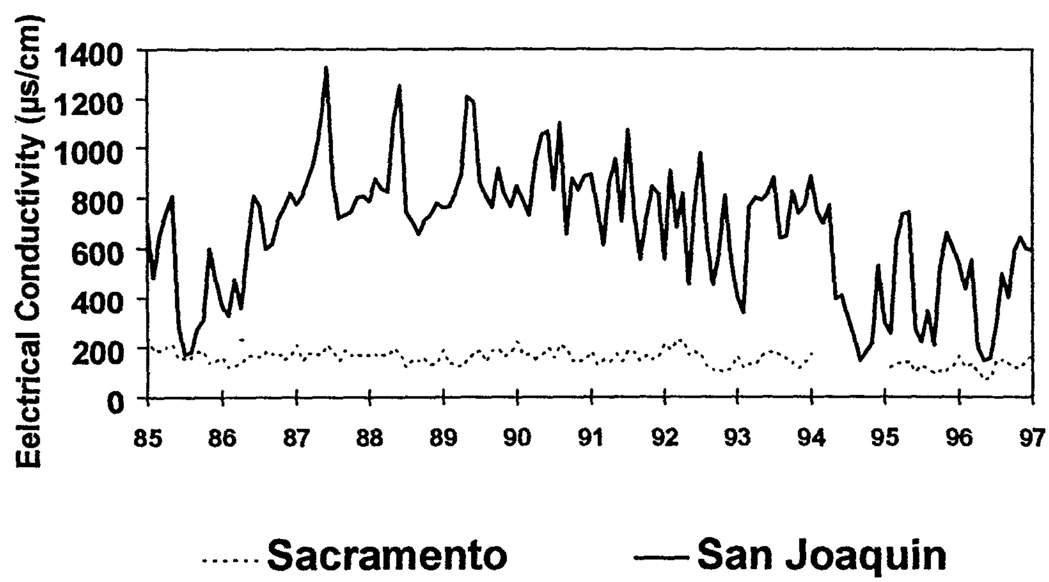

Figure 2. Comparison of Sacramento and San Joaquin River Water Quality

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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 Basin, outside of capture of high quality water from adjacent watersheds. Water imports into the San Joaquin Basin have high salt concentrations and loads because the water source is the Sacramento-San Joaquin River Delta. Intake to the Delta Mendota Canal 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 a significant part 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.

An average of approximately 600,000 tons of salt per year were imported into the Delta-Mendota Canal Service area on the west side of the SJR via the Delta Mendota Canal between 1985 and 1994. Another 160,000 tons per year, on average, were imported into the west side via diversions from the San Joaquin. Dissolution of in-situ salts averaged 250,000 tons per year for the same time period resulting in gross salt import and salt dissolution of 1,010,000 tons per year on the west side of the SJR 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 SJR. The net discharge of salt from the west side of the SJR is 620,000 tons per year, suggesting an increase of 390,000 tons per year. This leads to increasing salt loading to the SJR via groundwater accretions.

I.3 Local Actions to Reduce Salinity from Irrigated Lands

Sources

Surface agricultural runoff and subsurface agricultural drainage are the major source of salt in the lower San Joaquin River Basin. Salt loading from agricultural drainage in the SJR leads to impairment of water quality in the lower SJR and southern Delta. Surface agricultural runoff is also a significant source of salt in the Sacramento River, but salt concentrations of agricultural discharges in the Sacramento watershed are substantially lower than the SJR. This, in part, is due to agricultural supply water of better quality (lower salinity) in the Sacramento watershed than in the SJR watershed. Sacramento River flows are also generally much higher than the San Joaquin River, providing greater dilution flows, and lower salt concentrations. Though the Sacramento River may have locally acceptable salt concentrations, elevated background loads of salt in the Sacramento River makes it a less effective source of dilution water for the much more saline SJR when mixed in the Delta.

Distinction in all geographic areas must be made between surface runoff and subsurface agricultural drainage water. Agricultural surface runoff contributes a large load of salt to the SJR and Sacramento River, though at low concentrations relative to subsurface agricultural runoff. Surface agricultural runoff flows contribute salt load to the SJR and Sacramento Rivers throughout the basins, compared with subsurface drainage that has a much more limited areal extent (mostly in the San Joaquin 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 have elevated salt concentrations.

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 groundwater and ultimately, indirect, long- term loading via groundwater accretions, to surface waters if salt is not removed. Surface agricultural runoff can also have adverse impacts due to other constituents of concern. Although it is an important source of salt, surface agricultural runoff may also provide the majority of flow in the SJR upstream of the major east side tributaries during low flow periods. Surface agricultural runoff may, however, at times exceed existing water quality objectives but still provide dilution flow relative to subsurface drainage and groundwater accretions.

Subsurface drainage from specific geographic areas, such as the Drainage Problem Area of the Grassland watershed in the San Joaquin River Basin, can also have 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.

Impacts

Elevated salinity in the SJR leads to frequent accedence of existing water quality objectives for the SJR at Airport Way Bridge near Vernalis, established by the SWRCB to protect agricultural beneficial uses in the South Delta (see figure 1). These elevated salt concentrations also lead to impairment of water quality exported from the Delta for agricultural, municipal, and industrial uses. Salinity is important to agriculture because in elevated concentrations it harms crops, and it 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, it 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

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use water efficiently. Fish and wildlife cam also be impacted 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 SJR, required to meet established water quality objectives. Table 1 (Regional Board, SWRCB) shows the acceptable salinity levels that are protective of environmental, agricultural, municipal, and industrial beneficial uses. Current Basin Plan Amendment work (CRWQCB) will likely result in geographic expansion of salinity water quality objectives in the SJR Basin. There can be seasonal environmental impacts to the environment related both to salinity and specific ions toxicity to some species.

A complete discussion of water quality impairment in the lower SJR and southern Delta due to salts in agricultural drainage is not possible without consideration of a broad set of approaches for a problem of such broad scope. Following is the list of approaches that have been identified and will be more fully discussed:

- Source Control / Drainage Reduction
- Re-use
- Reverse Osmosis
- Cogeneration
- Agroforestry

I.3.1 Solution Approaches

Goal

The primary goal of the proposed solution approaches is to reduce salt concentrations in the lower SJR and southern Delta to levels that are protective of existing beneficial uses (Table 2). This 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 goal is therefore to implement solution approaches that do not adversely impact water quality in the SJR over the long-term. It is not sufficient to consider short-term improvement of water quality in the SJR or the Delta as an assessment endpoint because such an assessment may ignore the long-term ability to sustain such an improvement. The desired goal must therefore include the more complexly defined ability to meet water quality objectives over the long-term.

TABLE 1
SUMMARY OF WATER QUALITY OBJECTIVES
FOR THE LOWER SAN JOAQUIN RIVER BASIN
(CRWQCB, CVR, 1994; 1996)

	CONSTITUENT			
Location	Salinity (mmhos/cm)	Selenium[1,2] (mg/l)	Boron[2] (mg/l)	Molybdenum[2] (mg/l)
Vernalis	*MAXIMUM 30-DAY RUNNING AVERAGE* *1 April - 31 Aug.* **700 mmhos/cm** *1 Sept. - 31 May* **1,000 mmhos/cm**			
Mouth of Merced River to Vernalis		MAXIMUM **12 mg/l** 4-Day AVERAGE **5 mg/l**	MAXIMUM *15 March - 15 Sept.* **2.0 mg/l** *16 Sept. -14 March* **2.6 mg/l** MONTHLY MEAN *15 March - 15 Sept.* **0.8 mg/l** *16 Sept. -14 March* **1.0 mg/l** *Critical WY* **1.3 mg/l**	MAXIMUM **15 mg/l** MONTHLY MEAN **10 mg/l**
Sack Dam to Mouth of Merced River		MAXIMUM **20 mg/l** *4-Day AVERAGE* **5 mg/l**	MAXIMUM **5.8 mg/l** MONTHLY MEAN *15 March - 15 Sept.* **2.0 mg/l**	MAXIMUM **50 mg/l** MONTHLY MEAN **19 mg/l**
Salt Slough		MAXIMUM **20 mg/l** MONTHLY MEAN **2 mg/l**	MAXIMUM **5.8 mg/l** MONTHLY MEAN *15 March - 15 Sept.* **2.0 mg/l**	MAXIMUM **50 mg/l** MONTHLY MEAN **19 mg/l**
Mud Slough (north)		MAXIMUM **20 mg/l** *4-Day AVERAGE* **5 mg/l**	MAXIMUM **5.8 mg/l** MONTHLY MEAN *15 March - 15 Sept.* **2.0 mg/l**	MAXIMUM **50 mg/l** MONTHLY MEAN **19 mg/l**

1. Refer to other sources for more detail including compliance schedule.
2. Selenium, boron and molybdenum are total concentrations.

Table 2 Lower San Joaquin River Beneficial Uses from Sack Dam to the Delta as Designated in the Water Quality Control Plan

(Source: *Water Quality Control Plan, Central Valley, San Joaquin River Basin*; CVRWQCB 1994; 1996)

SURFACE WATER BODIES (1)			AGRI-CULTURE		INDUSTRY			RECREATION			FRESHWATER HABITAT (2)		MIGRATION		SPAWNING			
		MUN	AGR		PRO	IND	POW	REC-1		REC-2	WARM	COLD	MIGR		SPWN		WILD	NAV
		MUNICIPAL AND DOMESTIC SUPPLY	IRRIGATION	STOCK WATERING	PROCESS	SERVICE SUPPLY	POWER	CONTACT	CANOEING AND RAFTING (1)	OTHER NONCONTACT	WARM	COLD	WARM (3)	COLD (4)	WARM (3)	COLD (4)	WILDLIFE HABITAT	NAVIGATION
MENDOTA DAM TO SACK DAM		P	E	E	E			E	E	E	E		E	E	E	P	E	
SACK DAM TO MOUTH OF MERCED RIVER		P	E	E	E			E	E	E	E		E	E	E	P	E	
MOUTH OF MERCED RIVER TO VERNALIS		P	E	E	E			E	E	E	E		E	E	E		E	
SACRAMENTO/SAN JOAQUIN DELTA		E	E	E	E	E		E		E	E	E	E	E	E		E	E
SALT SLOUGH			E	E				E		E	E				E		E	
MUD SLOUGH (NORTH)			L(5)	E				E		E	E				E		E	

LEGEND
E=EXISTING BENEFICIAL USES
P=POTENTIAL BENEFICIAL USES
L=LIMITED

(1) Shown for streams and rivers only with the implication that certain flows are required for this beneficial use.
(2) Resident does not include anadromous. Any Segments with both COLD and WARM beneficial use designations will be considered COLD water bodies for the application of water quality objectives.
(3) Striped bass, sturgeon, and shad.
(4) Salmon and steelhead.
(5) Elevated natural salt and boron concentrations may limit this use to irrigation of salt and boron tolerant crops. Also low flow conditions may limit use.

