CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

San Joaquin River Basin Plan Amendment

SALINITY: A LITERATURE SUMMARY FOR DEVELOPING WATER QUALITY OBJECTIVES

DRAFT

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INTRODUCTION

The State Water Resources Control Board's 1995 Bay-Delta Water Quality Control Plan directed the Central Valley Board to continue their effort to reduce salt loads in the San Joaquin River (SJR). The State Board reiterated its prior directive to the Regional Board to reduce annual salt loads discharged to the San Joaquin River by at least 10 percent.

This report was prepared as part of a Basin Planning effort described in the *Work Plan for the San Joaquin River Basin Plan Amendment Addressing Salinity and Boron* (CRWQCB, CVR 1997). It summarizes the impact of salts on the beneficial uses and will be used as background for the development of salinity objectives for the Lower San Joaquin River. The report has three sections. The first section presents a brief overview of salinity in the San Joaquin River. The second summarizes the effects of salinity on six categories of beneficial uses. The third discusses various water quality criteria for salinity.

SALINITY IN THE SAN JOAQUIN RIVER

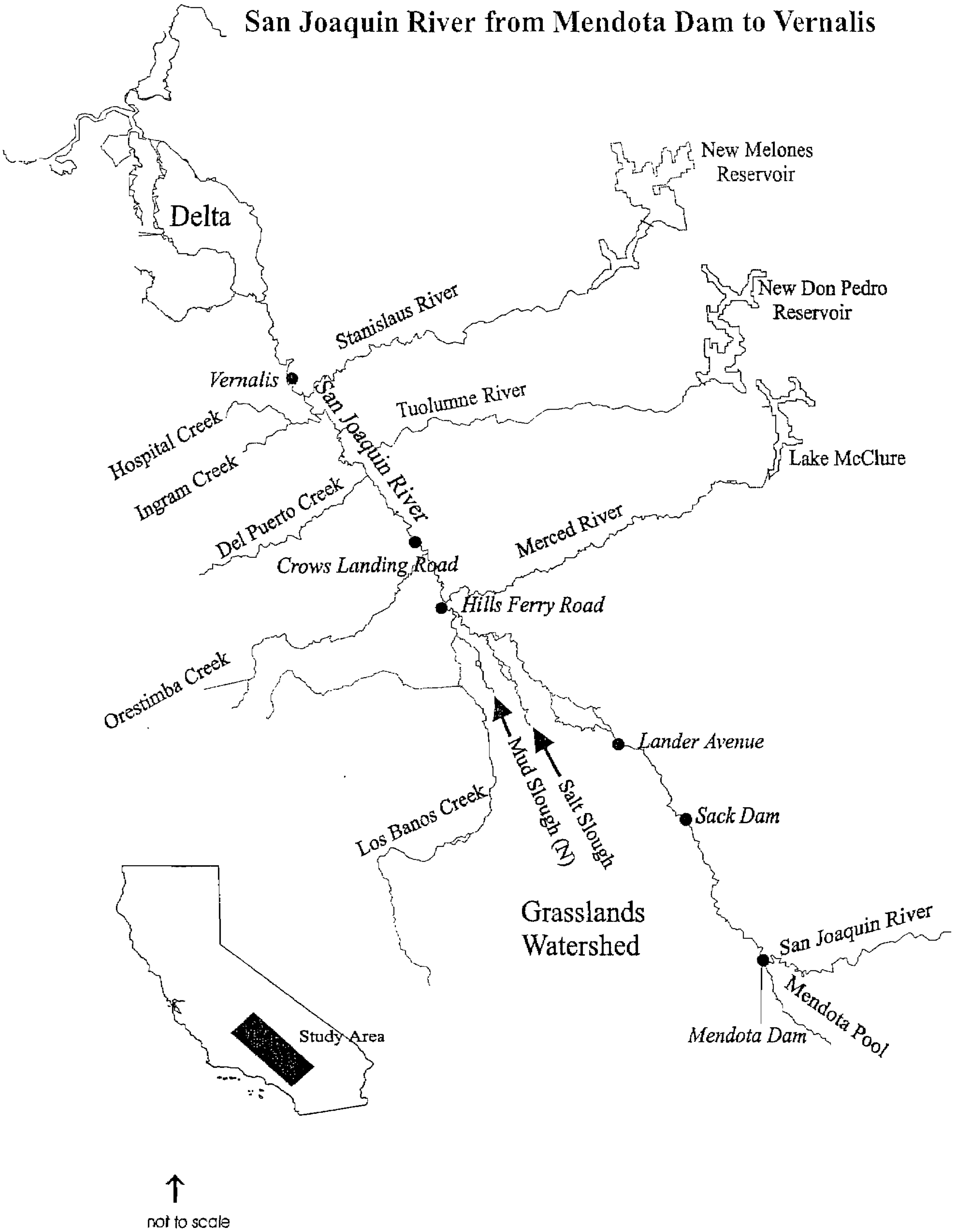
Salinity in water is typically measured as electrical conductivity (EC) or total dissolved solids (TDS). It has also been reported, particularly in older documents, as specific conductivity and dissolved solids. Empirical relationships between TDS (in mg/L) and EC (in μmhos/cm) have been correlated with a high degree of confidence. TDS to EC ratios for the San Joaquin River from Lander Avenue to Vernalis (Figure 1) have averaged from 0.590 to 0.686 by location (SWRCB, 1987, Appendix C).

Figure 2 compares EC from May 1985 through January 1998 for a downstream site, Airport Way near Vernalis, and a site approximately 30 miles upstream at Hills Ferry Road above the confluence of the Merced River. EC is consistently higher at the upstream site. For a single grab sample, electrical conductivity ranged from 132 to 1,680 μmhos/cm (TDS of 85 to 1,092) in the Lower San Joaquin River at Airport Way. EC at Hills Ferry Road ranged from 76 to 4,120 μmhos/cm (TDS 50 to 2,680).

Table 1 presents the mineral composition for these two locations as compared to seawater. The SJR is more of a sulfate-dominated system than sea water, which is more chloride-dominated. The SJR also has a higher proportion of calcium and magnesium ion compared to sodium than sea water.

FIGURE 1.

