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Effects of Total Dissolved Solids

On Aquatic Organisms

A Literature Review

by Phyllis Weber Scannell

and Laura L. Jacobs

June 2001

Alaska Department of Fish and Game Division of Habitat and Restoration

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EFFECTS OF TOTAL DISSOLVED SOLIDS ON AQUATIC ORGANISMS

A LITERATURE REVIEW

by

Phyllis Weber Scannell
and
Laura L. Jacobs

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INTRODUCTION

On May 27, 1999, the Alaska Water Quality Standards (18 AAC 70) were amended to include the following criterion for Total Dissolved Solids:

(A) Water Supply (iii) aquaculture	TDS may not exceed 1000 mg/l. A concentration of TDS may not be present in water if that concentration causes or reasonably could be expected to cause an adverse effect to aquatic life (see note 15).
(A) Water Supply (iv) industrial	C. No amounts above natural conditions that can cause corrosion, scaling, or process problems.
(B) Water Recreation (i) contact recreation	Not applicable.
(B) Water Recreation (ii) secondary recreation	Not applicable.
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife	Same as (1)(A)(iii).

Note15 is included in the Appendix.

On August 10, 2000 Cominco Alaska Incorporated requested that the State of Alaska Department of Environmental Conservation (ADEC) take the regulatory and permitting actions needed to establish a site-specific criterion for total dissolved solids (TDS) in Mainstem Red Dog Creek and Ikalukrok Creek (Figure 1) (letter from J. Kulas to W. McGee, August 10, 2000).

The request was later revised to a maximum limit of 1500 mg TDS/L in Mainstem Red Dog Creek (letter from J. Kulas to W. McGee, January 4, 2001). The criterion would apply during the discharge period, except during Arctic grayling (*Thymallus arcticus*) spawning in the spring. No other fish species are known to spawn in Mainstem Red Dog Creek. During Arctic grayling spawning, the TDS limit in Mainstem Red Dog Creek would be 500 mg/l as provided in 18 AAC 70.020.

Chum salmon (*Onchorhynchus keta)* and Dolly Varden (*Salvelinus malma)* spawn throughout Ikalukrok Creek up to the confluence with Dudd Creek (Station 7). The Alaska Department of Fish and Game (ADF&G) has requested that instream concentration of TDS not exceed 500 mg/l at Station 7 during the chum salmon and Dolly Varden spawning period. Discharge and water quality data for Stations 10 and 7 indicate that when TDS is at or below 1500 mg/l at Station 10, it usually does not exceed 500 mg/l at Station 7, except when stream flows are low in Ikalukrok Creek, as in late September. Cominco Alaska has established real-time telemetry to return stage (flow), temperature, and conductivity data from Stations 7 and 10 and adjusts the volume of treated effluent to avoid exceeding 1500 mg/l at Station 10 after Arctic grayling spawning and 500 mg/l at Station 7 during chum salmon and Dolly Varden spawning.

Total dissolved solids (TDS) by definition, are the inorganic salts, organic matter, and other dissolved materials in water (US EPA 1986). The amount of TDS in a water sample is measured by filtering the sample through a 2.0 µm pore size filter, evaporating the remaining filtrate and then drying what is left to a constant weight at 180ºC (APHA 1992).

Concentrations of total dissolved solids in an unaltered system are a reflection of the geology of the drainage, atmospheric precipitation, and the evaporation-precipitation process (Wetzel 1983). The mean salinity of the world's rivers is approximately 120 mg/L (Wetzel 1983). The major ion found in natural waters is bicarbonate, with a mean for all North American river waters of 68 mg/L; the second most common anion is sulfate, with a mean concentration of 20 mg/L. The most commonly occurring cation in fresh water is calcium, with a mean of all North American river waters for which data were available, of 21 mg/L; the next most commonly occurring cations are sodium and silica, each with an average concentration of 9 mg/L (Wetzel 1983). Water with total dissolved solids concentrations greater than 1000 mg/L is considered to be "brackish" (Wetzel 1983). The major ions found at the Red Dog Mine are Na^{+}, K^{+}, Cl^{-}, Ca^{+2}, Mg^{+2}, and SO^{-2}_{4} (Table 1).