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Source Control / 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. Salt application to the irrigated lands of the SJR Basin could also be reduced through conservation measures. The San Joaquin Valley Drainage Program identified the most effective means of achieving higher irrigation efficiencies:

- improving management of irrigation systems
- adopting new or improving existing irrigation practices, including shortening furrows and installing tailwater return systems
- improving irrigation scheduling

Re-use

The SJVDP identified three forms of agricultural drainage re-use: 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 re-used 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 agroforestry). Residual brines, while much decreased in volume, would still need to be processed, stored, or disposed.

Reverse Osmosis

This 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 would still need to be used, stored or disposed.

Cogeneration

Waste heat from thermal generation of energy could be used to further concentrate saline drainage water. Residual salts would still need to be used, stored or disposed.

Agroforestry

Agroforestry systems sequentially reuse drainage water to produce salt tolerant crops and tree biomass and concentrate the salinity of residual brines. Agroforestry systems operate upon the principle that drainage water, salt, and selenium are resources of economic value. This concept makes agroforestry different from other drainage management technologies that only view drainage water as waste to be reduced, and salt to be discharged. Residual salts would still need to be used, stored, or disposed.

I.3.2 Existing Activities

Source Control / 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. A Memorandum of Understanding regarding Efficient Water Management Practices by Agricultural Water Suppliers in California was signed in May, 1997. This MOU provides a mechanism for planning and implementing cost effective water management practices.

The SJVDIP continues to promote source control as one of the in basin methods for reducing salt loading in the SJV. Much work in this area has already be done under the guidance of the CRWQCB through drainage operation plans.

Through 1992, the Grassland Area Farmers in the San Joaquin Valley increased irrigation efficiencies to just under 80 percent 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 Grasslands Area Farmers. These increased efficiencies have greatly reduced and, in some cases, eliminated surface return flows but have only slightly reduced subsurface drainage. Drainage management in the Grasslands area has been significantly improved during past two years.

Opportunities for drainage management in the Delta should be explored. Improvement in water use efficiencies in agriculture have been accomplished in various areas. More opportunities still exist.

Re-use

Drainage reuse is a key element of the San Joaquin Valley Drainage Program recommendations for drainage management. The intent of drainage reuse is to improve irrigation water use efficiency hence reducing the volume of drainage requiring disposal. In some cases reuse of drainage cannot be accomplished without installation of tile drains. This action requires the installation of subsurface recirculation systems which can require substantive 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 for evapotranspiration enhancement. A total of 3,500 acres was recommended for drainage reuse in the Grasslands area by the year 2000.

Studies have continued based on proposals made by the SJVDP. Grassland Area Farmers were able to reduce salt loads discharged into the Grassland Bypass Project by 25 percent from previous years as a result of recirculation and other activities. Research on potential for phytoremediation and volatilization of selenium in agricultural drainage reuse system setting is continuing. Sequential reuse system, in combination with water cycling or blending, is a basic component of agroforestry systems currently being tested on several farms in the San Joaquin Valley.

Reverse Osmosis, Cogeneration

None currently.

Agroforestry

Agroforestry has been practiced on several farms in the San Joaquin valley. The westside Resource Conservation District manages experimental and demonstration projects. State and federal agencies and universities continue to develop and evaluate agroforestry 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. The Department of Water Resources, working with other agencies, districts, and growers, is developing agroforestry components. Management schemes are being developed to assess the long-term viability of agroforestry. 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

- determination of any adverse wildlife impacts that are associated with irrigating agroforestry with drainage water containing selenium and avoidance or mitigation of those impacts

- development of agronomic design and management of agroforestry to improve evapotranspiration, growth, and sustainability

- safe disposal or use and marketability of salts.

I.3.3 Quantitative Evaluation

Mean salinity (electrical conductivity) of subsurface drainage ranges from 600 to 7,500 µs/cm along the main stem of the SJR and from 700 to 23,000 in the Grassland Watershed. The median for the two areas is 2,100 and 6,100 µs/cm respectively. All subsurface drainage contributed, on average, approximately 160,000 tons (16 percent) of the total one million tons of salt discharged to the Lower San Joaquin River, upstream of Vernalis, during water years 1985 through 1995. Surface agricultural runoff contributed, on average, approximately 280,000 tons of the total salt discharged to the Lower San Joaquin River during this same period. This surface agricultural runoff salinity ranges from 500 to over 2,000 µs/cm. Salinity of surface return flows is highly dependent upon the quality of supply water. It is also, therefore, highly dependent upon the degree of re-use. Each time water is reused, salt will be added and concentrated. Due to higher quality supply water, less saline soils, and lower degree of reuse, agricultural drainage in the Sacramento Basin will have much lower salinity.

Water quality modeling studies suggest that complete elimination of subsurface agricultural discharge from the SJR would not entirely eliminate water quality problems related to elevated salinity. Based on these studies, the rate of exceedance of existing objectives would be reduced by only a third (e.g. from 54 percent of the time for the April to August period from 1986 through 1997 to 36 percent of the time). Approaches to reduce salinity impacts that rely only on removal of tile drainage salt loads will therefore not solve all salinity problems in the SJR and Delta. Approaches that only reduce tile drainage salt loads will have even less effect. Elimination of all surface agricultural return flows would actually exacerbate water quality problems because these discharges often act as dilution flows in the SJR.

I.3.4 Estimate of Impacts

Re-use

Drainage water reuse by blending and recycling will increase the concentration of salts in soils which will have an adverse impact on crop yield. Sequential reuse of drainage water is needed to enhance and sustain land productivity. Deep percolation of the concentrated salts could affect groundwater quality.

Agroforestry

Agroforestry systems must be managed in a way that prevents access of wildlife to potential sources of selenium. Evaporation ponds can have wildlife impacts and the mitigation costs can be prohibitive. Wildlife safety is accomplished with minimal water ponding combined with hazing. No drainage water, salts and selenium are discharged from farms into rivers and other water bodies. Deep percolation of concentrated salts could affect groundwater quality.

Trees, a component of agroforestry systems, 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.

I.3.5 Feasibility analysis for each approach

<u>Adequate Data</u>

Source Control / Drainage Reduction, Re-use

There is adequate data available in the SJV from the large body of work assembled by the SJVDP and UC Salinity/Drainage Program upon which to base the feasibility and effectiveness of these methods. Ongoing work of the SJVDIP, UC Salinity/Drainage Program, SJRMP, and the Grassland Bypass Project has added to this knowledge base. Considerable data exists on drainage water management in the SJR Basin. Data on irrigation efficiencies in the Grasslands area has been published by the districts, the Regional Water Quality Control Board, and others. Published data indicate that irrigation efficiencies have improved significantly after 1990. Irrigation efficiencies up to 75 percent have been reported. Data is lacking on the irrigation efficiencies on the lands that are not tile drained. Less data is readily available for the Sacramento River watershed.

Agroforestry

Agroforestry and solar evaporators are being tested for adequacy and operational criteria in the SJV. Salt separation from drainage water is feasible but salt purification and marketing requires additional studies. Presence of dust particles and trace elements may affect the use of any salt. Further studies are needed on:

- selection of salt tolerant plants and trees

- complete utilization of drainage water through sequential reuse and solar distillation
- salt utilization, marketing, and disposal
- management of wildlife habitats
- sustainability of agriculture and environment

Institutional framework

Source Control / Drainage Reduction, Re-use

These actions could be encouraged by water districts (continue education and use of BMPs) and larger entities such as the Grassland Area Drainers coordination of subsurface drainage as part of the Grassland Bypass Project. The CRWQCB could use its regulatory authority to encourage implementation of these actions (through use of drainage operation plans, for example). Expanded water quality objectives, development of total maximum daily load (TMDL) allocations for affected water bodies, and establishment of waste discharge requirements would provide further 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 also be considered.

Existing institutional opportunities (district policies, agreements, MOUs, MAAs, ordinances, planning process, technical assistance etc.) must be utilized. The SJRMP and the SJVDIP are two interagency programs which encourage implementation of in-valley drainage measures.

Resources

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

Timing

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, re-use, and agroforestry programs could be expanded immediately.

Likelihood of success

Much that can be achieved strictly through source control (exclusive of land retirement) and cycling or blending re-use has already been achieved; additional increased short-term load reductions will likely come at the expense of long-term increases in salt buildup in the SJ Basin (and associated increases in long-term loading to the SJR). 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. Shallow groundwater areas (0 to 10 feet) remained mostly constant from 1990 to 1994; but increased between 1994 and 1997.

Agroforestry

Agroforestry, 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 and the price will have to compete with abundant local and foreign markets.

Reverse Osmosis and Cogeneration

Reverse Osmosis and Cogeneration, on a scale needed for significant reductions are very expensive given current technology.

I.3.6 Suggested Action Plan

Source Control / Drainage Reduction, Re-use

Small, additional reductions in short term loading 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 incentive for water conservation and drainage water use
- Improving irrigation methods, irrigation management, and sequential reuse of drainage water (to improve water use efficiency)
- Use sprinkler irrigation combined with furrow to reduce drainage volume.

For all methods, adequate leaching of salts should be considered to prevent salt accumulation in soil profile. Irrigation improvements can be accomplished by low interest loans to districts.

Reverse Osmosis, Cogeneration

Current costs of these approaches should be updated.

Agroforestry

This approach has significant potential to reduce discharge of salts to the SJR, 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 or disposal mechanisms. This approach is a long term in-valley drainage management. In cases where concentration of selenium in drainage water is high, this approach may result, if not properly managed, in significant impacts on water birds using the solar evaporator. To mitigate or compensate these impacts, alternative habitats would be required which results in significant costs. The costs of land, cost of design and construction, operation and maintenance, water, and monitoring are expected to be high and paid by the land owners. Therefore, it is expected to have low acceptability unless other incentives are given. Salt marketing is a potential means of handling salts. Adequate leaching of salts also needs to be considered for all aspects of to prevent salt accumulation in soil profile.

Recommended action

On farm and district wide source control, drainage reduction and re-use should continue to be encouraged. Investigation of agroforestry, sequential drainage reuse, selection of salt tolerant plants and trees, management of wildlife habitats, salt and selenium separation concepts should continue. Potential uses of salts and markets should be investigated. Additional demonstration projects and training program for agroforestry systems should be developed.

I.4 Basin-wide Actions to Manage Salinity

I.4.1 Solution Approaches

Improve Quality of Supply

Improved water 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. Reduce salts in Delta water by improving water quality through conveyance alternatives such as isolated facility or through Delta; relocation of drainage from the Delta islands; and South Delta and Delta Region circulation barriers.