San Joaquin River from Mendota Dam to Vernalis



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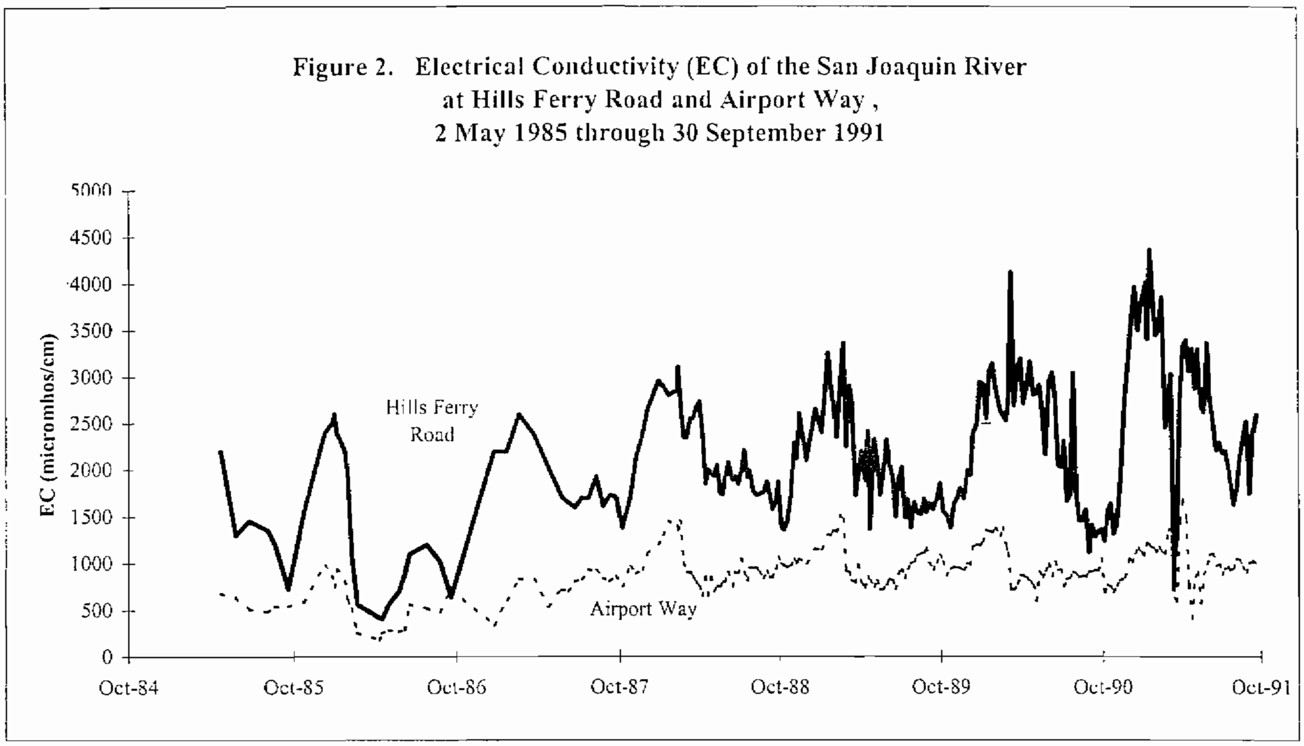
Figure 2. Electrical Conductivity (EC) of the San Joaquin River
at Hills Ferry Road and Airport Way ,
2 May 1985 through 30 September 1991
EC (micromhos/cm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Hills Ferry
Road
Airport Way
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91

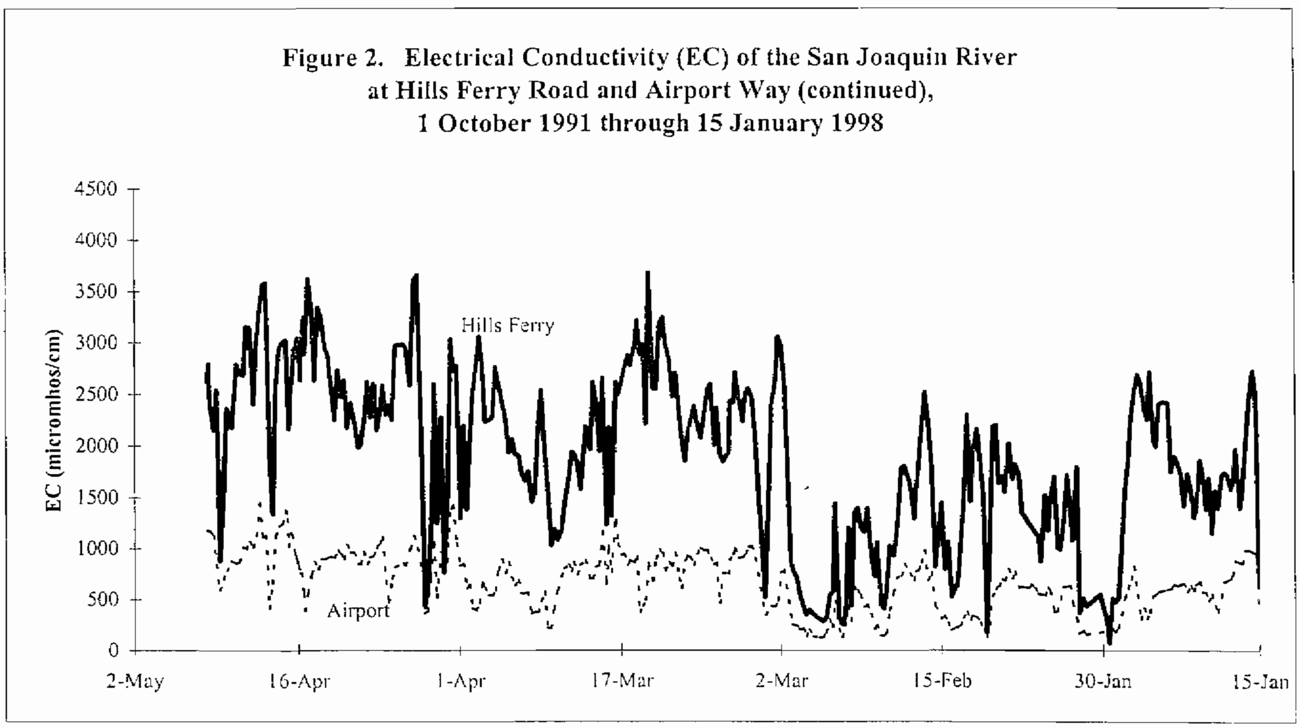
Figure 2. Electrical Conductivity (EC) of the San Joaquin River
at Hills Ferry Road and Airport Way (continued),
1 October 1991 through 15 January 1998
EC (micromhos/cm)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Hills Ferry
Airport
2-May
16-Apr
1-Apr
17-Mar
2-Mar
15-Feb
30-Jan
15-Jan

Table 1. Mineral Water Quality at Hills Ferry Road and Airport Way, October 1995 - June 1998, Compared to Sea Water

		Airport Way		Hills Ferry Road		Seawater	
		mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
Calcium	Ca	23	1.15	55	2.74	410	20.46
Magnesium	Mg	11	0.90	28	2.30	1,350	110.97
Sodium	Na	22	0.96	73	3.18	10,500	456.75
Potassium	K	2.7	0.07	4.6	0.12	390	9.98
Bicarbonate	HCO_3	57	0.93	101	1.66	142	2.33
Sulfate	SO_4	62	1.29	224	4.66	2,700	56.16
Chloride	Cl	53	1.49	157	4.43	19,000	535.80

Note: Seawater composition is from Hem (1985).

EFFECTS OF SALINITY BY BENEFICIAL USE CATEGORIES

A number of beneficial uses have been designated in the Basin Plan for the Lower San Joaquin River. Of these, municipal/domestic, fish and other aquatic life, industrial, irrigated agricultural, stock and poultry drinking water, and wildlife uses have been documented as being sensitive to various concentrations of salinity. Studies dealing with seawater, a chloride dominated system, are not emphasized in this report. Toxicological studies for evaporation ponds that have TDS concentrations as high as 395,000 mg/L are also not emphasized because of the differences between a more dilute flowing river and an evaporation pond system.

This report includes information from publications that deal with salinity in sulfate dominated systems similar to the San Joaquin River. Toxicological studies are usually performed on specific chemical constituents; however, some of these studies deal with the effects of saline water in general. Some publications provide summaries of water quality criteria. This report draws upon these publications to summarize the effects of salinity on beneficial uses.

