UNITED STATES DEPARTMENT OF THE INTERIOR

NATIONAL IRRIGATION WATER QUALITY PROGRAM
INFORMATION REPORT NO. 3

Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment

Salinity

Participating Agencies:

Bureau of Reclamation
U.S. Fish and Wildlife Service
U.S. Geological Survey
Bureau of Indian Affairs

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Salinity

Description

Salinity is a measure of the mass of dissolved salts in a given mass of solution. The term “salinity” includes many different types of salts. Salinity is not precisely equivalent to total dissolved solids content (TDS), but the two terms are closely related. For most purposes, they can be considered equivalent ([EPA 1986).

Measurement Techniques and Units

Salinity is usually assessed by measuring some related physical property, such as conductivity, density, sound speed, or refractive index. The conductivity and density methods are recommended for their high sensitivity and precision, and conductivity can be measured easily with field meters. The conductivity of a water sample is determined by measuring its electrical resistance between two electrodes and comparing this resistance with that of a standard solution of potassium chloride at 25 °C. Conductivity is the reciprocal of the measured resistance (Hem 1985).

Salinity is usually expressed in parts per thousand (ppt) for marine or other highly saline waters (e.g., those in the Salton Sea). (In contrast, “ppt” is used to denote parts per trillion for freshwater studies of trace elements and organics; however, ppt as used in this section refers to parts per thousand.) TDS is usually expressed in units of milligrams per liter (mg/L). For fresh water, the terms salinity and TDS are often used interchange-ably, and irrigation and drainage engineers and soil scientists typically express salinity in parts per million (ppm). One mg/L is numerically equivalent to one ppm by weight.

Conductivity (or specific conductance [SC]), in the International System of measurements (SI), is expressed in microsiemens per centimeter (µS/cm), although many reports still use the non-SI measurement micromhos per centimeter (1 µmho/cm = 1 µS/cm). Specific conductance is defined as the conductivity of a conductor 1 centimeter long and 1 square centimeter in cross-sectional area.

An approximate value for TDS can be derived from conductivity results, although the relationship between TDS and conductivity varies on the basis of ionic composition of the salts present in solution. For specific conductance less than 5,000 µS/cm at 25°C,

$$\text{TDS} = 0.584 \times \text{SC} + 22.1$$

where TDS = total dissolved solids in mg/L and SC = specific conductance in µS/cm.
For a specific conductance from 5,000 to 9,000 µS/cm,

$$\text{TDS} = 0.682 \times \text{SC} - 269$$

Roughly, for most waters, the concentration of dissolved solids in mg/L is in the range of 0.55 to 0.7 times the conductivity in µS/cm (Linsley and Franzini 1979). Another “rule of thumb” for converting conductivity measure-ments to TDS is to multiply SC by 0.64 (U.S. Bureau of Reclamation 1993). According to Hem (1985), the range of the slopes of the regression lines is 0.54–0.96 for dilute waters, and 0.67 is often used to derive TDS values from measured conductivity (pers. comms. from J. Yahnke, U.S. Bureau of Reclamation; and M.K. Saiki, U.S. Fish and Wildlife Service). Values in the upper part of this range (>0.7) tend to have higher sulfate concentrations, which are pertinent to National Irrigation Water

Quality Program work. Many of the sites being investigated are in Cretaceous marine shales, which tend to be high in gypsum ($CaSO_4$).

The conductivity of surface and ground waters varies widely (Hem 1985). In areas where the rainwater is relatively pure and the rocks are resistant to erosion, conductivity may be as low as 50 µS/cm. In other areas, conductivities may exceed 50,000 µS/cm; this is about the same as the conductivity of seawater. Surface waters of enclosed basins (where mineral accumulation occurs in ponded water) may have salinities equal to or greater than that of seawater.

Summary of Effects

Table 28 summarizes the predicted effects of salinity in the environment, based on the limited information currently available.