Real-Time Management

In this approach it is proposed to actively manage the assimilative capacity of the River by controlling discharge of salts from agriculture and wetlands through an interagency program of real time water quality management. 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 making 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 the impacts on the SJR and minimizing violations of water quality objectives.

The goal of real-time management is to make multiple use of water that is already being stored or released for other purposes. For example: currently, releases are being made from tributaries to the SJR for the explicit purpose of providing pulse/attraction flows for fish; releases are also being made from New Melones for the explicit purpose of providing dilution flows to meet water quality objectives at Vernallis. Coordination of existing reservoir releases for fish flows with existing discharges of salt can have the net result of reducing reservoir releases needed explicitly to provide dilution flows. Real-time management applied in this example will result in less storage and fewer releases being made explicitly for providing dilution flows. It will not reduce salt load to the River.

DMC Recirculation

Utilize recirculation of Delta Mendota Canal (DMC) water during critical spring months to increase the assimilative capacity of the San Joaquin River. A project has been proposed by South Delta stakeholders to temporarily store drainage water from Grasslands 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 it helps towards meeting the 1994 Accord pulse flow requirements at Vernalis and improve water quality in the South Delta. The circulation of water in the River and the Delta combined with South Delta barriers may help improve water quality in parts of the Delta.

Salt Disposal

Salt disposal requires transport out of the valley, long term in-valley storage, or use of residual salts as a commodity. Out-of-valley disposal would 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 would convey saline water to the Pacific Ocean either directly or through the San Francisco Bay and Delta.

I.4.2 Existing Activities

Improve Quality of Supply

Operation of fish and water level South Delta barriers on Old River, Middle River and Grant Line Canal restrict the diversion of SJR water into South Delta channels and can help to improve water quality. The Interim South Delta Program 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; Central Valley Project (CVP) and State Water Project (SWP) export pumping; local agricultural diversions and drainage water; inadequate channel capacity; and regulatory constraints. When the CVP and SWP are exporting 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 south Delta channels in order to eliminate "null zones" and correct water circulation problems in south Delta channels that result from the SWP and CVP operations.

The CALFED three conveyance alternatives, if modified to provide water with good quality for South Delta, Contra Costa Water District, and export south of Delta, would improve water quality, but will not be 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.

Real-Time Management

Opportunities for real-time management of drainage discharge are being explored. CALFED has recently funded a project by the San Joaquin River Management Program Water Quality Subcommittee (DWR, Central Valley Regional Water Quality Control Board and Lawrence Berkeley National Laboratory) to conduct studies of real-time 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 river assimilative capacity for salts. The SJRMP-Water Quality Subcommittee was awarded a grant in 1994 to demonstrate that improved management and coordination of tributary releases and agricultural drainage from Westside 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 westside with east side reservoir releases for salmon migration, recreation, and water quality.

DMC Recirculation

Recirculation of DMC water via the DMC and either Mendota Pool or the Newman Wasteway during critical spring months would increase the assimilative capacity of the River. At this point this is a proposal that has not been implemented.

Salt Disposal

The State Water Resources Control Board's Draft Environmental Impact Report for Implementation of the 1995 Bay/Delta Water Quality Control Plan, November 1997, Chapter VIII states:

> "The existing Central Valley CRWQCB 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 within the San Luis Unit of the Central Valley Project have been engaged in litigation against USBR claiming that USBR is obligated to provide drainage facilities. This matter was decided in favor of the plaintiffs and is currently before the federal court of appeals. In a related matter, Westlands Water District (WWD) , USBR, and State Water Resources Control Board began preparing a memorandum of Understanding two years ago whereby WWD and USBR would proceed with environmental documentation needed to evaluate alternatives for a permit for disposal of drainage through a constructed drain. There has been no progress on this MOU in two years, but USBR has indicated that it would be reinitiating this process.

I.4.3 Quantitative Evaluation

Improve Quality of Supply

Use of water with better quality will reduce salt imported to the point of use. In case of the South Delta and the San Joaquin River Basin, use of better quality water will reduce the salts discharged to the River and the Delta. Currently the TDS of water exported for use in the SJRB is about 250-400 PPM. For example, based upon modeling results if under CALFED conveyance alternative three water exported for use south of the Delta will have about 100 PPM salts. Thus, the total salt imported to the Basin would be reduced 60-75 percent.

Operation of fish and water level South Delta barriers on Old River, Middle River and Grant Line Canal restrict the diversion of the SJR water into South Delta channels and can help to improve water quality. The flow and fish control structures will not reduce salinity overall in the Delta. They simply redistribute the San Joaquin River.

Effects of South Delta Flow and Fish Control Structures on South Delta Water Quality

The Interim South Delta Program ISDP has performed DWRDSM analyses on salinity (measured in mg/l Total Dissolved Solids [TDS]) for the Draft EIR/EIS, for the State Board Hearings, and for the Final EIR/EIS (unpublished). The following is a brief summary of what is predicted to occur during the operation of the flow and fish control structures.

Critical Year Analysis

To get a worst case picture of how the flow control structures can impact TDS levels, a summary of a critically dry year analysis follows:

In critically dry years under No Project conditions, null zones are created in both Middle River and Old River. Flow will reverse in the San Joaquin River upstream of Stockton and flow down Old River. When the three flow control structures operate, the null zones are eliminated. Flow reverses up Old River and Middle River and circulates down Grant Line Canal.

In south Delta channels, No Project TDS levels range between 200 to 510-mg/l. With the three flow control structures, TDS drops between 180 to 300-mg/l in Old River and Middle River, and Stages increase from 1 to 2-feet in south Delta channels.

When the three flow control structures operate, a hydraulic barrier is created at the Head of Old River, causing more San Joaquin flow to stay in the San Joaquin River. As a result, TDS levels can increase downstream of the Head of Old River (near Stockton), because San Joaquin flows are moving downstream (and the better quality Sacramento River water is not able to reverse upstream past Stockton).

Because TDS increases along the San Joaquin River near Stockton, TDS will also increase in the Central Delta. The Central Delta increase is caused by SWP and CVP export pumps reversing a greater proportion of San Joaquin River flow down Turner and Columbia Cuts. Under No Project conditions, the model shows a greater proportion of higher quality Sacramento River water being reversed down Turner and Columbia Cuts. TDS levels can increase from 120-135-mg/l to nearly 200-mg/l during critically dry periods. This can also raise TDS at the export facilities. ISDP DWRDSM model runs (using critical year conditions in July) show elevations in TDS from 178 to 189-mg/l. Opening up the Grant Line Canal Flow Control structure can mitigate for the elevated TDS levels. However, doing this reduces South Delta stages.

When the Head of Old River fish control structure is operated in April-May, the conditions change. One analysis done by DWR (May of a critically dry year) modeled no flow past the fish structure into Old River in spring operations. As a result, the stages downstream of the Head of Old River fish control structure are reduced unless the Middle River and Old River at Tracy flow control structures are also operating.

With the HOR fish control structure in place, TDS in the south Delta improved from 370- 410-mg/l to 280-330-mg/l. However, central Delta TDS levels rose from 120-330-mg/ to 215-370-mg/l. The TDS at Clifton Court Forebay increased from 187-mg/l to 225-mg/l TDS. Opening the radial gates at the Head of Old River in the spring and allowing more flow down Old River can mitigate for increased TDS in the Central Delta. This reduces the reversed flows down Turner and Columbia Cuts.

In summary, the flow and fish control structures do not remove TDS from the system, they simply move it around. To mitigate for the elevated TDS levels caused by flow and fish control structures in the central Delta, ISDP is proposing operating criteria that opens Grant Line and Head of Old River structures to allow more San Joaquin River flow into the south Delta.

The proposed DMC circulation project may help improve water quality for agriculture in the South Delta and for users along the SJR. Limited simulation studies indicate that the fish flow releases can be reduced by circulation of water through DMC. Water quality in the SJR and the South Delta will be improved during period when drainage water is withheld in the Grasslands area. Only limited studies have been done on potential benefits of the circulation concept. No studies have been conducted to examine the extent of impacts or benefits to CCWD and to the SWP and DMC water supplies and fisheries. No quantitative evaluation is available for discharge point relocation.

Real-Time Management

Real-time water quality management requires techniques that update the state of knowledge of a system continuously and allow actions to be taken to meet water quality objectives. Such techniques are being developed for the SJR Basin to promote voluntary compliance with state water quality objectives for priority pollutants such as selenium, boron and total dissolved solids. The SJRMP-WQS operated a water quality monitoring system that included the SJR and tributary sites to demonstrate the concept of real-time management of water quality. The SJRMP-WQS developed a water quality forecasting model to provide 14 day forecasts of San Joaquin Electrical Conductivity at Vernalis to assist water agencies such as the USBR-CVO in their daily operations to meet water quality objectives. The SJRMP-WQS also developed a website and public list server to improve communication between agencies and stakeholders concerned with SJR salinity.

DMC Recirculation

The proposed DMC circulation has not been implemented. Circulation concept is in the stage of modeling. The limited simulation studies indicate that if drainage water is withheld during March and part of April and released in April and part of May along with pulse flow (circulation), then the water quality in the SJR will be improved during period that drainage water is withheld. While this approach is intended to reduce concentration of salts in the River by managing the drainage discharge, it will not reduce the total load of salts. It is expected to increase the salt load due to this additional Delta water discharged to the River.

Salt Disposal

[Not applicable at this time.]

1.4.4 Estimate of Potential Impacts

Improve Quality of Supply

South Delta barriers will improve water quality in the South Delta Channels and thus improve water for Delta agriculture and export uses south of the Delta; it may also affect other urban users taking water from the Central Delta. ISDP is designed to comply with all regulatory standards including the salinity objectives in the May 1995 SWRCB Water Quality Control Plan (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 require additional treatment costs, and this could be considered a significant adverse impact, even if the WQCP standards are being met.

ISDP operational changes required to avoid potential adverse impacts to protected fish and wildlife can have a positive effect on water quality. Consequently, ISDP is currently re-evaluating its salinity impacts based on revised operating criteria resulting from ongoing ESA consultation.

Real-Time Management

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 and short-term surface storage), may have negative impacts on wildlife, if the ponds are poorly designed or if water remains ponded during the wildfowl nesting season. This concept requires close cooperation between agencies that do not have a history of coordinated interaction - hence some institution building will be required. Real-time management shifts the temporal distribution of salt loads. Therefore, there is a potential for increased concentration of salinity when load increases at a particular time which may result in an environmental impact.

DMC Recirculation

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 SJRMP-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 increases the assimilative capacity of the river for salts and other contaminants and improves the water quality in the River. Concerns have been raised by urban water users 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 have an impact. Circulation of water may have an impact on the fisheries, on water supply exports at the SWP and

DMC, and may impact water quality in the CCWD intakes. Other issues such as potential impacts on sediment transport from Newman Wasteway to the River, flooding, etc. have not been studied.