Municipal and Domestic Water Supplies

According to McKee and Wolf (1963), many communities have used water containing from 2,000 to 4,000 mg/L of dissolved salts when no better water is available. But such waters are generally not palatable, may act as a laxative on new users, and may not quench thirst. Waters containing more than 4,000 mg/L of total salts are normally considered unfit for human use, but tolerance of higher salt concentrations is greater in hot climates than in temperate climates. Waters containing 5,000 mg/L or more of dissolved solids are reported to be bitter and act as bladder and intestinal irritants (McKee and Wolf, 1963).

In 1963, it was generally agreed that the salt concentration of good, palatable water should not exceed 500 mg/L (McKee and Wolf, 1963). However, water having higher concentrations could be consumed without harmful physiological effects and may be a source of necessary minerals. McKee and Wolf (1963) also stated that water with a TDS of over 1,000 mg/L should be evaluated based on the local situation, alternative water supplies, and the reaction of the local population.

United States Protection Agency (US EPA) has published water quality criteria reference documents. In a study of water with TDS values ranging from 100 to 2,300 mg/L, consumer acceptance decreased as mineral content increased (US EPA, 1973). High concentrations of mineral salts, particularly sulfate and chloride, can result in expensive corrosion damage in water systems. US EPA (1973), however, recognized that a large number of water supplies that contained dissolved solids with concentrations greater than 500 mg/L were used without obvious side effects.

Consumer surveys in 29 California water systems were taken in the 1960s to measure taste thresholds of dissolved salts (US EPA, 1976; 1986). Results by ranges of dissolved solids concentrations were follows:

319 to 397 mg/L dissolved solids as "excellent,"
658 to 755 mg/L as "good," and
1,283 to 1,333 mg/L as "unacceptable."

Salinity levels have been recommended for public drinking water. In 1962, the U.S. Public Health Service recommended a maximum dissolved solids concentration of 500 mg/L for drinking water unless more suitable supplies were unavailable (US EPA, 1976; 1986). The Environmental Health Law under California Code Regulations (CCR) Title 22, Article 16, recognizing that salinity and other constituents may adversely affect the taste, odor, or appearance of drinking water, recommended a secondary maximum contaminant level (MCL) of 500 mg/L TDS (900 µmhos/cm EC) with an upper limit of 900 mg/L TDS (1,600 µmhos/cm EC). This MCL is applied to community water systems administered by the California Department of Health Services and is referenced for domestic and municipal water supply use in the Regional Board's Basin Plan water quality objectives chapter (p. III-3.00). In a policy entitled "Sources of Drinking Water," the State Water Resources Control Board (SWRCB) in Resolution No. 88-63 stated that surface and ground water with a TDS less than 3,000 mg/L (5,000 µmhos/cm EC) is suitable or potentially suitable for municipal or domestic water supply.

Fish And Other Aquatic Life

According to McKee and Wolf (1963), an industrial waste report states that 95 percent of the inland waters in the United States with dissolved solids concentrations under 400 mg/L supported a good mixture of fish populations. A few fresh water fish species have been found in natural waters with a salt concentration as high as 15,000 to 20,000 mg/L of dissolved solids. Fish can gradually acclimate to higher saline concentrations than they are accustomed to, but fish in lower salinity water cannot survive sudden exposure to higher salinity levels.

According to US EPA (1976; 1986), all species of fish and other aquatic life must tolerate a range of salinity to survive in nature. They cite studies in Saskatchewan, Canada that indicated many common freshwater species survived in water of 10,000 mg/L dissolved solids. Only two species, whitefish and pike-perch, survived 15,000 mg/L. Only one species, stickleback survived 20,000 mg/L dissolved solids. Dissolved solids in excess of 15,000 mg/L were considered unsuitable for freshwater fish.

The San Joaquin Valley Drainage Program (1990a) reviewed the biological effects of total dissolved solids from agricultural drainage. Preliminary experiments had shown juvenile chubs to be more sensitive than larger fish (Pimentel and Bulkley, 1983). Squawfish, chub, and bonytail preferred TDS ranges of 560 - 1,150, 1,000 - 2,500, and 4,100 - 4,700 mg/L, respectively. The same species of fish avoided high TDS concentrations of 4,400, 5,100, and 6,600 mg/L, respectively. Temperature was considered an important variable in determining acceptable salinity levels. Low temperature reduces the ability of fish to regulate internal salt balance. Hence, salinity concentrations acceptable in the summer months were avoided in the winter.

According to Saiki, *et al.* (1992), survival of Chinook salmon was significantly reduced by exposure to 100% tile drain water with TDS that ranged from 12,000 to 18,000 mg/L. Much of their analyses dealt with the toxicity of trace elements. They also evaluated the dilution effect of San Joaquin River water collected at Crows Landing Bridge. Chinook salmon that survived 28 days of exposure were analyzed for trace elements (selenium and boron). Concentrations of these two trace elements in whole Chinook salmon bodies increased as the percentage of drain water increased. TDS in the River water ranged from 900 to 1,400 mg/L; TDS in the drain water ranged from 18,000 to 23,000 mg/L.

Juvenile salmon migrating from the Merced, Tuolumne and Stanislaus Rivers move from a freshwater environment to the San Joaquin River, which is sulfate-dominated, to the south Delta, which is fresher water, to the Bay, a chloride dominated water body. These out-migrants are also undergoing physiological changes during smoltification that allow them to adapt to marine environments. There is no information available on the effects of sulfates from the San Joaquin River on juvenile Chinook salmon during the out-migration and smoltification process. It is also unknown how long these smolts remain in the San Joaquin River. Analyses suggest that mortality during the smolt life stage is an important determinant in adult production in the San Joaquin Drainage (CDFG, 1991).

Research is needed to determine the exact effects of salinity in the San Joaquin River on Chinook smolts and their rearing time in the river. Adult salmon migration into the San Joaquin River is initiated by fresh outflow from eastside tributaries. The timing of adult Chinook salmon migrating upstream to spawn may be delayed due to high salinity (Bull, 1998).

According to Saiki, *et al.* (1992), survival of striped bass was affected by exposure to tile drain water but not by exposure to reconstituted seawater. They stated that fish in reconstituted seawater, which had concentrations of TDS similar to the tile drainage water but with chloride instead of sulfate as the dominant anion, survived and developed well. They concluded that the toxicity of tile drain water is not a simple effect of excessive concentrations of dissolved salts. Tile drain water in their study was toxic because salmon and striped bass were not able to tolerate the unusual ratios of major cations, anions, and/or sulfates. They recommended considering potential toxicity from unusual ratios of major ions and high concentrations of sulfate.

The toxicity of agricultural drainage water was not directly related to high concentrations of total dissolved solids. Saiki, *et al.*, (1992) ran twenty-eight day exposure tests using waters with different mixtures and concentrations of salts. Juvenile chinook salmon and striped bass survived and grew well in reconstituted sea water with TDS concentrations similar to those in the agricultural drainage water, but with chloride instead of sulfate as the dominant anion. However, fish in drainage water at lower salt concentrations (50% dilution) experienced either death or poorer growth.