Table 1. Inter-laboratory comparison of water chemistry results (i.e., major ions) of the effluent collected from the Red Dog Mine, Alaska.

Concentration (mg/L)	**Columbia Analytical (June 6 1996)**	Columbia Analytical (June 27 1996)	Analytical Environmental (June 27 1996)
Calcium	498	665	590
Carbonate	NA[1]	NA	9.1
Chloride	7.7	10	15
Flouride	NA	<1.0	0.7
Magnesium	39.3	40.6	37
Potassium	15	19.4	17
Sodium	20.6	30.8	28
Sulfate	1400	1900	1800
Ion Balance (% Difference)	0.25	3.3	10.7
Total Dissolved Solids	NA	2740	2700

[1]Not analyzed.

This review examined published literature and technical reports to determine if the proposed site-specific limits for TDS are sufficient to protect fish spawning and rearing, and non-fish species in Red Dog and Ikalukrok Creeks. We examined all available documents that addressed toxicity of TDS to aquatic species and focused on the range of concern (500 to 1500 mg/L).

Toxicity of TDS is influenced by the ionic composition of the test water as well as the species tested and the life history stage. During our review of the literature, we found the following common observations on the toxicity effects of TDS, with particular respect to aquatic species found in Alaska and the TDS components that would be similar to those found in mine effluent:

1. Toxicity is due primarily to ionic properties rather than osmotic effects.

2. For chum, coho, and Atlantic salmon, Rainbow and brook trout, striped bass and fathead minnow, the life stage most sensitive to TDS exposure is during fertilization to egg hardening.

3. Concentration of TDS in the range of 750 mg/L significantly reduces fertilization and hatching rates in coho and chum salmon, and extends the developmental time to epiboly and the eyed-egg stage.

4. After egg hardening, fish do not appear to be affected by elevated concentrations of TDS up to 2000 mg/L.

5. No detrimental effects of calcium sulfate were reported on fish sperm motility for concentrations of TDS below 3000 mg/L.

6. Aquatic invertebrate growth and survival is affected by concentrations of TDS >1500 mg/L. Concentrations of TDS showing adverse effects were from 1692 mg/L to > 2430 mg/L.

7. Few studies were found on effects of elevated TDS concentrations on freshwater algae. No range of concentrations causing toxic responses could be determined from published reports.

The review is presented in two sections. The first section contains tables summarizing the results of the TDS studies, including the species and life stage tested, the TDS components, if given, the concentration producing an effect, and the endpoint used. Table 2 reports studies with aquatic algae, Table 3 reports studies of aquatic invertebrates, Table 4 reports studies of fish, and Table 5 reports studies of laboratory micro-organisms. The second section of this review contains a discussion of each paper that was examined, how the tests were conducted, and any shortcomings. Finally, there is a list of the papers reviewed and a list of papers that were cited in other papers, but not included in this report.

Figure 1. Ikalukrok Creek and Red Dog Creek below the Red Dog Mine, northwest Alaska.

SUMMARY OF EFFECTS CONCENTRATIONS REPORTED IN LITERATURE

Table 2. Studies of Effects of Elevated TDS on Freshwater Algae

Species	**Effects Concentration mg/L**	**TDS Components**	**Effects Unit**	**Notes**	**Reference**
Algae	>1400	Not specified	Productivity	Decline in productivity	Kerekes and Nursall 1966, in Sorensen et al 1977
Blue-green algae	>1	NaCl	Productivity	Inhibition of growth	Batterton and van Balen 1971, in Sorensen et al 1977
Selanastrum capricornutum	551.3	CaSO4	EC20	All sample concentrations resulted in toxic effects	LeBlond 2000
S. capricornutum	250 - 500		Productivity	Inhibition of growth	Cleave et al. 1976, in Sorensen et al 1977
S. capricornutum	≥2020	$CaCO_4$	Growth	No toxic effects at 99, 664, 1180, or 1640	EVS Environment Consultants 1997c