Salt Disposal

[Not applicable at this time.]

I.4.5 Feasibility analysis for each approach

Adequate Data

Improve Quality of Supply

Information on CALFED alternatives can be found in the Programmatic Environmental Impact Report/Environmental Impact Statement reports and information on the South Delta barriers can be found in the Interim Environmental Impact Report/Environmental Impact Statement for South Delta. The best data available will be presented in the ISDP Final DEIR/EIS (you will not find a quantitative analysis in the Draft EIR/EIS). DWRDSM modeling done subsequent to release of the DEIR/EIS depicts salinity changes due to ISDP for 71-years of hydrology. No detailed feasibility analysis has been done for DMC circulation proposal. Existing CALFED reports contain data on water quality and quantity of agricultural 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 for forecasting potential opportunities for river discharge. CVRWQCB has published a report on the water quality data in the SJR 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 the DWR, the U.S. Bureau of Reclamation and the U.S. Geological Survey measure flow and stage routinely for a variety of applications. Only the California Data Exchange Center, a department within the 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 U.S. Army Corps of Engineers use this information to determine reservoir release schedules during high runoff periods.

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The real-time, water quality management system under development for the SJR 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:

1. Use of water quality sensors: currently only EC, temperature and pH are continuously logged, although there are a great number of constituents of concern within California's river systems;

2. A continuous and integrated system of data error checking and validation because the data are used for regulatory purposes;

3. Addition of control systems that can be used to manage agricultural and wetland drainage water flow and water quality; and

4. Institutions that coordinate actions and responses of regulators, operators, and other public and private entities. Long-term commitment by agencies to support real-time data collection and water quality forecasting efforts.

DMC Recirculation

Preliminary modeling results exist on reduction of fish flow releases due to proposed DMC circulation and reoperation of discharge of drainage water to the River.

Salt Disposal

There is much data that shows the salt imbalance in the San Joaquin Valley but more work must be done to fully assess the feasibility of salt storage/marketing or the impacts of a drain at any outfall.

<u>Institutional framework</u>

Real-Time Management

These approaches can be promoted by districts through internal district policies. The CVRWQCB can also utilize its regulatory authority to encourage the districts and/or discharges to promote these policies. Use of incentives such as grants, low interest loans for drainage reuse, drainage reduction and improved irrigation efficiency should be considered. The existing institutional opportunities (district policies, agreements, MOUs, MAAs, ordinances, planning process, education etc.) must be utilized. Conduct workshops and write technical papers to gain confidence of stakeholders and potential users of the system. Rely on agency and non-agency programs. GAF is one such non-agency effort that is working to reduce drainage discharge to the River. (See Action Item C.) SJVDIP is an interagency program which encourages implementation of in-valley drainage measures.

DMC Recirculation

Require coordination among government agencies, local districts, farmers, and other stakeholders. Use of MOUs and formation of working groups such as the SJRMP-WQS (comprising of CRWQCB, USBR, DWR and LBNL) to gain user acceptance.

Resources

CALFED future funding is expected to be the most significant source of funding for water quality actions. Government agencies, districts, and other stakeholders have technical expertise and the resources needed to accomplish the actions. Existing programs both at the government and local level are important institutional resources that have to be utilized to the maximum extent.

Timing

Improve Quality of Supply

Barriers currently exist to reduce fish migration toward the State and Federal pumping stations. More information is needed in order to operate these barriers for water quality management in addition to the existing fish migration and water stage objectives. ISDP has been working independently from CALFED and is currently completing the Final EIR/EIS. For planning purposes, DWR is using the schedule below:

Admin. Draft EIR/EIS	June 19, 1995
Public Draft EIR/EIS	July 1996
Initiate ESA Consultation– Submit BA	April 28, 1997
Draft BO Received from DFG	March 11, 1998
Draft BO Received from FWS	April 2, 1998
Draft BO Received from NMFS	No idea
Final BOs Received	September 1998
Final EIR/EIS Issued	November 1998
ROD/NOD Issued	December 1998
Final Design Begins by DWR's DOE	December 1998
Construction Start	June 2001
Operation of all structures	June 2006*

* This schedule can be accelerated if necessary.

Real-Time Management

CALFED has funded this project for enhancement of the existing network of EC and flow monitoring stations and for improvement of model forecasting capability on the SJR. Continued outreach to potential cooperators to improve communication among drainage producers and between east-side reservoir operators and to increase confidence in forecast flow and EC. The organizational infrastructure to manage agricultural subsurface drainage is currently being put into place (CALFED grant). On-site infrastructure would need to be expanded to increase drainage storage capacity.

DMC Recirculation

DMC recirculation has been proposed for use in the SJR Basin, but has not been implemented.

<u>Likelihood of success</u>

None of the actions proposed here are expected to solve the salinity problems entirely. However, the combination of these actions will improve water quality to a large degree. In addition the basin-wide approaches complement the local level actions detailed in section 1.3.

Improve Quality of Supply

This approach will have incremental improvement effect on water quality.

Real-Time Management

This approach requires coordination among interested and impacted parties.

DMC Recirculation

This approach needs to be tested and will have incremental improvement effect in water quality.

Salt Disposal

This is the only one of the listed approaches that reduces salt loading to both the SJR and the SJV. In that sense, this approach has the greatest likelihood of success over the long term because the only way to maintain reduced salt loading to the SJR is to also reduce the long term buildup of salts in the SJV. On the other hand, this method may be difficult to implement because of problems associated with finding an acceptable location where salts can be disposed. And concerns over potential environmental impacts of such a discharge or disposal.

I.4.6 Suggested action plan

Improve Quality of Supply

Consideration should be given to reducing salt import to the area of use. This action item includes South Delta barriers, intake relocation for urban and discharge reduction or relocation for some Delta agricultural drainage, and DMC circulation proposal. South Delta barriers can be used to manage drainage flows, tidal currents, and stages in the SJR, Middle River and interconnecting channels. However, the impact of flow barriers on the quality of source water for CCWD should be evaluated. An approach is 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.

Recommended Action

Identify drainage reduction measures for Delta islands, identify potential drainage discharge relocation projects, and study water quality benefits of South Delta Barriers.

Real-Time Management

Previous real-time water quality modeling efforts in the Grasslands Basin have mostly focused on screening level assessments of operational constraints on, and opportunities for, agricultural drainage discharges. The USBR developed a sophisticated planning model that considered several alternatives to meet selenium and boron water quality objectives in the SJR (Quinn et al. 1993). 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 USBR 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 Grasslands Bypass project, considerable investment has been made by water districts in the Grasslands Basin in facilities to allow recycling of subsurface drainage water and to prevent commingling of tailwater and subsurface drainage water. Sumps have been retro-fitted 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 sort of technologies and reactive management to continually refine the operation of these systems will be needed to achieve SJVDP goals.

Recommended Action

Encourage coordination among diverters and dischargers and other beneficiaries of the SJR and provide incentives for such coordination and implementation of measures that help manage the salinity in the SJR.

DMC Recirculation

Simulation results has indicated that salinity will be improved at Vernalis during drainage retention and salinity will not change during circulation and release of drainage water. However, salinity will be improved during drainage retention and during circulation upstream of Vernalis. If South Delta barriers are operating during circulation, water quality for agricultural use in South Delta will be improved. This improvement in water quality for the South Delta will result in less salts discharged to the Delta Channels. If less salts are discharged to the Delta Channels, and if the Delta outflow is the same, long-term water quality should be improved at the intake location (federal and perhaps SWP and CCWD intakes). The use of Delta barriers will divert the River water from South Delta to Central Delta and thus improving the quality of water to agriculture in South Delta and export uses south of Delta. However, at this time, the beneficial and adverse impacts of these actions on the water quality at the State and Federal pumps and at the CCWD water intakes are unknown. It appears that the circulation will reduce the fish flow release requirements by about 2,000 acre feet.

DMC proposal shows some improvement in water quality in the River and the South Delta and the next step is to conduct more studies including modeling to identify and evaluate the impacts on fisheries, on SWP, DMC export, and on water quality for CCWD.

Recommended Action

Conduct numerical modeling and simulation studies to examine the benefits and impacts on the Delta and the export water users and fisheries. If promising, conduct a demonstration project.

Salt Disposal

No basin-wide recommendation for salt disposal is included in the action plan at this time.

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I.5 Evaluation of Other Sources of Salinity

Evaluation of salt discharges from urban runoff and wastewater and industrial plant discharges have been combined into this one 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 exclusive of irrigated agricultural sources of salt. This expansion of scope will allow:

- 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 also 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. As this action involves only *evaluation* of salt sources, no specific actions other than recommendations for assessment and monitoring will be given.

This action item specifies the need to evaluate loading of salt from a variety of sources and over large geographic areas. The suggested approaches to perform this evaluation are:

1. Evaluate and rank sources based on existing reports
2. Present a range of specific approaches to reduce salt loading for each type and area of discharge
3. Compile additional data to fill data gaps
4. Establish monitoring programs to monitor and evaluate specific sources

Sources

The following are non-agricultural sources of salinity that must be quantified:

- Urban Runoff
- Wastewater Treatment Plants
- Industrial Discharges

- Wetlands
- Mine Drainage
- Other (dairies, fertilizer, etc.)
- Note: Seawater Intrusion is not considered here; see Action 2 of Water Treatment.

Each of these sources may have individual components that will require additional study. Wastewater treatment plants , for example, may have a large volume of salt contributed from municipal processes such as water softeners.

Specific sources may have only limited 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 Regional Board Amendment Addressing Salinity and Boron (CRWQCB,CVR 1998 draft). The following beneficial uses are considered:

drinking water--human health

industrial-- economic

agriculture -- productivity, increased water usage, economics

environment

Data gaps

The CRWQCB,CVR is compiling load and concentration data for all sources of salt in the SJR Basin (CRWQCB, CVR 1998 draft) 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.

1.5.1 Solution Approaches

Desired Goal

Salt is widely distributed throughout the San Joaquin - Sacramento River and Delta system. Salinity of water supplies is increasing with the increased re-use of water as a means of conservation. Salt from all sources has similar impact on 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. These sources must be quantified and ranked in order of magnitude of impact. The increased frequency with which established water quality objectives can be met through minimization of salt loads should be estimated for specific sources. A combination of the following approaches can be used to obtain the information necessary to evaluate the relative loading of salts.

Approaches

1. Evaluate 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

2. After initial ranking, present a range of specific approaches that should be considered for each type and area of discharge, such as wetlands in SJR versus wastewater treatment plants in the Sacramento River. A listing of possible solution approaches for the specific sources can then be developed such as restricted timing of releases, changes in management, more restrictive NPDES permits, etc.