Mehrle, *et al.* (1987) did chronic toxicity tests on striped bass (*Morone saxatilis*) larvae in water to simulate Chesapeake Bay area conditions. Saline water at a TDS of 2,000 mg/L caused significant mortality after 30 days of exposure. They concluded that both the contaminants and salinity of the water must be considered in evaluating the effect of environmental contaminants on striped bass.

Striped bass is an introduced sport fish. Research has been performed on their spawning habitat in the Sacramento-San Joaquin Delta estuary. California Department of Fish and Game (CDFG, 1989) studied the effects of salinity on striped bass in the Delta estuary and concluded:

> "Low flows in the San Joaquin River near Stockton often combine with Agricultural drain water to create an effective dissolved solids barrier to upstream migration and spawning by striped bass. This problem has two causes; upstream water diversions and agricultural waste waters. The basic water quality problem is one of high total dissolved solids.
>
> A major complication here is that if the dissolved solids barrier is eliminated, adult bass will move much father up the San Joaquin before they spawn. The resultant eggs and larvae, however, would immediately become vulnerable to ready entrainment into the nearby SWP and CVP pumping plants near Byron."

Turner and Farley (1971) ran laboratory experiments to determine the effects of Delta salinity, temperature, and dissolved oxygen on the survival of artificially spawned striped bass eggs and larvae. Egg survival occurred in water with TDS of 1,000 mg/L (1,538 µmhos/cm EC) and lower throughout the temperature range (58 through 72 degrees F). Spawning of striped bass upstream in the Lower San Joaquin River upstream of the Delta is infrequent because of water diversions

(Miller, 2000). However, reducing salinity upstream is important for protecting stripped bass spawning habitat in the Delta.

Dwyer, *et al.* (1992) analyzed toxicity of striped bass and water flea (*Daphnia magna*) using irrigation drain water entering Stillwater Wildlife Management Area, Nevada. They noted that *D. magna* showed 100% mortality (or immobility) in test waters at 10,000 to 11,500 mg/L of TDS after 48 hours of exposure. Striped bass were more tolerant of highly saline waters than *D. magna*; their tolerance was inversely related to the hardness of the water. Lethal effects of salinity on striped bass depend on the specific ionic composition of the saline water. A mixture of trace elements was toxic to striped bass even though individual elements were below expected acutely lethal concentrations. Dwyer, *et al.* (1992), concluded that salinity is an important water quality characteristic, but the ionic composition of water must also be considered.

Mount and Gulley (1992) developed relationships for salinity that predict acute toxicity of saline waters to freshwater organisms based on major ion composition. Their study focused on seven major ions (sodium, potassium, calcium, magnesium, chloride, sulfate, and bicarbonate) and three freshwater test species (two water fleas, *Ceriodaphnia dubia* and *Daphnia magna*, and a flathead minnow, *Pimephales promelas*). The sulfate ion was the least toxic; potassium was the most toxic of the ions analyzed. Sodium and calcium did not appear to be directly toxic to any of the test species. Their relationships were based on laboratory toxicity tests on over 3,000 combinations of major ions and the development of multivariate regression equations that related major ion concentrations to survival of the three test species.

Industrial

The effects of salinity on industrial uses have been published in criteria documents. According to McKee and Wolf (1963), dissolved solids in industrial waters can result in foaming inside boilers and can interfere with clearness, color, or taste of many finished products. Elevated concentrations of salts also can accelerate corrosion. Table 2 displays their recommended concentrations for industrial waters used in various processes. Food processing, food equipment, and dairy wash waters are existing uses of water in the San Joaquin Valley, and are the most probable beneficial industrial uses. These uses can tolerate an EC of 1,300 micromhos/cm or lower.

US EPA's (1973) water quality criteria summarize characteristics of surface waters that have been used as sources of industrial water supplies. Maximum concentration of dissolved solids ranged from 150 mg/L used in the textile industry to 118,524 mg/L for use in oil recovery injection waters. A maximum of 1,000 mg/L was used for cooling water. The chemical and petroleum industry used maximum concentrations of 2,500 and 3,500 mg/L, respectively. The primary metals industry used 1,500 mg/L of dissolved solids. Table 3 shows maximum values for industrial processes according to EPA (1976).

TABLE 2. Limiting Concentrations Of Dissolved Solids For Industrial Waters (McKee And Wolfe, 1963)

Industry and Use of Water	Limiting Concentration, mg/L
Boiler feed water	50-3000 (varies according to pressure)
Brewing, light beer	500
Brewing, dark beer	1,000
Brewing and distilling, general	500-1500
Canning and freezing	850
Carbonated beverages	850
Confectionery	50-100
Dairy wash waters	850
Food equipment washing	850
Food processing, general	850
Ice manufacture	170-1300
Plastics, clear	200
Paper manufacturers:	
Fine papers	200
Ground wood papers	500
Kraft paper, bleached	300
Kraft paper, unbleached	500
Soda and sulfate pulp	250
High-grade paper products	80
Lower-grade products	150-200
Rayon manufacture	100-200

TABLE 3. Total Dissolved Solids Concentrations of Surface Waters That Have Been Used as Sources for Industrial Water Supplies (EPA, 1976; 1986)

Industry/Use	Maximum Concentration (mg/L)
Textile	150
Pulp and Paper	1,080
Chemical	2,500
Petroleum	3,500
Primary Metals	1,500
Copper Mining	2,100
Boiler Make-up	35,000

Irrigated Agriculture

Salinity can impact agricultural crops. As salt content increases in soil water, it becomes increasingly more difficult for crops to draw moisture into roots. Crops have been observed to wilt in fields as a result of saline conditions in soils even with adequate soil moisture. Seasonal and climatic factors, such as high evapotranspiration rates, may contribute to such conditions. Continued irrigation with highly saline irrigation water will result in salt accumulation in the root zone. Irrigation with water low in TDS is needed to leach salts from the zone.

Ayers and Westcot (1985) also provided ranges of EC and TDS as guidelines for interpreting water quality for irrigation as follows:

	Degree of Restriction on Use		
	None	Slight to Moderate	Severe
EC in μmhos/cm	<700	700-3,000	>3,000
TDS in mg/L	<450	450 - 2,000	>2,000

They also provide yield potential for crops for different concentrations of salinity in irrigation water.

According to Maas (1990), salt tolerance of crops depends on the frequency of irrigation with highly saline water, soil fertility, physical condition of the soil, salt distribution in the soil profile, irrigation method, and climate. He stated that crops may be able to tolerate periodically high levels of saline water if salts are leached from the soil by irrigation water low in salts. Adequate nutrients can help alleviate the inhibition of growth caused by elevated salinity levels.

Maas (1990) also reports that crop tolerance to salt depends on the type and frequency of irrigation with saline water at TDS concentrations of 2,450 mg/L or less. The extent of crop damage varied depending on whether a drip, furrow, or sprinkler irrigation system was used. He states that climate influences plant response to salinity more than any other factor. Studies on several crops grown at high temperatures and low relative humidity showed decreased yields associated with highly saline waters.

Maas (1990) also discussed salt tolerance during stages of growth. He stated that most plants are tolerant during germination, but became more sensitive to salts during states of emergence and early seedling growth. Young plant roots of emerging plants are exposed to greater stress from salts than the roots of more mature plants.