Table 3. Studies on Aquatic Invertebrates

Species	**Effects Concentration mg/L**	**TDS Components**	Effects Unit	**Reference**
Chironomus tentans Diptera larvae	2,089	$CaSO_4$	Growth reduced by 45%	Chapman et al., 2000
C. tentans	1,750 and 2,240	$CaSO_4$	Reduced survival	Chapman et al., 2000
C tentans	2,035	$CaSO_4$	10 day, LC50[1]	USEPA 1999
C tentans	1,598	$CaSO_4$	IC0[2]	USEPA 1999
Ceriodaphnia dubia Cladoceran	1,692		LC50	Tietge and Hockett 1996
Daphnia magna Cladoceran	1,692		LC50	Tietge and Hockett 1996
C. dubia Cladoceran	>2,430 – 24 hr >1,910 – 48 hr	$CaSO_4$	LC50	Mount et al. 1997
D. magna Cladoceran	>1,970 – 24 and 48 hr	$CaSO_4$	LC50	Mount et al.,1997

[1]LC50 = Lethal Concentration 50, or concentration causing 50% mortality
[2]IC0 = Inhibition Concentration 0, or concentration causing inhibition of 0% of the population.

Table 3. Studies on Aquatic Invertebrates, continued

Species	**Effects Concentration mg/L**	**TDS Components**	Effects Unit	**Reference**
Hexagenia bilineata, Mayfly	2,270	K, Li, Mg, Mo, Na, SO_4, NO_3	15 day test, 80% survival	Woodward et al. 1985
H. bilineata	1,230	K, Li, Mg, Mo, Na, SO_4, NO_3	30 day test 70% survival	Woodward et al. 1985
Dugesia gonocephala flatworm	1230	Cl^-		Palladina 1980, cited in ENSR 1997
Tubifex tubifex, segmented worm	2000	K^+	EC50[1]	Khangarot 1991, cited in ENSR 1997
T. tubifex	814	Ca^{+2}	EC50	Khangarot 1991, cited in ENSR 1997
Cricotopus trifascia, Diptera larvae	1567	K^+ Mortality	LC50	Hamilton 1975, cited in ENSR 1997
C. trifascia	1406	CL^-		Hamilton 1975, cited in ENSR 1997
Hydroptila angusta, caddisfly	2316	K^+	LC50	Hamilton 1975, cited in ENSR 1997
H. angusta, caddisfly	2077	Cl^-		Hamilton 1975, cited in ENSR 1997

[1]EC50 = Effects Concentration, or concentration effecting 50% of the population.
LC50

LC50

Table 3. Studies on Aquatic Invertebrates, continued

Species	**Effects Concentration mg/L**	**TDS Components**	**Effects Unit**	**Reference**
Cyclops abyssorum prealpinus, cyclopoid copepod	7000	Ca^{+2}	EC50	Baudoin 1974, cited in ENSR 1997
C. abyssorum prealpinus,	280	Mg^{+2}	EC50	Baudoin 1974, cited in ENSR 1997
Daphnia magna, <24 hr Cladoceran	5015	NaCl	48-hr, LC50	Hoke et al. 1992
D. magna, <24 hr	5000	NaCl	48-hr, LC50	Hoke et al. 1992
D. magna, 4^{th} instar	4000	NaCl	48-hr, LC50	Hoke et al. 1992
Cerodaphnia dubia, <24 hr Cladoceran	835	NaCl	48-hr, LC50	Hoke et al. 1992
C. dubia, <24 hr	735	NaCl	48-hr, LC50	Hoke et al. 1992
D. magna, <24 hr	1400	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992
D. magna, <24 hr	1150	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992

Table 3. Studies on Aquatic Invertebrates, concluded.

Species	**Effects Concentration mg/L**	**TDS Components**	Effects Unit	**Reference**
D. magna, 7 day	1780	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992
Daphnia magna, 7 day	2200	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992
D. magna, 7 day	1250	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992
C. dubia, <24 hr	1160	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992
C. dubia, <24 hr	1000	$NaHCO_3$	48-hr, LC50	Hoke et al. 1992

Table 4. Studies of Effects of Elevated TDS on Fish.