3. Compile readily available data for all sources from CALFED cooperating agencies and other entities. This approach is similar to Approach 1 except more

raw data from cooperating agency files needs to be compiled (such as salinity data from NPDES permits)

4. Establish programs to monitor and evaluate specific sources for which limited data exists. Collect additional data to fill data gaps identified in approaches 1 and 3.

1.5.2 Existing Activities

Following are some of the groups (and activities) that are currently working on issues related to salinity:

- SJRMP Water Quality Subcommittee (Real Time Management)
- Sacramento River watershed group
- CRWQCB Salinity Basin Plan Amendment Process
- CVPIA wetland water supply
- Grassland Bypass Project
- San Joaquin Valley Drainage Implementation Program
- San Joaquin River Tributary Group (Vernalis Adaptive Management Program)

Institutional Frameworks

SJVDIP & Grassland Bypass Project (continue education and use of BMPs), CRWQCB (regulatory incentive, e.g. new water quality objectives) SJRMP (timing-- see management item)

Suggested Strategy

Support and funding should be provided to assemble data on salt sources for which little data exists, including:

- urban runoff

- municipal and industrial discharges
- wetland water supplies and discharges
- groundwater accretions (long term impacts of all salt sources on groundwater)

Support and funding should also be provided to fill data gaps for these sources.

CalFed Water Quality Program Actions

II -- Selenium Control Actions

This report will address the following two CALFED Water Quality Program Actions:

Agricultural Drainage and Runoff Action 1: Reduce the impairment of environmental beneficial uses to the Lower San Joaquin River and Delta regions associated with selenium concentrations and loadings by controlling sources of selenium in agricultural subsurface drainage.

Wastewater and Industrial Discharge Action 3: Reduce the impairment of environmental beneficial uses in the Delta Region associated with selenium loadings through source control and treatment of industrial discharges to the Suisun Bay and Carquinez Strait area.

II.1 Introduction

Selenium is a semi-metallic trace element that is widely distributed in the earth's crust at levels less than 1 mg/kg and has chemical properties similar to sulfur. Selenium is naturally abundant in the marine shale sedimentary rocks and soils weathered from the rocks of the Coast Range Mountains to the 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 seleniferous geologic formations and soils are subject 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 has also been shown to bioaccumulate in aquatic food webs, which highlights dietary exposures to selenium as a significant exposure pathway for aquatic organisms.

Sources

Selenium in the Lower San Joaquin River and Bay/Delta regions comes 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 oil refineries in the Suisun Bay and Carquinez Straits area. The selenium is a byproduct of the crude oil refining process. The San Joaquin Valley crude oil, used primarily by the Bay Area refineries, has 2- 12 times higher levels of selenium compared to crude oil from other sources. Substantial amounts of selenium are also conveyed to the San Joaquin River in natural storm runoff in years with high rainfall, primarily by Panoche and Silver Creeks. Annual selenium loads in the San Joaquin River at Vernalis between 1986 and 1995 averaged 4,040 kg (8,906 pounds) with a range of 1,615 to 7,819 kg (3,558 to 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 was around 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 loads from municipal sources are based on limited data and concentrations of selenium in these discharges have met the 5 ug/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 have the most significant impacts on the North Bay area, particularly during low riverine flow periods. From 1989 to 1992, the average annual selenium load from refineries was 2,162 kg.

Biological Effects of Selenium

Selenium is an essential nutrient but 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 while similar problems are seen in low selenium diets (for the beneficial health effects of selenium see Appendix A). Adequate dietary levels (from feed) is generally 0.1 to 0.3 ug/g (ppm) but the toxicity threshold for sensitive animals is only ten times higher at around 2 ug/g. Data suggests that regulatory standards for selenium should be placed no more than ten times higher than normal background levels for an adequate margin-of-safety (unless there are species-specific and site-specific data to justify a variance from the general rule).

In freshwater ecosystems, normal background levels of selenium in water range from 0.1 ug/L to 0.4 ug/L (ppb). Estuarine and marine ecosystems have selenium levels in water ranging from 0.009 to 6.0 ug/L but most are less than 1.0 ug/L. Sediment background levels are below 1.0 ug/g, while aquatic plants are generally below 1.5 ug/g. Normal selenium levels in fish and invertebrates (whole body) are usually less than 2.0 ug/g, but have been reported as high as 4.0 ug/g. Whole body levels in reptiles, amphibians, and birds are also less than 2.0 ug/g. In mammals, tissue levels of selenium again average less than 2 ug/g.

Selenium occurs in natural waters primarily in two forms, selenate and selenite. Wastewater related to fossil-fuel and similar sources contain 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 just 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 to selenium in the water has only a minor effect on aquatic organisms. Adverse-effects levels for selenate and selenite are generally above 1,000 ug/L (ppb). 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.

As little as 0.1 ug/L of selenomethionine, an organic form of selenium, can accumulate in zooplankton to an average level of 14.9 ug/g (ppm) total selenium. This level of selenium in zooplankton, if fed to most species of fish, would cause dietary toxicity. Just 3.2 ug/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 contamination. Survival of juvenile rainbow trout (*Oncorhynchus mykiss*) was reduced when whole-body levels of selenium exceeded 5 ug/g. Smoltification and seawater migration among juvenile chinook salmon (*Oncorhynchus tshawytscha*) were impaired when whole-body tissue levels reached about 20 ug/g. However, mortality among larvae, a more sensitive life stage, occurred when levels exceeded 5 ug/g. Bluegill embryos resulting from ovaries containing 38.6 ug/g selenium exhibited 65 percent mortality.

The interactive effects of winter stress syndrome and selenium on fish are important even for waters containing less than 5 ug/L (ppb) selenium. These effects should be a critical part of selenium hazard assessments. The effects of other forms of stress (cold weather, migration, smoltification, disease, parasites, etc.) 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 and more recently, this was confirmed for mallard ducks. Numerous other 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 historic mining activities and other discharges may increase the risks of selenium exposure.

Selenium Risk Guidelines

Risk management via levels of selenium in water is a troublesome process for selenium. Water column levels of selenium are imperfect and measures of total selenium loading and food chain 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 there has been rapid biotic uptake and/or sediment deposition from elevated loading (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. The current EPA chronic criteria for selenium is 5 ug/L. Site-specific criteria for water delivery channels in the Grasslands area of the San Joaquin Valley is 2 ug/L to protect wetland uses. Numerous peer-reviewed papers, using different evaluation methods, recommend that water concentrations of selenium that would be protective of aquatic and semi-aquatic organisms should be around 0.9 to 2.0 ug/L. A summary of field data shows that fish and wildlife toxicity commonly occurs in nature at waterborne selenium levels below 5 ug/L (ppb), supporting recommendations from researchers. Selenium bioaccumulates rapidly in aquatic organisms and a single pulse of selenium ($\geq$10 ug/L) into aquatic ecosystems could have lasting ramifications, including elevated selenium levels in aquatic food webs.

Toxicity to fish and wildlife is ultimately determined by how much selenium moves into the food chain. Therefore, tissue levels of selenium are more useful in developing risk guidelines. Based on the review of more than 100 papers, the following toxic effects thresholds for the overall health and reproductive vigor of freshwater and anadromous fish exposed to elevated levels of selenium was recommended by one researcher: 4 ug/g whole body; 8 ug/g skinless fillets; 12 ug/g liver; and 10 ug/g ovary and eggs. This person also recommended 3 ug/g as the toxic threshold for selenium in aquatic food-chain organisms consumed by fish. Ecological risk guidelines were developed in 1993 to evaluate monitoring results from the Grasslands Bypass Project in the San Joaquin Valley. These include: bird eggs, 3 ug/g; fish whole body, 4 ug/g; vegetation as diet, 2 ug/g; invertebrates as a food, 3 ug/g; sediment, 2 ug/g; and water, 2 ug/L. Another researcher summarized selenium effect levels from hundreds of reviewed papers and identified similar risk thresholds.

The San Francisco Bay Regional Water Quality Control Board 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 ug organic Se/g), algae and other aquatic plants (0.45 ug organic Se/g), sediment (1.5 ug/g, dw), bivalves (3.2 ug/g as elevated and 4.5 ug/g as an alert level), and rallid eggs (2.9 ug/g as elevated).

Selenium Levels in the Bay/Delta

Waterborne levels of selenium in the San Francisco Bay Estuary are currently less than 1 ug/L and has been measured no higher than 2.7 ug/L within the estuary. Although these levels are relatively low, selenium has bioaccumulated to adverse levels in biota leading San Francisco Bay Regional Water Quality Control Board staff to recommend decreasing current selenium loading to the estuary by 50 percent or more.

Bivalve tissue from several monitoring programs in the late 1980s and early 1990s show elevated selenium levels in the North Bay area ranging from 0.6 to 7.3 ug/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 ug/g in 1995 and 1996.

Studies in 1990, found up to 3.3 ug/g whole-body selenium in juvenile striped bass from three sites in the San Francisco Bay estuary. This is a value just below the recommended 4 ug/g toxicity threshold, even though waterborne selenium typically averages less than 1 ug/L within the estuary. Striped bass collected from Mud Slough in 1986, when the annual median selenium level in water was 8 ug/L, averaged 6.9 ug/g whole-body selenium, and contained up to 7.9 ug/g.

White sturgeon remain nearly year-round in the San Pablo Bay area, the part of the San Francisco Bay estuary with some of the highest selenium levels. A 1991 report documented that developing ovaries of white sturgeon from San Francisco Bay contained as much as 71.8 ug/g selenium, or 7-times over the recommended threshold for reproductive toxicity of 10 ug/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 7.3 ug/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 the range (14 to 209 ug/g) similar to waterfowl found at Kesterson NWR.

II.2 Problem Statement

Current Regulatory Status

The U.S. EPA listed San Pablo Bay, Carquinez Strait, and Suisun Marsh as impaired waterbodies in 1990 due to elevated selenium levels in diving ducks which had triggered health advisories. The San Francisco Bay Regional Water Quality Control Board (Regional Board) 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 (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 U.S. EPA established an aquatic life criteria of 5 ppb for the entire Bay/Delta estuary because the salt water criteria appeared to be under protective, as evidenced by the high potential for selenium bioaccumulation and increasing levels in bay organisms. The SF Bay Regional Board in the 1995 Basin Plan established the more protective freshwater effluent limitations for the estuary for similar reasons. Several Petitions for Review were filed by various parties but were ultimately dismissed by the State Water Resources Control Board because the Regional Board was to address the issues. The Regional Board proposed a Mass Emission Strategy in 1992 that targeted a 90 percent selenium load reduction by the year 2001. Cease and Desist Orders related to selenium discharges have been issued to several of the refineries which require implementation of full-scale treatment systems or control and/or removal strategies by 1998. The Regional Board determined that treatment technologies would provide the greatest emission reduction and be the fastest and most economical methods to achieve selenium reduction compared to conversion to a cleaner crude oil. Bench- and pilot-scale testing has occurred throughout the 1990s and more detailed evaluations and implementation of the most promising technologies continues. Control strategies include waste stream treatment (ion exchange, biochemical treatment, iron co-precipitation), sour water reuse, the use of an alternative crude oil, and wetland discharge. Additional environmental studies (impacts to 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.