Salt tolerance varies by crop. Fruit and nut crops are generally more sensitive to salts than grasses and forage crops. Maas (1990; figure 13.3) and Maas and Grattan (1999; Figure 3-3) developed a number of tables relating salt tolerance as EC ranges to crop type. Table 4 summarizes these results. Based on a SJVDIP (1999) table of these ranges and on conversion factors in Ayers and Westcot (1995; Figure 10 and Table 2), crop tolerance to salinity at 100% relative crop yield for EC in soil saturation extract (ECe) and TDS (mg/L) and (ECw) in irrigation water in μmhos/cm are classified as follows:

	ECe	ECw	TDS

Sensitive	0 – 1,600	0 - 1,067	0 – 693
Moderately Sensitive	1,600 – 3,200	1,067 - 2,133	693 - 1,386
Moderately Tolerant	3,200 – 6,300	2,133 – 4, 200	1,386 – 2,730
Tolerant	6,300 – 10,200	4,200 – 6,800	2,730 – 4,420
Yields Unacceptable For Most Crops	>10,200	>6,800	>4,420

Conversions factors are: 1,000 µmhos/cm = 1 dS/m; TDS/EC ratio of 0.65; ECe = 1.5 ECw
The EC and TDS ranges in irrigation water were based on research on EC in the soil saturation extract. The relationship of EC in irrigation water can vary depending on leaching, evaporation, porosity, and other site-specific factors. The addition of less saline water through irrigation or rainfall can reduce the effects of salinity in Lower San Joaquin River water.

Maas and Grattan (1999) published a monograph updating the effects of salinity on crop yields. The most common response to salt stress is stunting of growth. As Maas concluded in 1990, young developing seedlings are most susceptible to injury even though most crops are tolerant during germination. However, generally most plants become increasingly tolerant to salinity during late stages of growth after establishment. Salt stress can delay germination and emergence. Cultural practices, such as irrigation methods and seed bed arrangements, can improve the crops susceptibility to salinity.

Poultry and Livestock Drinking Water

Much of the research on the effect of salinity in poultry and livestock drinking water was performed prior to 1960. Table 5 summarizes this research. Poultry and livestock can be injured by drinking water that contains excessive dissolved solids. Weakness, reduced milk or egg production, bone degeneration, and death may result from drinking highly saline waters.

Animals can temporarily drink highly saline water without harmful effects. Animals can also adjust to gradual increases in concentrations of salts, but a sudden increase from slightly to highly mineralized waters causes acute distress and diarrhea of varying severity. According to McKee and Wolfe (1963), the ability to adapt to saline water depends on the salt composition present, animal species, diet, age, physiological condition, season of year, climate, and other factors.

The US EPA (1973) *Water Quality Criteria* document summarizes several studies on the effects of saline waters on beef heifers in Nevada. Waters containing about 5,000 mg/L or less of sodium sulfate showed no effects of specific ions, but heifers drank less, lost weight, and had increased methemoglobin and sulfhemoglobin levels. More recent US EPA criteria publications (1976; 1986) state that chickens, swine, cattle, and sheep can survive saline waters with up to 15,000 mg/L of sodium and calcium combined with bicarbonates, chlorides and sulfates. However, these animals could survive on only 10,000 mg/L water with only salts of potassium and magnesium.

Table 4. Relative Salt Tolerance of Agricultural Crops [1, 2] (Maas, 1990; Maas and Grattan, 1999)

TOLERANT [3]	
(ECw 4,200 - 6,800 µmhos/cm)	
Barley	*Hordeum vulgare*
Cotton	*Gossypium hirsutum*
Sugar beet	*Beta vulgaris*
Wheat	*Triticum aestivum*
Bermudagrass	*Cynodon dactylon*
Asparagus	*Asparagus officinalis*
MODERATELY TOLERANT [3]	
(ECw 2,133 - 4,200 µmhos/cm)	
Cowpea	*Vigna unguiculata*
Oats	*Avena sativa*
Safflower	*Carthamus tinctorius*
Sorghum	*Sorghum bicolor*
Barley (forage)	*Hordeum vulgare*
Canary grass, reed	*Phalaris, arundinacea*
Clover, sweet	*Melilotus*
Fescue, tall	*Festuca elatior*
Wheat (forage)	*Triticum aestivum*
Artichoke	*Helianthus tuberosus*
Beet, red	*Beta vulgaris*
Squash, zucchini	*Cucurbita pepo melopepo*
Artichoke, Jerusalem	*Helianthus tuberosus*
Fig	*Ficus carica*
MODERATELY SENSITIVE	
(EC_w 1,067 - 2,133 µmhos/cm)	
Broadbean	*Vicia faba*
Corn as maize	*Zea mays*
Peanut	*Arachis hypogaea*
Sugarcane	*Saccarum officinarum*
Sunflower	*Helianthus annuus*
Alfalfa	*Medicago sativa*
Cowpea (forage)	*Vigna unguiculata*
Timothy	*Phleum pratense*
Trefoil, big	*Lotus uliginosus*
Vetch, common	*Vicia angustifolia*
Broccoli	*Brassica oleracea botrytis*
Cabbage	*B. oleracea capitata*
Cauliflower	*B. oleracea botrytis*
MODERATELY SENSITIVE	
(EC_w 1,067 - 2,133 µmhos/cm)	
Celery	*Apium graveolens*
Corn, sweet & forage	*Zea mays*
Cucumber	*Cucumis sativus*
Lettuce	*Latuca sativa*
Muskmelon	*Cucumis melo*
Pepper	*Capsicum annuum*
Potato	*Solanum tuberosum*
Radish	*Raphanus sativa*
Spinach	*Spinacia oleracea*
Squash, scallop	*Cucurbita pepo melopepo*
Sweet potato	*Ipomoea batatas*
Tomato	*Lycopersicon lycopersicum*
Turnip	*Brassica rapa*
Grape	*Vitis sp.*
SENSITIVE [3]	
(ECw 0 - 1,067 µmhos/cm)	
<u>Fibre, Seed, and Sugar Crops</u>	
Sesame	*Seasamum indicum*
Rice, paddy	*Oryza Satira*
Bean	*Phaseolus vulgaris*
Carrot	*Daucus carota*
Onion	*Allium cepa*
Pea	*Pisum sativum*
Almond	*Prunus dulcis*
Apple	*Malus sylvestris*
Apricot	*Prunus armeniaca*
Avocado	*Persea americana*
Cherry, sweet	*Prunus avium*
Lemon	*Citrus limon*
Orange	*Citrus sinensis*
Peach	*Prunus persica*
Persimmon	*Diospyros virginiana*
Plum	*Prunus domestica*
Strawberry	*Fragaria sp.*
Parsnip	*Pastinaca sativa*

[1] Classification of tolerance is from Maas (1984), Maas (1990), and Maas and Grattan (1999).

[2] These data serve only as a guide to the relative tolerance among crops. Absolute tolerance varies with climate, soil conditions, and cultural practices.

[3] The relative and detailed tolerance ratings are defined and can be found in Maas (1984) and SJVDIP (1999).

Wildlife

The San Joaquin Valley Drainage Program (1990a) reviewed the toxic effects of elements in agricultural drainage on wildlife. According to this report, toxicity depends on many factors, such as concentration of the compound, ability of the organism to acclimate, individual ions present, availability of alternative freshwater habitats, and the age of the organisms. Different ions (sodium, potassium, calcium, and magnesium) in highly saline waters cause different toxic effects on animals.