Species	Life Stage at exposure	Effects Concentration mg/L	TDS Components	Observed Effects	Reference
Onchorhynchus nerka Coho Salmon	Fertilization	1250	$CaSO_4$	Reduced fertilization	Stekoll, et al., 2001
O. nerka	Fertilization	750 (LOEC)	$CaSO_4$	Reduced survival at epiboly	Stekoll, et al., 2001
O. keta Chum Salmon	Fertilization	750	$CaSO_4$	Reduced fertilization: 97% fertilization on 0 mg/L (control), reduced at 750 mg/L and 1800 mg/L.	Stekoll, et al., 2001
Pimephales promelas Fathead Minnow	?	1,201	NaCO3	LC50	Tietge and Hockett 1996
P. promelas	?	>1,970	$CaSO_4$	LC50 – 24, 48, 96 hr	Mount et al. 1997
O. mykiss Rainbow Trout	Hardening	613 1500	$CaSO_4$ $CaSO_4$	46% eye-up 4% survival (control was 76% in 101 mg/L)	Ketola et al. 1988
Salmo salar Atlantic Salmon	Hardening	32 2110 1395	$CaSO_4$ $CaSO_4$ CaCl	76% survival[1] at eye-up 34% survival 35% survival	Ketola et al. 1988

[1]These values are likely the No Observed Effects Concentration (NOEC).

Table 4. Studies of Effects of Elevated TDS on Fish, Continued.

Species	**Life Stage at exposure**	**Effects Concentration mg/L**	**TDS Components**	**Observed Effects**	**Reference**
Salmo salar Atlantic Salmon	Hardening	32 2110	$CaSO_4$ $CaSO_4$, Na_2SO_4, KCl, NaCl, $MnSO_4$	68% survival[1] at eye up 33% survival	Ketola et al. 1988
Salvelinus fontinalis Brook Trout	Hardening	2,229 64 82	$CaSO_4$ $CaSO_4$ $CaSO_4$	38% survival at eye-up 75% survival[1] 71% survival[1]	Ketola et al. 1988
Morone saxitalis Striped Bass	Fertilization	>1,000		Reduced egg survival	Turner and Farley 1971
P. promelas Fathead Minnow	Fertilization	275-450		Lower fertilization rates	Peterka 1972
Stizostedion vitreum Walleye Pike	Hatching	2,200-3,600		No hatching	Peterka 1972
Esox lucius Northern Pike	Hatching	2,200-3,600		1% Hatched	Peterka 1972

[1]These values are likely the No Observed Effects Concentration (NOEC).

Table 4. Studies of Effects of Elevated TDS on Fish, Continued.

Species	**Life Stage at exposure**	**Effects Concentration mg/L**	**TDS Components**	**Observed Effects**	**Reference**
P. promelas	Hatching	2,200-3,600	$NaHCO_3$, $Na2CO_3$, K_2CO_3	22-93%	Peterka 1972
P. promelas	Adult	>2,000	$NaHCO_3$, $Na2CO_3$, K_2CO_3	Toxicity	Peterka 1972
O. mykiss	Spermatozoa	19.2 106.2	KCl KCO_3	Activity was inhibited	Stoss et al. 1977
S. vitreum	Hatching	200 1150 2400	$NaSO_4$	41% Survival (control[1]) 38% 7%	Koel and Peterka 1995
E. lucius	Hatching	200 1150 2400	$NaSO_4$	92% Survival (control) 68% 33%	Koel and Peterka 1995
Perca flavescens Yellow perch	Hatching	200 1150 2400	$NaSO_4$	88% Survival (control) 70% 73%	Koel and Peterka 1995
Catostomus commersoni White sucker	Hatching	200 1150 2400	$NaSO_4$	87% Survival (control) 95% 66%	Koel and Peterka 1995

[1]Note: Poor survival in control for this test.

Table 4. Studies of Effects of Elevated TDS on Fish, Continued.

Species	**Life Stage at exposure**	**Effects Concentration mg/L**	**TDS Components**	**Observed Effects**	**Reference**
Cyprinus carpio Common carp	Hatching	200 1150 2400	$NaSO_4$	71% Survival 69% 49%	Koel and Peterka 1995
P. promelas	Adult	2,610		88% Survival – 30 days	Woodward et al. 1985
Ptychocheilus lucius Colorado squawfish	Adult	2,610		32% -15 days 27% - 30 days	Woodward et al. 1985
Morone chrysops Sunshine Bass	Growth and blood hemocrit levels	5, 10, 20, 40, and 80	Ca	No benefits found[1] No tests at higher concentrations	Seals et al. 1994

[1]Note: Authors were testing for benefits of Ca, i.e., its ability to inhibit absorption of metals.