Irrigation water applied to agricultural lands in the Grasslands area of the westside San Joaquin Valley leach selenium from the soil to the shallow groundwater table. Tile drains have been installed on some farmland acreage in order to reduce the harmful effect of groundwater and salt reaching the crop root zone. These drains have had the unintended effect of accelerating 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.

The Central Valley Regional Water Quality Control Board has set water quality objectives and an implementation timetable for selenium for the San Joaquin River in order to protect beneficial uses. These objectives are most difficult to meet in the San Joaquin River just downstream of where Mud Slough discharges. Further downstream eastside tributaries provide dilution water which tends to lower the concentrations. In certain months these water quality objectives have been exceeded.

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 has been difficult. Continued work to improve upon the current or develop new treatment technologies is needed.

Basic tissue monitoring has documented selenium in bivalves, 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: 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 to fish and wildlife (e.g. immunosuppression, sensory damage); bioaccumulation rates and impacts of selenium in an estuarine environment verses a freshwater environment; and evaluation of various seleno-amino-acids in biota for the purpose of establishing the toxic and ecotoxic mechanisms of selenium which will be critical to the establishment of site-specific water quality criteria.

CALFED has granted funding to Dr. Samuel Luoma of the USGS to conduct a three-year study to provide a quantitative description of the different sources of selenium concentrations in the Bay-Delta, a determination of how changes in sources may affect selenium tissue concentrations in primary consumers, a linkage of selenium concentrations in primary consumers to uptake by predators, a direct determination of whether selenium affects reproduction and development in sturgeon, models which can forecast outcomes of alternative selenium remediation/restoration strategies, and a baseline of monitoring data.

Continued and additional monitoring of tissue concentrations of selenium in estuarine invertebrates and species that prey on them is needed to confirm whether control actions are working. If interactive effects of mercury and selenium are found in the estuary, the monitoring of methyl-mercury should also be expanded.

II.3 Selenium from Agricultural Sources

II.3.1 Solution Approaches

Goal

The primary goal of the proposed solution approaches is to meet water quality objectives and load limitations for selenium set by the Central Valley Regional Water Quality Control Board for the San Joaquin River and Mud and Salt Sloughs (see Appendix B). The long-term viability of solutions can best be achieved by implementing approaches that not only reduce and remove selenium from agricultural soils and drainage that is discharged to the San Joaquin River, but that also result in the production of beneficial selenium products that are valuable to selenium deficient areas in California and other parts of the world (see Appendix A), and provide a new product for enhanced economic viability and sustainability of agriculture in the Grasslands area of the westside San Joaquin Valley.

Following is a list of approaches that have been identified to potentially reduce the impact of selenium discharged in agricultural drainage waters on the beneficial uses of waters. Some approaches listed below are discussed in the Salinity Control Actions paper, the remainder are discussed in detail below.

Drainage Treatment

Source Control/Drainage Reduction (see Salinity Control Actions)

Timing of Release (see Salinity Control Actions)

Drainage Reuse (see Salinity Control Actions)

Land Retirement

Long-term solution to salinity (see Salinity Control Actions)

Phytoremediation

Selenium Marketing

Active Land Management

Upper Watershed Management

Agroforestry/Salt Separation (see Salinity Control Actions)

Tradable Loads

Drainage Treatment

Drainage treatment is the removal of selenium from agricultural drainage water through processes which 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.

Land Retirement

Land retirement is intended to reduce the selenium load in regional agricultural subsurface drainage by eliminating irrigation and drainage discharge from selected, voluntarily retired lands. The assumption is made that groundwater levels under retired lands will drop, even if irrigated agriculture continues on adjoining and upslope lands. The 1990 San Joaquin Valley Drainage Program Management Plan recommended that a total of 3,000 acres be retired in the Grassland Subarea by the year 2040, with no retirement by the year 2000.

Phytoremediation

Selenium may be removed from agricultural soils by phytoremediation with selenium-accumulating crop species, either by harvesting and removal of plant material, and/or by volatilization of selenium during the growing season.

Selenium Marketing

The goal of selenium management is to develop on-farm production of selenium utilization products and develop marketing opportunities (see Appendix A). 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-State and worldwide. Additionally, the possibility exists of refining and marketing industrial grade selenium as a corollary to drainage treatment.

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.

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.

Tradable Loads

Tradeable 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.

II.3.2 Existing activities

Drainage Treatment

Research and development of treatment projects for the removal of selenium from agricultural drainage have been ongoing since the mid 1980's. 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 under the direction of Professor William Oswald of UC Berkeley has been operating for over a year in the Panoche Drainage District near Firebaugh. CALFED recently funded the continuation and development of this project for an additional three years. The Flow-Through Wetland Treatment Pilot Project for the bioremediation of selenium in agricultural drainage, under the direction of Dr. Norman Terry of UC Berkeley, has been in operation for more than a year in the Tulare Lake Drainage District.

The Drainage Treatment Technical Committee working under the auspices of the joint State-federal interagency San Joaquin Valley Drainage Implementation Program is currently evaluating the status and progress of treatment methods for the removal of selenium from agricultural drainage, including an economic evaluation. The Committee's report is scheduled for completion in September, 1998.

Land Retirement

The USBR has initiated a voluntary Land Retirement Program under the Central Valley Project Improvement Act (CVPIA). Applications have been received from interested landowners in the Westlands Water District and the USBR is currently evaluating those applications as well as planning a Land Retirement Demonstration Project which will include restoration of wildlife habitat. No applications for voluntary land retirement have yet been received from growers in the Grasslands subarea.

The Land Retirement Technical Committee working under the auspices of the joint State-federal interagency San Joaquin Valley Drainage Implementation Program is currently evaluating the previous assumptions that have been made regarding the efficacy of land retirement, including the elimination of selenium-containing subsurface drainage from retired lands. The Committee is evaluating computer models, developed and refined since the SJVDP land retirement recommendation was made in 1990, that 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 is scheduled for completion in September, 1998.

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 in their tissues, and volatilize it to the atmosphere. Other forage and plant species such as astragulus, birdsfoot trefoil, tall fescue, kenaf, and atriplex, including some natives, have the same or enhanced ability. Some genuses of plants such as *Astragulus* and *Atriplex* are called selenium accumulators, and can achieve selenium tissue concentrations of several hundred up to a thousand ppm. Other plants are called non-accumulators, including most crop and forage species, but many still can achieve tissue selenium concentrations of up to about 50 ppm. The advantage in using crop and forage species over selenium accumulators is two-fold: (1) the crop and forage species may be harvested and marketed as beneficial human vegetable and livestock feed supplementation or as 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 green house and field trials have been conducted that demonstrate 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 within only three years. Simulated field trials with tall fescue have demonstrated that leachate selenium concentrations and soil selenate concentrations are reduced with successive harvests. A research project to ascertain the degree of selenium accumulation and volatilization from each of the components of the drainage reuse agroforestry system at Red Rock Ranch near Five Points, Fresno County is currently in-progress under the direction of Dr. Norman Terry of UC Berkeley. A final report is scheduled to be 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. Drs. Teresa Fan and Richard Higashi of UC Davis are currently conducting a research project designed to determine the ecologic processes ongoing in the Lost Hills Water District evaporation pond, the function of brine shrimp growth and harvest in the bioremediation of selenium, and optimum management techniques for salt utilization as well as selenium bioremediation.

Selenium Marketing

Current investigation of opportunities to produce and market selenium products is very 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.

Active Land Management

Assessment of the efficacy of current source control practices in selenium drainage load reduction under the Grassland Bypass Project and Use Agreement is ongoing as well as evaluation of opportunities for further reduction. 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

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traditional cropping systems. The alternatively managed parcel would be rotated within a section, and 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 the USBR, 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 are initiating 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.

II.3.3 Quantitative Analysis

[Some phytoremediation data appears above and data for a market analysis of selenium is available in Appendix A. Other data for quantitative analysis has not been prepared for inclusion in this report at this time.]

II.3.4 Estimate of Impacts

[Not applicable at this time.]

II.3.5 Feasibility

General

Data for analysis will come from measurement of flow and water quality parameters in Mud Slough and the San Joaquin River to determine compliance with water quality objectives and calculation of selenium loads, including percent and total reduction in discharged selenium load. Data is currently being compiled and evaluated by operators of the various field systems, including Grassland Area Farmers for the Grassland Bypass Project, and Grassland Water District for wetlands management. In addition, information that is developed by the SJVDIP Drainage Reuse, Drainage Treatment, Land Retirement, and Salt (and Selenium) Utilization Technical Advisory Committees, and local Subarea reports will be utilized. Additional information will be obtained from experts working in the field.

Drainage Treatment

Factors to be considered in feasibility of drainage treatment include capital and operational costs of treatment facilities per volume of treated drainage, concentration and percent reduction in selenium, and cost of waste-product disposal. While several methods of drainage treatment have proven to be effective in substantially removing selenium from small volumes of agricultural drainage, none has yet been proven to be economically feasible at the required scale of full operation. The separation, refinement, and purification of selenium, as an integral part of the drainage treatment process, for marketing for beneficial uses as an alternative to waste-product disposal has not yet been investigated. The effect of selenium product marketing on the cost effectiveness of treatment methods has also not yet been determined.

Land Retirement

Factors included in a feasibility analysis of the efficacy of land retirement in the reduction of selenium discharge from agricultural drainage would include the validity of model predictions, and the results of monitoring data from future pilot land retirement projects. Of particular significance are changes in watertable elevations and soil, water, and air quality on retired parcels.

Phytoremediation

Factors would include selenium mass and concentration in plant tissues, total weight of harvestable crop, reduction in available and total soil selenium, and mass of volatilized selenium.

Bioremediation of selenium in evaporation ponds is a process that has substantial potential for removal of selenium from agricultural drainage. Because of the short time period required for brine shrimp growth, the system could be adapted to a surface detention basin for timed-release of drainage. Because the bioremediation function may be obtained with a minimum pond size of 2 acres, the function may be integrated within agroforestry reuse systems. The harvest of brine shrimp provides an economic return to the grower.

Selenium Marketing

As is evident in the market information provided in Appendix A, a worldwide demand for selenium exists for beneficial industrial uses and essential nutritional needs of both humans and animals, wild and domestic. The U.S. is presently required to import selenium to meet existing domestic demand. A large need and demand for selenium products exists right in California, providing an opportunity to market selenium as a beneficial product of the Grasslands area, thereby reducing the total load of selenium being discharged in agricultural subsurface drainage to Mud Slough and the San Joaquin River.