Factors, affecting the salt gland can influence survival of ducks in highly saline water (SJVDP 1990a). Ducklings begin secreting saline fluids from the salt gland about six days after birth and require fresh water until that age. Marine birds generally have far larger and more developed salt glands than inland birds. Research suggests that ducks suddenly restricted to high salt concentrations in water, such as during a drought following wet years, are at the greatest risk of salt toxicity as compared to those continuously exposed to salty water.

The SJVDP final report (1990b) states that freshwater ducklings were very sensitive to salty water. Toxicity tests showed that molt was delayed in mallard ducklings that drank water with a TDS concentration of 3,000 mg/L, and growth was reduced when drinking water with an EC of 7,720 µmhos/cm.

Swanson, *et al.* (1984) investigated duckling use of North Dakota saline lakes dominated by sodium, magnesium, and potassium sulfates. In field studies, five species of ducklings less than three days old experienced some mortality when exposed to waters with a specific conductance of 16,000 µmhos/cm (TDS of 10,000 mg/L). The ducklings could not tolerate salt concentrations that exceeded 20,000 µmhos/cm (TDS of 13,000 mg/L) unless a supply of fresh water was also available. Fifty percent mortality occurred after one day of exposure.

TABLE 5. Effects of Total Salts on Animals
(McKee and Wolfe, 1963)

Concentration (mg/L)	Animal	Reported Effects
2,860	Poultry	Safe upper limit
3,000	Livestock	Injurious
3,600-5,756	Cattle	Deleterious
4,000	Livestock	Injurious
4,000	Rats	No deleterious effect
4,290	Pigs	Safe upper limit
4,546-7,369	Cows	No harmful effect
5,000	Livestock	Interim threshold limit
5,000	Cattle	Tolerated
5,700	Horses	Satisfactory
6,260	Horses	Thrived
6,435	Horses	Safer upper limit
7,000	Cattle	Reduced weight
7,150	Dairy cattle	Safe upper limit
7,150	Cows	Reduced milk production
7,800	Horses	Safe upper limit
7,865	Horses	Thrived
8,000	Sheep	Tolerated
9,100	Horses	Harmful
9,100	Cattle	Lost condition
9,400	Cattle	Safe upper limit
10,000	Beef cattle	Safe upper limit
10,000	Rats	Deleterious
10,000	White rats	Tolerated
10,000	Livestock	Loss of weight
11,400	Cows and sheep	Satisfactory
12,900	Adult dry sheep	Safe upper limit
13,500	Horses	Sustained without work
14,700	Sheep	Thrived
15,000	Farm animals, dry	Satisfactory upper limit
15,000	Lactating cows and pigs	Injured
15,000	Horses, cattle, sheep	Fatal during long periods
15,600	Sheep	Safe upper limit
18,000	Cattle	Thrived
18,600	Sheep	Used temporarily

SALINITY CRITERIA

Table 6 summarizes salinity concentrations in water that affect: municipal, human drinking water, fish, aquatic life, industry, irrigated agriculture, poultry, ducklings, and livestock drinking water, and beneficial uses. The most sensitive uses are irrigated agriculture, human drinking water, and industrial. Based on the review of the literature done in this report, fish, poultry, livestock, and ducks are sensitive to sudden increase in salinity.

A review of state water quality standards (US EPA,1988) showed 10 states set TDS numerical standards for various uses. Minnesota, Mississippi, and Virginia set a standard of 500 mg/L for domestic consumption and public water supply. Mississippi had a TDS standard of 1,500 mg/L for recreation use. Nevada and New York set a standard of 500 mg/L TDS for specific water body classes. Iowa set a TDS standard of 750 mg/L for all classes of water. New Jersey had a TDS standard of 500 mg/L for a general surface water classification. Ohio set their TDS standard as a 1,500 mg/L average for warm water and exceptional warm water habitat. Tennessee set their TDS standard at 500 mg/L TDS for domestic and industrial water supply. Utah's TDS criteria were 2,000 mg/L for both domestic purposes and 1,200 mg/L for agricultural usage. The Utah agricultural standard for TDS of 1,200 mg/L was based on stream water quality and concentrations of water applied to specific crops without damage (McNeal, 1998).

The SWRCB Technical Committee report for *Regulation of Agricultural Drainage to the San Joaquin* River evaluated water quality criteria for constituents of concern, including salinity (SWRCB, 1987). They stated that salinity was a concern because of its effect on irrigated crops, which they considered the most sensitive beneficial use. The committee proposed a concentration of 700 µmhos/cm or 415 to 430 mg/L TDS as the salinity water quality criterion to protect all San Joaquin River beneficial uses. This criterion recommended to fully protect irrigated agriculture was considered to be lower than the criteria needed to protect other beneficial uses, such as stock watering, fish, and wildlife. The criterion was intended to permit all crop water uses on every soil type in the Lower San Joaquin River Basin and downstream in the southern Delta. The Technical Committee stated that an EC above 3,000 µmhos/cm or a TDS of 2,000 mg/L is generally too high to support agriculture, but did not discuss the EC levels between 700 and 3,000 µmhos/cm.

The water quality control plans of the nine California Regional Water Quality Control Boards contain numerical salinity objectives as summarized below. Site-specific ranges in many locations varied depending upon background levels.

North Coast Region (1) -- set site-specific objectives based on specific conductance and/or TDS for 50 and 90 percentile values of the monthly means for a calendar year. Objectives range from a specific conductance (90% upper limit) of 2,000 µmhos/cm for Meiss Lake to 150 µmhos/cm for Salmon River watershed streams. Meiss Lake in northeast California is naturally salty, while the Salmon River in northwest California and is naturally low in salts.

San Francisco Bay Region (2) -- gives a range of EC water quality limits of 200 to 3,000 µmhos/cm for agricultural water supply. Their objective for municipal supply is 900 µmhos/cm for EC and 500 mg/L for TDS.

Central Coast Region (3) -- has EC guidelines for interpreting water quality for irrigation.

Table 6. Summary, Effects of Salinity in Water

USES	EC µmhos/cm	TDS mg/L	REFERENCE
Municipal Usage			USEPA, 1976, 1986
Excellent	491 - 611*	319 - 397	
Good	1,012 – 1,161*	658 - 755	
Unacceptable	1,974 – 2,051*	1,283 - 1,333	
Drinking Water			
Federal Drinking Water Secondary MCL		500	USEPA, 1976, 1986
State Drinking Water Secondary MCL Recommended	900	500	CCR Title 22
Upper Level	1,600	1,000	CCR Title 22
State Sources of Drinking Water Policy	5,000	3,000	Marshack, 1998
Fish and Other Aquatic Life (toxicity can depend upon constituent makeup)			
Squawfish, Chub, and Bonytail (avoided water with these concentrations)	6,770 - 10,153*	4,400 - 6,600	Pimentel and Bulkley, 1983
Water Flea (*D. magna*) (100% mortality)	15,385 - 7,690*	10,000 - 11,500	Dwyer, *et al.*, 1992
Chinook Salmon (survival significantly reduced)	18,500 - 27,700*	12,000 - 18,000	Saike, *et al.*, 1992
Industrial			
Limiting Concentrations	75 - 4,615*	50 - 3,000	McKee & Wolf, 1963
San Joaquin River Basin Industries	1,300*	845	
Irrigated Agriculture			Maas, 1990; SJVDIP, 1999
Sensitive Crops	0 –1,067	0 – 693*	
Moderately Sensitive	1,067 – 2,133	639 – 1,386*	
Moderately Tolerant	2,133 – 4,200	1,386 – 2,730*	
Tolerant	4,200 – 6,800	2,730 – 4,420*	
Unacceptable	>6,800	>4,420*	
Poultry and Livestock Drinking Water			
Chicken, Swine, Cattle & Sheep (Survival)	23,075*	15,000	USEPA, 1973
Various Effects on Animals (injurious, safe upper limit, or harmful)	4,400 - 28,615*	2,860 - 18,600	McKee & Wolf, 1963
Waterfowl			
Mallard Duckling			SJVDP, 1990
molt delay	4,615*	3,000	
growth reduced	7,720	5,020*	

* Calculated based on a TDS/EC ratio of 0.65.