Table 4. Studies of Effects of Elevated TDS on Fish, Concluded.

Species	**Life Stage at exposure**	**Effects Concentration mg/L**	**TDS Components**	**Observed Effects**	**Reference**
O. mykiss Rainbow trout	Swim-up	>2,080	CaSO4	No effects at concentrations tested	EVS 1997
O. mykiss	Post-hardening eggs	>1961	CaSO4	NOEC	Chapman et al. 2000
O. mykiss	Fertilization and early development	1200	Primarily CaSO4	7-day, IC25[1]	EVS 1998
O. mykiss	Fertilization and development to eyed stage	600	Primarily CaSO4	15-day, IC25	EVS 1998
O. keta Chum salmon	Fertilization and early development Embryo viability Embryo viability	282 and 361 (2 tests) 618 and 1,376 (2 tests) 330 and 382 (2 tests) 667 and 676 (2 tests)	Primarily CaSO4	7 day, IC25 7-day, IC50 NOEC[2] LOEC[3]	EVS 1998

[1]IC25 = Inhibition Concentration 25, or concentration inhibiting 25% of the population
[2]LOEC = Lowest Observed Effects Concentration
[3]NOEC = No Observed Effects Concentration

Table 5. Studies of Effects of Elevated TDS using Standardized Toxicity Tests.

Test Name	**Effects Concentration, mg/L**	**Effects Unit**	**TDS Components**	**Notes**	**Reference**
Vibrio fischeri Micro-Tox Bacteria	1960	EC20	$CaSO_4$	Inhibited growth in concentrations from 1775 to 2500 mg/L	LeBlond and Duffy in press

PAPERS REVIEWED FOR THIS REPORT

Chapman, P.M., H. Bailey, and E. Canaria. 2000. Toxicity of Total Dissolved Solids Associated with Two Mine Effluents to Chironomid Larvae and Early Life Stages of Rainbow Trout. Environmental Toxicology and Chemistry 19(1):210-214.

SUMMARY OF RESEARCH

No adverse effects were seen in either the embryo (1,961 mg/L synthetic effluent) or the swim-up fry test (2,080 mg/L) when exposed to 100% synthetic effluent.

No adverse effects were seen in % survival of chironomid larvae when exposed to full strength Red Dog Mine synthetic effluent (2,089 mg/L TDS), although growth was apparently reduced by about 45% in the same solution. No adverse effects were observed in chironomid larvae exposed to 1,134 mg/L TDS.

Reduced survival of Chironomidae larvae occurred at 1,750 mg/L and 2,240 mg/L, but not at 1,220 mg/L TDS. No growth effects were observed at any exposure level.

LIMITATIONS OF THE STUDY

Rainbow trout eggs were not tested during these assays.

Swim-up fry only were exposed for the first 4 days of an assay, after which dilution water was used to replenish assay waters, instead of exposing them to the synthetic effluent for 7 days.

Rainbow trout eggs were fertilized first and then exposed to synthetic effluent representing Red Dog Mine waters. Exposure to the synthetic effluent should have occurred during fertilization, as others have found this to be a more sensitive stage to elevated TDS.

Dickerson, K.K., W.A. Hubert, and H. L. Bergman. 1996. Toxicity Assessment of Water from Lakes and Wetlands Receiving Irrigation Drain Water. Environmental Toxicology and Chemistry. 15(7): 1097-1101.

LIMITATIONS OF THE STUDY

Although TDS was measured in samples, it was not reported for the 22 lakes and wetlands that were not toxic to *Ceriodaphnia dubia, Daphnia magna*, or *Pimephales promelas*.

Constituents of the water samples from eight water bodies that proved to have toxic effects to the three organisms tested, included trace elements that were at levels much higher than the Alaska Water Quality criteria for aquatic life.

ENSR. 1997a. Review of Toxicity Studies Conducted on Kensington Mine Effluent. Document Number 2012-001-200. March 1997.

Summary of Research

ENSR reviewed the Kensington toxicity study, conducted by EVS Environment Consultants, in December 1996 (EVS 1997: Toxicity of total dissolved solids (TDS) in Coeur mine effluent, Larval *Chironomus tentans*).