Biotic Effects

Salinity is a critical factor influencing the distribution and maintenance of aquatic life in estuaries and other brackish areas. Estuaries are characterized by high densities of a few species, with species richness increasing along the salinity gradient (Hall and Anderson 1995). Nonmarine saline water bodies tend to have fewer species than freshwater bodies, but many of them host large populations of those few species. Examples of such water bodies include Mono Lake and the Salton Sea (Setmire et al. 1993, CH2M Hill 1994), both in California. In the San Joaquin Valley of California, evaporation basins are the disposal receptors for much of the subsurface agri-cultural drainwater. These evaporation basins are highly saline and contain a high concen-tration of nutrients. Like other saline water bodies, evaporation basins have high invertebrate populations and high wildlife use but relatively low species diversity (Parker and Knight 1989, CH2M Hill et al. 1993).

Plants

Maas (1990) listed salinity sensitivities for many types of grasses and forage crops. Some of these are shown in table 29 (expressed in terms of conductivity [µS/cm] of a saturated soil extract [EC_e]). Some of the cultivated grasses shown there also grow wild, so their tolerances could be used as an indicator for naturally occurring grasses. These thresholds represent the maximum soil salinities that do not reduce crop yield below that achieved under nonsaline conditions.

Invertebrates

Studies conducted at the Stillwater Wildlife Management Area (SWMA), Nevada, provide data for evaluating toxic effects of salinity and contaminants in irrigation drainwater effluent. Ingersoll et al. (1992) conducted static acute effluent tests with water collected from the SWMA. The test animals for this study consisted of amphipods (*Hyalella azteca*), daphnia (*Daphnia magna*), and two species of fish. In reconstituted water representative of one of the sample sites, salinity was acutely toxic to amphipods at a concentration of 22 ppt and to daphnia at 8 to 10 ppt. Dwyer et al. (1992) found a similar toxicity level for daphnia.

A study conducted by Galat et al. (1988) produced similar results for salinity effects in benthic invertebrates (table 30). The 96-h LC50 for *H. azteca* was 19.5 ppt, short-term mortality for *Chironomus utahensis* was 100 percent at a salinity of 13.3 ppt, and mortality of *Heterocypris* sp. was 50 percent at a salinity of 18.6 ppt.

Fish

Fish species represented in the Ingersoll et al. (1992) study at SWMA were fathead minnows (*Pimephales promelas*) and striped bass

Table 28.—Summary of comprehensive biotic effects of salinity

[All values are aqueous concentrations in parts per thousand (=g/L)]

Affected organisms	Effect level (ppt) No effect	Level of concern	Toxicity threshold	Reference/Explanation
Plants				
Freshwater marsh grass	—	—	10–12	Pezeshki et al. 1987
Clover, various grasses	—	—	0.9	Maas 1990, salt tolerance threshold, 1.5 dS/m (=1,500 µS/cm)
Invertebrates				
Amphipods	—	—	22	Ingersoll et al. 1992, acute toxicity
Daphnia magna	—	0.3–6	6–10	Level of concern from Dwyer et al. 1992. 6-10 ppt is acute toxicity level from Ingersoll et al. 1992
Hyalella azteca	—	8.0–11	16–19.5	Galat et al. 1988. After 100 days at 8–11 ppt, sample populations were 80–90% less than control group. 16 ppt = 96-h LC10; 19.5 ppt = 96-h LC50
Chironomus utahensis	—	5.5–8.9	13.3	Galat et al. 1988. Cumulative mortality of 30–50% after 17 days at 5.5–8.9 ppt. 13.3 ppt = 96-h LC100
Heterocypris spp.	—	9.0–11	13–18.6	Galat et al. 1988. Approximate 96-h mortality 5% at 9–11 ppt, 7% at 13 ppt, 50% at 18.6 ppt
Fish				
Fathead minnow	—	—	6–10	Ingersoll et al. 1992, acute toxicity
Striped bass	—	—	14–34	Ingersoll et al. 1992; Dwyer et al. 1992, acute toxicity
Striped bass 2-day larvae	—	6	12	Winger and Lasier 1994. Mortality after 6 days: 20% at 6 ppt, 36% at 12 ppt
Birds				
Mottled duck	—	—	9–18	Moorman et al. 1991. "Threshold level" 9 ppt; 100% mortality at 18 ppt
Mallard	9–12	10–15	—	Nystrom and Pehrsson 1988; Swanson et al. 1984
Black duck	—	—	20	Swanson et al. 1984
Peking duck	—	20	—	Nystrom and Pehrsson 1988
Amphibians	—	—	—	—
Mammals	—	—	—	—