µmhos/cm poses a severe problem for irrigation water. EC values from 750 to 3,000 µmhos/cm are considered to have increasing problems. These objectives for irrigation An EC of less than 750 µmhos/cm is interpreted as having no problem and an EC of over 3,000 waters were obtained from University of California Agricultural Extension Service guidelines, and they are meant to be flexible and modified by local experience and conditions.

Site-specific water quality objectives for TDS were set for 24 hydrologic sub-areas as a baseline for evaluating water quality management. Objectives ranged from 150 mg/L for Boulder Creek to 1,400 mg/L for the San Benito River.

Los Angeles Region (4) -- has basin-specific objectives for TDS that range from 250 to 1,500 mg/L. They also apply the following general TDS guidelines for reaches where site-specific objectives have not been determined:

Municipal	500 mg/L
Industrial Processing	50 to 1,500 mg/L
Agricultural	450 to 2,000 mg/L

These general guidelines would apply to areas impaired by minerals or where historic data is lacking to designate objectives based on natural background conditions. The actual effluent limit will be set to protect the most sensitive beneficial uses.

Central Valley Region (5) -- The Sacramento Basin above the Delta has EC water quality objectives that range from 150 µmhos/cm in well-mixed waters of the Feather River, to 340 µmhos/cm (90 percentile) on the Sacramento River at the I Street Bridge, 1,300,000 tons of TDS in Grouse Lake in Northeastern California. An EC objective of 150 µmhos/cm (90 percentile) has been set for the Upper San Joaquin River from Friant Dam to the Mendota Pool.

Objectives also have been incorporated into the Basin Plan from the SWRCB's Bay Delta Plan. Water Quality objectives by beneficial use were set for Delta water in the State Water Resources Control Board's 1991 *Water Quality Control Plan for Salinity* (Bay Delta Plan) and are in Table III-5 in the 1998 CRWQCB- CVR Basin Plan. Maximum 14-day running average EC values vary from 450 to 2,780 µmhos/cm depending on water year type (wet, above normal, below normal, dry, and critical) and season for the Western Delta and the Interior Delta. Maximum 30-day EC as a running average of mean daily values for the South Delta (including the San Joaquin River at Vernalis) has been set at 700 µmhos/cm from 1 April through 31 August and at 1,000 µmhos/cm from 1 September through 31 March for all water year types. The maximum 30-day EC as a running average of mean daily values for waters exported via the California Aqueduct and the Delta Mendota Canal is 1,000 µmhos/cm.

According to the Basin Plan (Table III-5), additional salinity objectives have been set for Delta striped bass spawning habitat that range from 440 to 3,700 µmhos/cm as a 14-day running average of mean daily EC, depending on water year type. Objectives vary with deficiencies in water supplies and apply from 1 April through 31 May or until striped bass spawning has ended. For non-critical or non-dry years, a 14-day running average objective of mean daily values has been set at 1,500 μmhos/cm at Antioch and 440 μmhos/cm at Prisoners Point on the San Joaquin River.

Lahontan Region (6) -- TDS objectives by water bodies vary from a low of 10 mg/L in a Sierra Nevada stream to 80,700 mg/L in Mono Lake.

Colorado River Basin Region (7) -- has an average annual TDS objective of 2,000 mg/L with a maximum of 2,500 mg/L for the Coachella Valley and Palo Verde Valley Drains. They also had an average annual TDS objective of 4,000 mg/L with a maximum of 4,500 mg/L for the New River, Alamo River, and Imperial Valley Drains. These objectives were set to limit the inflow of salt into the Colorado River and Salton Sea (Coulter, 1998). The Salton Sea has an EC of over 52,000 μmhos/cm (Westcot, *et. al.*, 1990a).

Santa Ana Region (8) -- TDS objectives vary from 110 mg/L for a San Bernardino Mountain stream to 2,000 mg/L for a "freshwater marsh." The Region states that for most irrigation uses, water should have a TDS concentration under 700 mg/L. They reference the Department of Health Services secondary drinking water limit of 1,000 mg/L TDS for taste considerations and a quality related consumer cost analysis that shows TDS of 500 mg/L or below benefits consumers. The Santa Ana Region's general guidelines for interpreting irrigation water quality vary by degree of restriction on use and are based on Ayers and Westcot (1984).

San Diego Region (9) -- refers to the recommended secondary drinking water standard for TDS of 500 mg/L with a upper limit for 1,000 mg/L for taste considerations. A TDS of less than 450 mg/L (EC <700 micromhos/cm) would result in no restriction of use; a TDS of over 2,000 mg/L (EC > 2,0000 micromhos/cm) would result in severe use restrictions. The site-specific TDS objectives by hydrologic area ranged from 300 to 2,100 mg/L. Objectives set by hydrologic area mostly ranged from 500 to 1,000 mg/L. The highest site specific TDS objective of 2,100 mg/L is for only one area, the San Ysidro Hydrologic Sub Area, which is near the ocean at the California/ Mexico border. The lowest site-specific TDS objective of 300 mg/L is set for waters in the mountains east of San Diego.

Numerical salinity objectives specifically for aquatic life in general were not found in any of the Regional Board's Water Quality Control Plans. However, the San Francisco Bay Region Plan has a narrative objective which states that controllable water quality factors shall not increase the TDS in waters of the State so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat.

REFERENCES

Ayers, R.S. and D.W. Westcot. 1985. *Water Quality For Agriculture*. United Nations Food and Agriculture Organization, Irrigation and Drainage Paper 29 Rev. 1, Rome. 174 p.

Bull, J. 1998. California Dept. Fish and Game (CDFG), Fresno. Personal Communication on 12/17/98 by E-Mail.

CDFG. 1989. *Striped Bass Restoration and Management Plan for the Sacramento-San Joaquin Estuary, Phase I.* 39pp.

CDFG. 1991. *Preliminary Evaluation of Chinook Salmon Smolt Quality in the San Joaquin Drainage.* Sport Fish Restoration Report (as cited by J. Bull, 1998).

California Regional Water Quality Control Board, Central Valley Region (CRWQCB, CVR). 1988. *Amendments to the Water Quality Control Board for the San Joaquin Basin (5C) for The Control of Agricultural Subsurface Drainage Discharges.* Draft Report.