The study was reviewed in regard to methods and conclusions. ENSR also analyzed the chemical composition of the Kensington mine effluent to determine the likelihood of adverse effects to aquatic organisms.

ENSR made the following conclusions:

- The tests were conducted according to established methods or appropriate modifications;
- Statistical analyses of the test results were valid. Although survival was significantly reduced in the 75 percent treatment, there was no reduction in the 100 percent treatment and there was no dose-response relationship;
- Comparisons of Kensington effluent ion concentrations to existing salinity-toxicity relationship data suggest that TDS ions in Kensington effluent should not be acutely toxic to *Ceriodaphnia dubia*; and
- The toxicity of TDS ions measured in the Kensington effluent (average = 539 mg/L) is well below the levels that have been shown to cause toxicity in some freshwater benthic macroinvertebrates.

ENSR included a brief literature review on toxicity of total dissolved solids. The following table is taken from their report, complete references are given in the section References Cited, not Reviewed.

Species	Common Name	TDS Components	End Point	Effects Concentration	Reference
Dugesia gonocephala	Flatworm	Cl^-	Mortality	1230	Palladina 1980
Tubifex tubifex	Segmented worm	K^+	EC50	2000	Khangarot 1991
Tubifex tubifex	Segmented worm	Ca^{+2}	EC50	814	Khangarot 1991
Cricotopus trifascia	Chironomid midge	K^+	LC50	1567	Hamilton 1975
Cricotopus trifascia	Chironomid midge	CL^-	LC50	1406	Hamilton 1975
Hydroptila angusta	Caddisfly	K^+	LC50	2316	Hamilton 1975
Hydroptila angusta	Caddisfly	Cl^-	LC50	2077	Hamilton 1975
Cyclops abyssorum prealpinus	Cyclopoid copepod	Ca^{+2}	EC50	7000	Baudoin 1974
Cyclops abyssorum prealpinus	Cyclopoid copepod	Mg^{+2}	EC50	280	Baudoin 1974

LIMITATIONS OF THE STUDY

In their conclusions, ENSR states that "concentrations of TDS ions measured in Kensington effluent are well below the levels that have been shown to cause toxicity in some freshwater benthic macroinvertebrates." The Coeur Mine effluent consists primarily of calcium sulfate; however, most of the studies reported in the ENSR review were conducted with ions other than calcium sulfate. Comparisons of reported effects from the EVS study with effects reported by ENSR are not valid unless the chemical compositions are similar.

ENSR. 1997b. Review of Rainbow Trout Toxicity Study Conducted on Synthetic Kensington Mine Effluent. Document Number 2012-001-202. April 1997.

SUMMARY OF RESEARCH

- ENSR reviewed the report Toxicity of Total Dissolved solids (TDS) in Coeur Mine Effluent: Rainbow Trout Swim-Up Fry by EVS Environment Consultants, dated March 1997.
- The EVS study and Laboratory Report were prepared for Coeur Alaska, Juneau, AK. To support their request for a site-specific water quality criterion of 1,000 mg TDS/L in Sherman Creek.
- ENSR examined three aspects of the EVS study: the methods used in the laboratory tests, the results and statistical analysis from the study, and the effluent chemistry data.
- From their review, ENSR concluded that EVS conducted the toxicity tests with rainbow trout (*Onchorhynchus mykiss*) according to appropriate modifications of existing methods.
- The statistical analyses of the test results were confirmed by ENSR. There were no significant reductions in survival or growth in any of the synthetic effluent treatments.
- ENSR further stated "Swim-up rainbow trout are not likely to be adversely affected by the concentrations of common (TDS) ions found in the Kensington Mine effluent (i.e., <2,080 mg/L)."

LIMITATIONS OF THE STUDY

ENSR reported that the 7-day swim-up fry test is not specifically described in either Environment Canada or EPA documents. The methods described in the EVS report do not correspond precisely with procedures outlined in Environment Canada (1990) or (1992). "The methods are, however, consistent with methods used in other short-term chronic tests (e.g., fathead minnow short-term chronic test, Lewis et al. 1994) and may be acceptable for the use of rainbow trout in a short-term chronic study."