Table 29.—Salt tolerance thresholds of herbaceous crops

[Data from Maas (1990)]

Common name	Botanical name	Threshold (µS/cm)
Alfalfa	*Medicago sativa*	2,000
Barley (forage)	*Hordeum vulgare*	6,000
Bermudagrass	*Cynodon dactylon*	6,900
Clover, ladino	*Trifolium repens*	1,500
Clover, Berseem	*Trifolium alexandrinum*	1,500
Clover, alsike	*Trifolium hybridum*	1,500
Clover, red	*Trifolium pratense*	1,500
Clover, strawberry	*Trifolium fragiferum*	1,500
Corn (forage)	*Zea mays*	1,800
Cowpea (forage)	*Vigna unguiculata*	2,500
Fescue, tall	*Festuca elatior*	3,900
Foxtail, meadow	*Alopecurus pratensis*	1,500
Hardinggrass	*Phalaris tuberosa*	4,600
Lovegrass	*Eragrostis* sp.	2,000
Orchardgrass	*Dactylis glomerata*	1,500
Ryegrass, perennial	*Lolium perenne*	5,600
Sesbania	*Sesbania exaltata*	2,300
Sphaerophysa	*Sphaerophysa salsula*	2,200
Sudangrass	*Sorghum sudanense*	2,800
Trefoil, big	*Lotus uliginosus*	2,300
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*	5,000
Vetch, common	*Vicia angustifolia*	3,000
Wheat (forage)	*Triticum aestivum*	4,500
Wheat, Durum (forage)	*Triticum turgidum*	2,100
Wheatgrass, fairway crested	*Agropyron cristatum*	7,500
Wheatgrass, standard crested	*Agropyron sibiricum*	3,500
Wheatgrass, tall	*Agropyron elongatum*	7,500
Wildrye, beardless	*Elymus triticoides*	2,700

(*Morone saxatilis*). In their results, the reconstituted water samples from SWMA were acutely toxic to striped bass at a salinity of 22 ppt and to fathead minnows at 8 to 10 ppt. Dwyer et al.'s (1992) results for striped bass were similar. These cited results do not, however, apply to all striped bass. Like salmon, striped bass have both anadromous (seagoing) and landlocked varieties. The marine striped bass readily tolerate salinities of 33–37 ppt (J. Yahnke, U.S. Bureau of Reclamation, pers. comm.).

Nelson and Flickinger (1992) conducted 96-hour acute toxicity tests to determine the salinity tolerance of the Colorado squawfish (*Ptychocheilus lucius*). The tests yielded a 96-hour LC50 of 13.1 ppt using saline water diluted with fresh wellwater. This result is fairly consistent with the salinity tolerances of other freshwater fishes, especially those of the family Cyprinidae (minnows and carps).

According to EPA Ambient Water Quality Criteria (1986), the goldfish (*Carassius auratus*) has a 96-hour LC50 of 16.1 ppt, and the fathead minnow has a 96-hour LC50 of 11.9 ppt.

In a study by Saiki et al. (1992), juvenile Chinook salmon (*Oncorhynchos tshawytscha*) and striped bass were exposed to serial dilutions of agricultural subsurface drainwater, reconstituted drainwater, and reconstituted seawater. The researchers found that after 28 days of exposure, the survival of chinook salmon averaged 28 percent in the full-strength agricultural subsurface drainwater and was 100 percent in all other

Table 30.—Biological effects of various concentrations of salinity on selected species