Two methods of developing selenium products are possible. First, a number of methods of drainage treatment to remove selenium from subsurface drainage have been tested and some are currently being refined. At present, while several of these methods have been shown to be technically and actually feasible, none has yet been demonstrated to be economically feasible or cost-effective. The feasibility and cost of separation and purification of selenium from drainage treatment byproducts to achieve the standard of 99.5 percent purity for the industrial market should be investigated to determine if the income from the marketing of selenium could make any of the drainage treatments cost-effective. This may be unlikely given the current market price for selenium, but the market may change in the future, and more efficient methods of selenium separation and purification may be developed.

The second method is to produce an organic product and then to market that product directly to consumers in California and elsewhere through either wholesale or retail trade. The list of potential products could include organic high-selenium vegetables (such as the conventional broccoli, or unconventional salicornia) for human consumption, high-selenium yeast fermentation products for human nutritional supplements, hay and forage or compressed tablets for livestock consumption, other products for wildlife diet supplementation, and organic compost as an amendment for selenium deficient soils. Another opportunity would be the commercial harvesting of brine shrimp for the aquarium trade, grown in drainage detention ponds. The aquarium market requires a minimum selenium standard in food content. Commercial production of brine shrimp is currently underway in some Tulare Basin evaporation ponds.

The possibility even exists for the direct marketing of drainage water. This is not as far-fetched as it might seem. Among the literally thousands of internet web sites that are direct marketing selenium products for human and animal nutritional and health benefits, one enterprising gentleman in southern California is marketing what he calls Selenium Mineral Water, with the reputed health benefits of cancer prevention, improved immunity, increased longevity, and even mood lifting, at the retail price of $50/gallon.

Two problems may be encountered in the cultivation of high-selenium organic products. First, irrigation has leached much of the selenium from the soil root zone and into the shallow groundwater table where it is collected in tile drains for discharge. This selenium is therefore inaccessible to shallow-rooted crops, although it could be accessed by deep-rooted crops that can tap into the shallow groundwater. The increasingly widespread practice in the Grasslands of reusing subsurface drainage for irrigation of crops offers an opportunity to "recycle" selenium as well as drainage and to incorporate the selenium into agricultural products for marketing. The second problem is that high sulfate content in the soil, as is characteristic of the natural salts in the soil and water of the Grasslands, may restrict the uptake of selenium by plants, and high sulfate content in feed products may limit the absorption of selenium by livestock. More investigation is needed in this potential limitation on selenium use. However, the average applied water salinity of .8 dS/m with the use of recycled drainage is well below the level of 10-20 dS/m soil salinity level at which significant reduction in crop selenium accumulation would be expected to occur.

Active Land Management

[no text submitted]

Upper Watershed Management

[no text submitted]

Tradable Loads

[no text submitted]

II.3.6 Suggested Action Plan

Much of the selenium reduction that can be accomplished is occurring because of the load limitations required under the Use Agreement for the Grassland Bypass Project. Additional approaches will need to be implemented to achieve significant further reductions as specified in the Waste Discharge Requirements adopted by the Regional Board (see Appendix B). Long-term strategies need to be identified and implemented to achieve the long-term objectives for the San Joaquin River. The CALFED Water Quality Program should be comprised of a combination of the approaches described below.

Drainage Treatment

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.

Land Retirement

CALFED should encourage voluntary land retirement on a compensated basis, in areas where underlying shallow groundwater contains elevated selenium levels, the land is saline, and difficult to drain. Action by CALFED to promote voluntary land retirement in the Grasslands area as a means to reduce the discharge of selenium in agricultural drainage to the San Joaquin River should build upon the results of the USBR Land Retirement Demonstration Project, and the forthcoming SJVDIP Land Retirement Technical Committee report.

Phytoremediation

CALFED should encourage and solicit proposals for trial demonstration products for selenium phytoremediation through uptake and volatilization by selenium accumulating plant species that have 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, the reduction of selenium in discharged drainage, and reduction in the recycling of selenium leached through the soil back into shallow groundwater for future discharge.

CALFED should encourage and solicit proposals for the construction of small pilot evaporation systems in the Grasslands subarea for testing bioremediation of selenium and production and harvest of brine shrimp. The small evaporation systems would ideally be integrated into a drainage reuse system. CALFED could support the existing research at Lost Hills Drainage District by funding a monitoring program.

Selenium Marketing

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, new marketing opportunities, etc.

Active Land Management

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

CALFED should address selenium in stormwater runoff from Panoche and Silver Creeks, and provide funding to determine the specific contribution of upper watershed areas to selenium loads in discharged agricultural drainage, to identify and evaluate remediation alternatives, and ultimately assist with implementing the selected alternatives for reducing high selenium runoff from upper watershed areas. CALFED should also encourage and facilitate the ongoing effort to develop a Panoche/Silver Creek Coordinated Resource Management Plan.

Tradable Loads

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. The CALFED program should build upon the results of the Grassland Area Farmers' incipient program.

Research Needs

The necessity for overall selenium load limitations need to be verified through appropriate research and information gathering. A question has been raised over the adequacy of concentration based standards if control activities prove that concentration objectives can be met. The Environmental Protection Agency 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, there will be a need for the monitoring to determine what the appropriate standard would be for the San Joaquin River.

Additional field trials of selenium accumulating crop and forage species is 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 selenium products.

II.4 Selenium from Refineries

II.4.1 Solution Approaches

Goal

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 San Francisco Bay 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 percent by the year 2001. This goal has been set by the San Francisco Bay Regional Water Quality Control Board with the intent to reduce selenium concentrations in estuary organisms. If goals 1 and 2 above are met before the full 90 percent selenium reduction has occurred then this goal may be amended accordingly, but if those goals are not reached the Regional Board may have to take additional actions.

Treatment of Waste Streams

Selenium occurs in several different waste streams within 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 waste water treatment plant, and aerobic and anaerobic biochemical treatments.

Use of Alternative Crude Oil

The San Joaquin Valley crude oil, used primarily by Bay Area refineries, has 2 to 12 times higher levels of selenium compared to crude oil from other sources. A change to a cleaner crude oil would provide a reduction of selenium at the front end of the refining process.

Sour Water Reuse

Water used for desalting within the refining process (sour water) can be recycle and reused. This 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, waste water may be discharged through a wetland to remove selenium before the final discharge to the Bay. This treatment methods needs to be wildlife safe.

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II.4.2 Existing Activities

Refineries and regulatory agencies have spent millions of dollars studying the chemistry of the selenium in the various waste water 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 percent. Detailed evaluations and implementation of the most promising technologies such as iron co-precipitation and ion exchange continues. Delays in implementing full-scale treatment systems have occurred. Several refineries have met the 50 ppb discharge limit in the proposed selenium reduction schedule while other were to meet this limit by July 31, 1998. The Regional Board, along with other dischargers, is monitoring selenium loads from municipal waste water discharges and urban runoff to determine the significance of these sources.

Current environmental research includes the evaluation of selenium sources, levels, and consequences in the Delta in a study proposed by Samuel Luoma (USGS) and selected for funding by CALFED. An evaluation of the impacts of methyl-mercury and selenium interactions on clapper rail reproduction is being done by Steven Schwarzbach (USFWS). There is also ongoing monitoring of trace element in water, sediment, and bivalves through the Regional Monitoring Program.

II.4.3 Quantitative Analysis

[Not applicable at this time]

II.4.4 Estimate of Impacts

[Not applicable at this time]

II.4.5 Feasibility

Treatment of Waste Streams

The Regional Board determined that treatment technologies would provide the greatest emission reduction and be the fastest and most economical methods to achieve selenium reduction compared to conversion to a cleaner crude oil. The various forms of treatment processes have different levels of selenium removal success. Pilot studies have shown as much as 95 to 99 percent removal, but these removal rates can vary significantly among the different waste streams and from facility to facility. Also, they may not be as efficient on a full-scale level. Pilot studies using ion-exchange treatment systems have shown up to 95 percent selenium removal from phenolic waste streams, Sorbplus treatment up to 99 percent selenium removal from non-phenolic waste streams, and primary waste water treatment plants can remove 60 to 69 percent of the selenium from non-phenolic and other waste streams. Aerobic and anaerobic biochemical system have shown success in removing selenium also. The promising iron co-precipitation processes also produces a significant amount of selenium contaminated sludge that would likely require additional treatment and disposal as a hazardous waste. Location of the treatment process within the waste streams and pretreatment may reduce the amount of sludge generated. Costs for implementation of full-scale treatment facilities range in the many tens of millions of dollars.

Use of Alternative Crude Oil

San Joaquin crude oil contains up to 600 ppb selenium, compared to a maximum of 250 ppb in crude oil from other places in the world. Each refinery uses a different amount of San Joaquin crude oil in its refining process. Switching to a greater percentage of cleaner crude oil would reduce the selenium loads. Refineries have argued that each facility is designed to handle that particular mixture of crude oil and switching to a different crude would require a significant and expensive change to the facilities. The Regional Board has determined that a combination of treatment processes would be faster, more economical, and produce greater selenium load reduction than switching to a cleaner crude. Using less San Joaquin Valley crude along with other treatment and control options would help reduce selenium loads.

Sour Water Reuse

Many refineries recycle and reuse sour water for desalting, some up to 100 percent, and have seen a reduction in selenium loads. This control method in combination with other treatment and control options would help reduce selenium loads.

Wetland Discharge Treatment

This final end-of-pipe removal process, needs to be wildlife safe to avoid creating attractive nuisances. Wetlands efficiently remove selenium but fish and wildlife resource using such facilities are at risk. Elevated selenium levels in biota and deformed bird embryos have been documented in one such wetland used by a refinery in the estuary.

Adequate Data

Although, pilot treatment projects have shown promise, implementing full-scale projects has been a slow, difficult, and expensive endeavor. Current information on the effects of selenium in biota has been sufficient to develop general risk guidelines as proposed in several peer reviewed journals but site-specific information in needed to adequately address the local needs of regulators and dischargers.

Institutional Framework

The U.S. EPA, State Board, and Regional Board regulatory framework is in place. The Regional Board has issued discharge requirements, cease and desist orders, and proposed a mass emission strategy, although not necessarily fast enough or to the satisfaction of all parties interested in this issue. Cooperation among the various petroleum refineries and interested parties will be important to the overall success of the program.

Timing

An earlier extension to meet discharge requirements ends July 31, 1998 and it appears that some refineries will not meet this deadline; thus, support from CALFED would be useful at this time.

Success

There is a strong possibility of success in reducing selenium loads from refinery discharges but how much, when, and at what economic costs are the important questions. Several refineries have reduced selenium loads using combinations of the various control and treatment technologies currently available.