EVS Environment Consultants. 1996. Toxicity of Total Dissolved Solids (TDS) in Red Dog Mine Effluent. Early Life Stages of Rainbow Trout and larval *Chironomus tentans*.

Summary of Research

The researchers exposed fertilized eggs and swim-up fry of rainbow trout (*Onchorhyncus mykiss*) and chironomid larvae (*Chironomus tentans*) to a range of total dissolved solids (TDS) concentrations. The composition of TDS imitated the treated water discharged from the Red Dog Mine – primarily calcium sulfate with minor amounts of other ions. No metals were added to the test water.

The highest TDS concentrations tested (in the range of 1993 to 2757 mg/L) did not affect rainbow trout embryo viability, rainbow trout fry survival and growth, or larval chironomid survival. Chironomid growth was the only end-point that showed adverse effects related to elevated TDS concentrations. Specifically, growth was not affected at measured TDS concentrations of 1584 mg/L, but was significantly reduced at an actual TDS concentration of 2089 mg/L.

LIMITATIONS OF THE STUDY

Reviewers of the study (e.g. USFWS 1997, ADEC 1997, ADFG 1997) provided comments on the study. General comments were:

- Rainbow trout is likely not more sensitive to pollution than species indigenous to the Wulik River Drainage.
- *Chironomus tentans* does not occur in Alaska and is not part of the diet of fish in the Wulik River drainage.
- Tests on *Chironomus tentans* were not conducted between the highest concentration showing no effects (1584 mg/L) and the lowest concentration showing effects (2089 mg/L).
- Rainbow trout eggs were dry fertilized, then placed in test solutions of synthetic effluent. Given that the eggs were not fertilized in the test solutions, it is not possible to predict effects of elevated TDS on rates of fertilization or on delayed egg development or higher mortalities that may occur later as a result of exposure at fertilization.

- Fertilization rates in the test fish, including controls, were unacceptably low. The fertilization rates achieved in many of the tests were lower than the minimum fertilization rate of 70% stated in the report's quality assurance. Therefore, many of the tests should be considered invalid.

- To determine possible effects from sudden changes in TDS concentrations, exposure of the trout embryo and swim-up fry to the test solutions was 4 days, after which the test solution was replaced with dilution water. For the Chironomid tests, exposure to the synthetic effluent was 5 days, followed by 5 days of dilution water. Data presented in the Appendices to the report show the earliest time any effects were observed was days 5, 6, or 7. Chironomid data are not divided into daily counts. Because toxic responses can be delayed, it is possible that effects from exposure to elevated TDS concentrations were not detected because the test organisms were not exposed for the full duration of the test period. No conclusions can be drawn on whether the reported effects are due to the high TDS concentrations or the sudden change in TDS, or if the absence of effects was due to the short exposure time to synthetic TDS solutions.

EVS Environment Consultants. 1997a. Toxicity of Total Dissolved solids (TDS) in Coeur Mine Effluent: Larval *Chironomus tentans*. Laboratory Report prepared for Coeur Alaska, Juneau, AK. January 1997.

SUMMARY OF RESEARCH

- The researchers tested simulations of mine effluent containing elevated total dissolved solids (TDS) on the survival and growth of *Chironomus tentans*. The synthetic effluent did not contain metals.

- The highest TDS concentration tested (2100 mg/L) did not affect larval chironomid growth and survival, although there was a non-dose related reduction in survival in the second highest concentration of 1440 mg/L.

- Growth was not affected in any of the synthetic effluent test concentrations from 360 to 2100 mg/L or in a soft water control of 72 mg TDS/L.

LIMITATIONS OF THE STUDY

- The researchers reported significant effects on survival of *Chironomus tentans* at 1440 mg/L, but not at the higher dose tested, 2100 mg/L. The causes of mortality at 1440 mg/L were not investigated.

- The report concludes there is no statistically significant effect on growth and survival of larval *Chironomus tentans*. However, their Table 3-1 shows a noticeable decrease in the median survival of the test organisms, as compared to the controls and soft water treatment.