Species	Salinity concentration in water (ppt)	Effects/Comments	Reference
Plants			
Freshwater marsh grass	10–12	Toxicity threshold	Pezeshki et al. 1987
Ruppia maritima	46	No growth	McMillan and Moseley 1967
Typha sp.	26	Growth ceased after 9 days	McNaughton 1966
	4.5–12.5	Reduction in height (salinity increased over time)	Shekov 1974
	12	Stunted growth	U.S.Department of Agriculture 1972
Invertebrates			
Amphipods	22	Acute toxicity	Ingersoll et al. 1992
Daphnia magna	0.3–6	Level of concern	Dwyer et al. 1992
	6 - 10	Acute toxicity	Dwyer et al. 1992; Ingersoll et al. 1992
Chironomid	89	LC50	Kokkinn 1986
	13.25	100% mortality at 96h	Galat et al. 1988
Hyalella azteca	19.5	LC50	Galat et al. 1988
Heterocypris sp.	18.57	LC50	
Fish			
Striped bass (*Morone saxatilis*) eggs	18	71% mortality at 72 h	Winger and Lasier 1994
	24	100% mortality at 72 h	
Striped bass (*Morone saxatilis*) 2-day-old larvae	0	100% mortality at 6 d	
	6	20% mortality at 6 d	
	12	36% mortality at 6 d	
	18	75% mortality at 6 d	
	24	100% mortality at 6 d	
Striped bass	14–34	Acute toxicity	Ingersoll et al. 1992, Lal et al. 1977, Dwyer et al. 1992
	15.6	100% mortality at 23 d	Saiki et al. 1992
	14.7	95% mortality at 28 d	
Fathead minnow	6–10	Acutely lethal	Ingersoll et al. 1992, Adelman and Smith 1976
Chinook salmon	20.5	75% mortality at 28 d	Saiki et al. 1992
	14.3–20.5	Reduced growth at 28 d	
Birds			
Mallard	~11	Reduced growth; fatal to young ducklings	Swanson et al. 1984
	8.8–12	100 percent mortality	Mitcham and Wobeser 1988b
	9–12	No effect	Nystrom and Pehrsson 1988, Swanson et al. 1984
	10–15	Level of concern	
	15	100 percent mortality (7-day-old ducklings)	Barnes and Nudds 1991
Mottled duck	9	Threshold level for adverse effects	Moorman et al. 1991
	12	Reduced growth, 10% mortality	
	15	90% mortality	
	18	100% mortality	
Peking duck	20	Level of concern	Nystrom and Pehrsson 1988

water types and dilutions. An important conclusion of this study was that salinity itself may not be as important as the ionic composition of the salts present in the water. The tile drainwater used in the study was toxic because fish were unable to tolerate atypical ratios of major cations and anions constituting the dissolved salts, the high concentrations of sulfate, or both.

Birds

Excess salinity in the drinking water of some birds can adversely affect health and reduce their survival (table 30). During the winter of 1985, a die-off of waterfowl was reported at White Lake, a highly saline lake in Mountrail County, North Dakota. Windingstad et al. (1987) studied this die-off and found that about 150 waterfowl died and another 250 became weak and lethargic, apparently as a result of salt poisoning. Frigid temperatures made fresh water unavailable, forcing the birds to ingest the saline waters, with resultant toxic effects. Although salinity was not measured at the time of the die-off, sodium concentrations of more than 17,000 mg/L were measured in July 1986.

Swanson et al. (1984) found that ducklings on saline lakes in North Dakota were closely associated with fresh inflow from spring seepage or from adjacent wetlands. Young ducklings died when water conductivity was 16,000 µS/cm (about 10.7 ppt salt) and could not tolerate water in prairie lakes that exceeded 20,000 µS/cm (13 ppt) unless fresh water was also available. Duckling growth was significantly reduced on water that measured 17,000 µS/cm (11.3 ppt).

Mitcham and Wobeser (1988a) tested the effects of saline water on ducklings ranging from 1 day old up to 28 days. The tested water contained sodium (up to 3.1 ppt) and magnesium (up to 3.0 ppt) as sulfates added to tap water at concentrations similar to those found in natural saline wetlands of Saskatchewan. Much of the ingested salt was excreted by passage of large volumes of fluid excreta. This effect occurred in birds given water with as little as 0.5 ppt magnesium or 1.0 ppt sodium. The supraorbital salt gland was actively excreting salt within 4 days in ducklings drinking water containing ≥1.5 ppt of sodium. Ducklings drinking water with 3.0 ppt of either ion, or 1.5 ppt of each, grew more slowly than control birds. Ducklings drinking water with 3.0 ppt of either sodium or magnesium had reduced thymus size and bone strength. Ducklings reared on fresh or slightly saline water adapted very poorly to an abrupt change to more saline water (SC = 15,250 µS/cm) at 14 days of age. These birds stopped eating, became inactive, and some died within 3 days; survivors had many tissue and biochemical alterations at 20 days of age. Many of the sublethal effects were subtle and nonspecific manifestations of stress and would be difficult to detect in wild ducklings on saline wetlands.