II.4.6 Suggested Action Plan

Support ongoing and new research of the impacts of selenium in the estuary to provide regulatory agencies with needed information to refine current actions. Evaluate the potential interactions between selenium and mercury. Continue and refine monitoring efforts to document improvement in the estuary from reduced selenium loadings. Work with regulatory agencies on developing incentives for selenium load reduction by the refineries.

POTENTIAL MARKET OPPORTUNITIES FOR AGRICULTURAL SELENIUM

Worldwide Production and Market for Beneficial Uses of Selenium

Worldwide production of refined selenium for beneficial uses was 2,150 metric tons in 1996 (year of most recent complete data). After Japan and Canada, the United States was the third largest producer at 379 metric tons. The primary production of selenium is as a by-product of copper refining, in the form of shot, lumps, and powder of 99.5% average minimum purity. Domestic commercial production of selenium is from three copper refineries, two in Texas, and one in Utah. Domestic production does not meet total U.S. demand, resulting in the import of 434 metric tons in 1996. Secondary production of selenium outside the U.S. is recovery from scrap manufactured products, principally copier machines. In comparison, the selenium discharged in Grasslands subsurface drainage to Mud Slough in the 1997 water year was 3.2 metric tons, about 0.15 % of worldwide production, and 0.84% of U.S. production. The average concentration of selenium in copper ore is about 20 ppb. This compares with a average selenium concentration in Grasslands drainage of 64 ppb, three times greater.

Worldwide uses for commercial selenium and percent of total in 1996 are as follows:

- glass manufacturing (decolorant, red traffic light pigment, and solar heat transmission reducer) 25%
- agriculture and other uses (livestock nutritional supplements, fertilizer compound) 20%
- metallurgy (lead replacement in plumbing fixtures, alloy compounds, batteries) 16%
- chemicals (human nutritional supplements, anti-dandruff shampoos - as in Selsun Blue, lubricants, rubber compounds, gun bluing, catalysts) 15%
- pigments (heat-stable red color in ceramics, plastics, paints, and inks) 8%
- electronics (copier photoreceptors - becoming obsolete usage, rectifier and photoelectric applications) 16%

Selenium is traded as a commodity worldwide. 1997 average price was $2.90/lb., down from $5.82/lb. in 1990. Increased worldwide and domestic production continues to exceed rising demand, resulting in a modest surplus and falling prices.

Importance of Selenium in Human and Animal Health

Recent research has shown that selenium is an essential element in the production of antioxidants in the human body and that selenium plays an important role in human disease prevention. Epidemiological evidence gathered worldwide shows that people who live in areas with naturally high soil selenium and with a dietary intake of about 750 mcg/day, have a significantly lower risk for cancer while showing no toxic effects. Cancer patients typically have low selenium levels, and those with lower than average levels experience more severe cancers. Lower selenium levels in humans are also associated with increased occurrence of heart disease, arthritis, and muscular dystrophy, as well as generally lowered immunities. Se supplementation has been found to be effective as a treatment for these illnesses and in stimulating the immune system, and additionally has shown indications of counteracting the effects of aging and protecting against the effects of some toxins (Lieberman and Bruning 1997).

The current U.S. Government Nutrition Standard, or Reference Daily Intake (RDI) for selenium is 70 mcg/day. Studies have shown that the average daily dietary intake of selenium is about 100 mcg/day, but that individual intakes vary widely depending on the source of food (Lieberman and Bruning 1997). In the U.S., high soil Se is found in North and South Dakota as well as the westside San Joaquin Valley, but most of the agricultural soils of the U.S. are deficient or depleted of selenium. Selenium is generally low in fruits and vegetables, and higher in seafoods and meats, but only if the animals had a diet high in selenium. Exceptions are onions, garlic, broccoli, and whole grains, which may have high concentrations if grown in high selenium soil. A dietary, organic form of selenium, selenomethionine, has been found to be the most assimilable form and least potentially toxic in humans. Selenomethionine can not be synthesized by the body, so must be obtained through diet or supplementation.

Selenium is the subject of research at places such as the National Cancer Institute, and research articles on selenium regularly appear in prestigious medical journals such as the *New England Journal of Medicine, British Medical Journal, Lancet, American Journal of Epidemiology, Cancer Research*, and *American Journal of Clinical Nutrition*, among others. A range of 200-400 mcg/day of selenium has now been recommended as an optimum daily intake for health maintenance and prevention of disease such as cancer. Selenium toxicity in humans, from intake of selenomethionine, has not been found to occur until levels exceed 2400 mcg/day for some, and more generally, 5000 mcg/day. Toxicity in humans from sodium selenate may occur at ingestion of more than 1000 mcg/day (Lieberman and Bruning 1997). While sodium selenite has been found to be carcinogenic in high doses, organic selenium has not been found to be carcinogenic (Ronzio 1997).

Pills typically containing 200 mcg of Se in the form of selenomethionine as a dietary supplement, can now be commonly found on U.S. store shelves not only in health food stores, but also pharmacies, supermarkets, and large discount chain stores. Selenium tablets for human consumption are now generally available worldwide. Literally thousands of internet sites directly market selenium products for human and animal health benefits. Pharmaceutical companies produce selenium supplements by cultivation and extraction from selenium-rich yeast.

Natural Scarcity and Requirement for Se Supplementation in Fertilizers and Animal Feed

On a worldwide scale, much larger areas of the earth are deficient in selenium than have an excess. Selenium deficiency is much more widespread than selenium toxicity. Natural selenium deficiency in parts of China has resulted in human deaths from Keshan's disease. Deficiencies in Finland and New Zealand have resulted in government programs of selenium supplementation. In Finland, concern over increased rates of cardiovascular disease and some types of cancer led to a government requirement since 1984 that all fertilizers sold and applied to Finnish soil be supplemented with 6 mg/kg of selenium. In addition to New Zealand, selenium fertilizers are also used in Australia, Sweden, and the United Kingdom. In the United States, natural selenium deficiency in soils is found throughout the Pacific Northwest, Northern Rockies and portions of the Great Basin, the Great Lakes and Mid-West regions, New England and the Northeast, and portions of the Southeast. A survey of state veterinary diagnostic laboratories found selenium deficiency has been diagnosed in 46 states, and as been identified as a major problem for livestock or wildlife or both in 37 states.

Selenium supplementation in livestock and poultry production has become a standard animal production technology and has been adopted worldwide. Selenium is in the group of mineral elements considered of vital necessity and indispensable for preserving animal health and maximizing productivity. Selenium is imparted to livestock through feed and forage grown in selenium sufficient areas, fertilization of grazing and haying soils, and direct supplementation with pellets, boluses, injections, salt licks, etc. The annual total of selenium use for livestock in the U.S. is 47.5 tons. In California, selenium supplementation of beef cattle is widespread in Northern California, and is even given to range cattle in some portions of the San Joaquin Valley. A study of mule deer herds in 15 regions of California found that two-thirds of the herds showed widespread selenium deficiency. One trial program of supplementation with boluses resulted in a 2.6-fold increase in fawn survival over a 3-year period.

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APPENDIX B
SUMMARY OF SELENIUM WATER QUALITY OBJECTIVES AND COMPLIANCE TIME SCHEDULE (CRWQCB, CVR, 1996)

Selenium Water Quality Objectives (in Bold) and Performance Goals (in italics)

	Applies No Later Than			
Water Body/Year Type	10 January 1997	1 October 2002	1 October 2005	1 October 2010
Salt Slough and Wetland Water Supply Channels	**2 µg/l monthly mean, 20 µg/l maximum**			
SJR below the Merced River to Vernalis; Above Normal and Wet Water Year Types	**12 µg/l maximum**	*5 µg/L monthly mean*	**5 µg/L 4-day avg.**	
SJR below the Merced River to Vernalis; Critical, Dry, and Below Normal Water Year types	**12 µg/l maximum**	*8 µg/L monthly mean*	*5 µg/L monthly mean*	**5 µg/L 4-day avg.**
SJR above the Merced River to Sack Dam and Mud Slough (north)	**20 µg/l maximum**			5 µg/L 4-day avg.

[1] The water year classification will be established using the best available estimate of the 60-20-20 San Joaquin Valley water year hydrologic classification (as defined in Footnote 17 for Table 3 in the SWRCB's *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary*, May 1995) at the 75 percent accedence level using data from the Department of Water Resources Bulletin 120 Series. The previous water year's classification will apply until an estimate is made of the current water year.

SELENIUM LOAD LIMITS IN POUNDS

MONTH	WATER YEAR 1998	WATER YEAR 1999	WATER YEAR 2000	WATER YEAR 2001
OCT		348	348	348
NOV		348	348	348
DEC		389	389	389
JAN		506	479	453
FEB		823	779	736
MARCH		1,013	959	906
APRIL		759	719	679
MAY		633	599	566
JUNE		569	539	509
JULY		569	539	509
AUG	533	506	480	453
SEPT	350	350	350	350
TOTAL ANNUAL LOAD	N/A	6,327	5,994	5,661

MONTHLY WASTE LOAD ALLOCATIONS (POUNDS OF SELENIUM) FOR THE PROJECT SERVICE AREA BASED ON APPLICABLE PERFORMANCE GOALS AND SELENIUM OBJECTIVES FOR THE SAN JOAQUIN RIVER AT CROWS LANDING

MONTH	EFFLUENT LIMITS WHICH APPLY NO LATER THAN 1 OCTOBER 2002	EFFLUENT LIMITS WHICH APPLY NO LATER THAN 1 OCTOBER 2002	EFFLUENT LIMITS WHICH APPLY NO LATER THAN 1 OCTOBER 2005	EFFLUENT LIMITS WHICH APPLY NO LATER THAN 1 OCTOBER 2005	EFFLUENT LIMITIS WHICH APPLY NO LATER THAN 1 OCTOBER 2010
	DRY YEARS	WET YEARS	DRY YEARS	WET YEARS	DRY YEARS
OCT	114	328	69	260	41
NOV	114	328	69	260	41
DEC	303	461	186	211	131
JAN	302	461	186	211	131
FEB	284	432	169	297	99
MARCH	284	432	169	297	98
APRIL	293	450	178	315	107
MAY	296	457	181	322	111
JUNE	126	262	76	212	64
JULY	127	264	77	214	65
AUG	132	274	83	225	70
SEPT	116	332	71	264	43
TOTAL ANNUAL LOAD	2,492	4,481	1,515	3,087	1,001

[1] As used in the above table, the term Dry Years includes years classified as Critically Dry, Dry, and Below Normal and the term Wet Years includes those classified as Above Normal and Wet. The water year classification will be established using the best available estimate of the 60 20-20 San Joaquin Valley water year hydrologic classification (as defined in Footnote 17 for Table 3 in the State Water Resources Control Boards's *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary*, May 1995) at the 75 percent accedence level using data from the Department of Water Resources Bulletin 120 Series. The previous water year's classification will apply until an estimate is made of the current water year.

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