California Regional Water Quality Control Board, Central Valley Region (CRWQCB, CVR). 1997. *Work Plan for a San Joaquin River Basin Plan Amendment Addressing Salinity and Boron.*

California Regional Water Quality Control Board, Central Valley Region (CRWQCB, CVR). 1998. *The Water Quality Control Plan (Basin Plan) The Sacramento River Basin and the San Joaquin River Basin. California Regional Water Quality Control Board, Central Valley Region.* Fourth Edition.

Coulter, K. SWRCB. 1998. Personal Communication on 1/8/98.

Dwyer, F.J., S.A. Burch, C.G. Ingersoll, and J.B. Hunn. 1992. Toxicity of Trace Element and Salinity Mixtures to Striped bass (*Morone saxatilis*) and *Daphnia magna*. *Environ. Tox. and Chem.* 11:513-520.

Hem, J.D. 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, Third Edition, U.S.G.S. Water Supply Paper No. 2254. 263 p. (as cited in Westcot *et al.* 1990a).

Marshack, J.B. 1998. *A Compilation of Water Quality Goals*. Staff Report of the California Regional Water Quality Control Board, Central Valley Region.

Maas, E.V. 1984. Salt Tolerance of Plants. In: *The Handbook of Plant Science in Agriculture.* B.R. Christie (ed.), Boca Rato, Florida. As cited in Ayers and Westcot (1985).

Maas, E.V. 1990. Chapter 13, Crop Salt Tolerance. In: K. K. Tanji (ed.); *Agricultural Salinity Assessment and Management.* American Society of Civil Engineers Manuals and Reports on Engineering Practices No. 71, ASCE, N.Y., pp. 262-304.

Maas, E.V. and S.R. Grattan. 1999. Crop Yields as Affected by Salinity. In: R.W. Skaggs and J. van Schilfgaarde (eds.): *Agricultural Drainage*. Number 38 in the series, Agronomy. Am. Soc. of Agronomy, Crop Science Soc. of America, Soil Science Soc. of America. pp. 55 –108.

McNeal, S. 1998. Personal Communication. Utah Division of Water Quality.

McKee, J. E., and H. W. Wolf. 1963. *Water Quality Criteria.* The Resource Agency of California, 2nd ed. State Water Quality Control Board, Publication No. 3A. 548 pp.

Mehrle, P.M., L. Cleveland, and D.R. Buckler. 1987. Chronic Toxicity of an Environmental Contaminant Mixture to Young (or Larval) Striped bass. *Water, Air, and Soil Pollution WAPLAC*, Vol. 35, No. 1/2, p.107-118. Abstract.

Miller, L. 2,000. CDFG, Bay Delta Division, Stockton. Personal Communication on 1/11/00 by E-Mail.

Mount, D.R. and D.D. Gulley. 1992. *Development of a Salinity/Toxicity Relationship to Predict Acute Toxicity of Saline Waters to Freshwater Organisms*. Interim Final Report for Gas Research Institute, Environ. and Safety Research Dept.

National Academy of Sciences (NAS). 1973. *Water Quality Criteria 1972*. National Academy of Sciences, National Academy for Engineering, EPA Ecol. Res. Ser. EPA-R3-73-033. U. S. Environmental Protection Agency, Washington D. C. Also cited as US EPA 1973.

Oster, J. D. 1998. U.C. Riverside. Personal Communication for the San Joaquin Valley Drainage Implementation Program, Discharge to the River Technical Subcommittee Report.

Oster, J. D. I. Shainberg, and I.P. Abrol. 1999. Reclamation of Salt-Affected Soils. In: R.W. Skaggs and J. van Schilfgaarde (eds.): *Agricultural Drainage*. Number 38 in the series, Agronomy. Am. Soc. of Agronomy, Crop Science Soc. of America, Soil Science Soc. of America. pp. 659 – 691.

Pimentel, R.L. and R.V. Bulkley. 1983. Concentrations of Total Dissolved Solids Preferred or Avoided by Endangered Colorado River Fishes. *Trans. of the American Fisheries Society* 112: 595-600.

Saiki, M. K., M. R. Jennings, and R. H. Wiedmeyer. 1992. Toxicity of Agricultural Subsurface Drain Water from the San Joaquin Valley, California, to Juvenile Chinook Salmon and Striped Bass. *Trans. of the American Fisheries Society* 121:78-93.

San Joaquin Valley Drainage Implementation Program (SJVDIP). 1999. *River Discharge Final Report*. Sacramento, CA. 111+ pp.

San Joaquin Valley Drainage Program (SJVDP). 1990a. *Fish and Wildlife Resources and Agricultural Drainage in the San Joaquin Valley, California. Vol. I and II.* Prepared by the San Joaquin Valley Drainage Program. Sacramento, CA.

San Joaquin Valley Drainage Program (SJVDP). 1990b. *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley.* Sacramento, CA. 183 pp.

State Water Resources Control Board (SWRCB). 1987. *Regulation of Agricultural Drainage to the San Joaquin River. The Technical Committee Report.* Main Report. SWRCB Order No. W.Q. 85-1 San Joaquin River Basin. Sacramento.

State Water Resources Control Board (SWRCB). 1991. *Water Quality Control Plan for Salinity, for the San Francisco Bay/ Sacramento-San Joaquin Delta Estuary, Technical Appendix.* Sacramento.

State Water Resources Control Board (SWRCB). 1995. *Water Quality Control Plan for the San Francisco Bay/ Sacramento-San Joaquin Delta Estuary.* SWRCB Order 95-1WR. Sacramento. 45 pp.

Swanson, G.A, V.A. Abomaitis, F.B. Lee, J.R. Serie, and J.A. Shoesmith. 1984. Limnological Conditions Influencing Duckling Use of Saline Lakes in South-Central North Dakota. *J. Wildlife Management.* 48(2):340-349.

Turner, J. L. and T.C. Farley. 1971. Effects of Temperature, Salinity, and Dissolved Oxygen on the Survival of Striped Bass Eggs and Larvae. *Calif. Fish and Game* 57(4):268-273.

U.S. Environmental Protection Agency (US EPA). 1973. *Water Quality Criteria, 1972.* Report of the Committee on Water Quality Criteria. National Academy of Sciences and National Academy of Engineering, Washington D.C. Ecological Research Series EPA. R3.73.033. 594 pp.

US EPA. 1976. *Quality Criteria for Water.* EPA 440/9-76-023. Washington D.C. 501 pp.

US EPA. 1986. *Quality Criteria for Water, 1986.*

US EPA. 1988. *State Water Quality Standards Summary*: Various States and Territories. EPA 440/5-99-040. Office of Water Regulations and Standards, Washington D.C.

Westcot, D.W. and R.S. Ayers. 1984. Ch. 3 Irrigation Water Quality Criteria. *Irrigation with Reclaimed Municipal Wastewater, A Guidance Manual.* State Water Resources Control Board Report No. 84-1 WR.

Westcot, D.W., C.A. Enos, J.E. Chilcott, and K.K. Belden. 1990a. *Water and Sediment Survey of Selected Inland Saline Lakes.* California Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., C.A. Enos, and P.A. Lowry. 1991. *Preliminary Estimate of Salt and Trace Element Loading to the San Joaquin River by Ephemeral Streams Draining the Eastern Slope of the Coast Range (Diablo range).* California Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., B.J. Grewell, and J.E. Chilcott. 1990b. *Trace Element Concentrations in Selected Streams in California: A Synoptic Survey*. California Regional Water Quality Control Board, Central Valley Region Report.

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