In a second study by Mitcham and Wobeser (1988b), 1-day-old mallard ducklings received drinking water from 10 naturally saline wetlands in Saskatchewan. Table 31 sum-marizes their results.

A study of the effects of saline water on the growth and survival of mottled ducks in Louisiana indicated a threshold level at 9 ppt. Reduced growth rate and negative effects on body mass and carcass components at 12 ppt suggested a range of tolerable salinity between 9 and 12 ppt (Moorman et al. 1991). Duckling mortality was 100 percent at 18 ppt salinity, 90 percent at 15 ppt, and 10 percent at 12 ppt.

Ducklings appear to be sensitive to increases in salinity; however, a study conducted on American black ducks, mallards, and their hybrids demonstrated that duckling mortality decreased with age and that acclimation to salt water is age-dependent (Barnes and Nudds 1991).

Table 31.—Effects of naturally saline drinking water on 1-day-old mallard ducklings

[From Mitcham and Wobeser (1988b)]

Water conductivity (µS/cm)	Salt concentrations (ppt) Sodium	Magnesium	Length of exposure	Effects
3,750–7,490	0.512–0.911	0.195–0.639	14 d	No apparent effect
4,000	0.821	0.56	28 d	Poor growth in last 2 weeks
7,720	1.98	0.062	14 d	Poor growth
20,000	2.55	1.31	14 d	6 of 10 died. Survivors had poor growth, other effects
21,500	3.86	1.3	14 d	7 of 9 died
35,000	8.79	1.31	60 h	100% mortality
67,000	12.3	5.26	30 h	100% mortality

Interactions

The bioavailability of chemicals—and hence their toxicity—may be altered by physicochemical factors such as salinity and temperature (Brecken-Folse et al. 1994). Estuarine organisms may face particular difficulties in coping with toxic substances introduced primarily from industrial and agricultural sources on land because (1) fluctuating salinity may impose a stress of its own and (2) the stress may be com-pounded by tidal variations in toxicant concentrations. In addition, salinity may control the speciation and hence the toxicity of certain heavy metals and other substances (Forbes 1991). Similarly, variations in the salinity of nonmarine wetlands may have the same sort of effect on the toxicity of chemicals that are present.

Hall and Anderson (1995) compared the effects of salinity on the toxicity of various classes of inorganic and organic chemicals. Their results indicate that the toxicity of most metals (e.g., cadmium, chromium, copper, mercury, nickel, zinc) increases with decreasing salinity. One possible explanation for this finding is the greater bioavailability of the free metal ion (toxic form) at lower salinity conditions. Another possibility is that at higher salt concentrations, physiological osmotic effects cause a greater flow of liquid through the kidneys, thus eliminating all salts, including toxic ions, out of the system. Hall and Anderson found no consistent trend for the toxicity of most organic chemicals with salinity. The one exception to this was the class of organophosphate insecticides, which appeared to gain toxicity with increasing salinity.

In a study using grass shrimp (*Palaemonetes* spp.) and sheepshead minnows (*Cyprinodon variegatus*), toxicity decreased as salinity increased for 4-nitrophenol (Brecken-Folse et al. 1994). However, the toxicity of 2,4-dinitrophenol decreased for sheepshead minnows but increased for grass shrimp as salinity increased.

Regulatory Standards

EPA has established no ambient water-quality criteria for salinity or dissolved solids. Secondary maximum contaminant levels for drinking water are 250 mg/L for chlorides, 250 mg/L for sulfates, and 500 mg/L for total dissolved solids (EPA 1995).

For standards and criteria set by State agencies, contact those agencies directly. See Appendix I for a listing of water quality officials in the 17 Western States.

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