- The report does not address the sensitivity of *Chironomus tentans* with respect to TDS and its relevance as "the most sensitive" species in Alaska streams." According to ADEC (Memorandum from Spanagel to Stambaugh 1997), an earlier ADEC in-house draft document called Information Needs For Site Specific TDS, stated the test species was selected because it is a "good lab species, with established protocols."

- *Chironomus tentans* is a laboratory species and is not known to occur in cold, clear water streams of northern climates. No tests have been done to determine if it is more or less sensitive to TDS exposure than aquatic invertebrate species found in Alaska.

EVS Environment Consultants. 1997b. Toxicity of Total Dissolved solids (TDS) in Coeur Mine Effluent: Rainbow Trout Swim-Up Fry. Laboratory Report prepared for Coeur Alaska, Juneau, AK. March 1997.

Summary of Research

- EVS Environmental Consultants addressed questions regarding the potential effects of total dissolved solids (TDS) in Coeur mine effluent with a laboratory study using synthetic effluent. The synthetic effluent did not include trace metals normally found in the mine effluent.

- In their study, trout swim-up fry (*Onchorhynchus mykiss*) were exposed to a range of TDS concentrations (approximate concentrations of 260, 520, 1040, 1560 and 2080 mg/L) with an ionic composition that matched that of the effluent. The test endpoints were survival and growth.

- The test results indicated that survival and growth were not affected in any of the test concentrations up to 2,080 mg/L.

Limitations of the Study

- Other studies identified the fertilization to egg hardening stage as the developmental period that was sensitive to TDS concentrations. This study did not expose rainbow trout until after this period. See comments in the following review.

- The study was conducted over 7 days and dry weight of each fish was determined at the end of the tests to calculate growth. There are no initial weights of the fish; therefore, it is not possible to estimate growth. The information on growth should not be used.

- Their conclusion should be limited only to the swim-up life stage of rainbow trout for a 7-day exposure. The results cannot be extrapolated to long-term exposures that might occur over the fresh-water phase of the fish or to effects that may occur during early life stages, including fertilization and hardening. Steckel et al. (2001) have reported the fertilization period to be the most sensitive period, while, Ketola et al. (1988) reported that the hardening stage was the more sensitive period of exposure to TDS effects than in later life stages.

EVS Environment Consultants. 1997c. Toxicity of Total Dissolved solids (TDS) in Coeur Mine Effluent: *Selenastrum capricornutum*. Laboratory Report prepared for Coeur Alaska, Juneau, AK. July 1997. 10pp.

EVS Environment Consultants conducted 96-hr toxicity tests to examine the effects of total dissolved solids (TDS) on cell numbers of the green algae, *Selanstrum capricornutum*. A synthetic effluent was prepared to match the overall chemical characteristics of effluent discharged from the Coeur mine. Average TDS of the mine discharge was 539 g/L; however, the synthetic effluent was prepared at concentrations of up to 2,100 mg/L TDS, but without trace metals, to determine if higher concentrations of TDS could be tolerated by the algal species.

After the 96-hr test period, the researchers reported no significant reduction in the number of *Selenastrum* cells in any of the test treatments of 99, 664, 1180, 1640, and 2020 mg/L. The researchers used Zn as a reference toxicant and controls to assess the relative health of the culture. J Results from these quality assurance procedures were within acceptable limits.

The test was not conducted over longer time periods.

EVS Environment Consultants. 1998. Effects of Total Dissolved Solids (TDS) on Fertilization and Viability of Rainbow Trout and Chum Salmon Embryos. Revised Final Draft. EVS Project No. 9/302-28. Prepared for Cominco Alaska Inc.

SUMMARY OF RESEARCH

- The potential effects of total dissolved solids (TDS) in Cominco Red Dog Mine effluent were addressed through studies using laboratory prepared mixtures of TDS. Trace constituents normally found in the mine effluent, including trace metals, were not included in the test waters.

- Rainbow trout (*Oncorhynchus mykiss*) and chum salmon (*O. keta*) eggs were fertilized in different concentrations of TDS solutions. The TDS solutions were formulated to contain ions similar to the Red Dog Mine effluent.

- Salmon eggs were exposed to elevated TDS at fertilization and maintained in the TDS solutions for the entire test duration. The highest test concentration was from 2,210 to 2,640 mg/L. The test endpoints included fertilization success and normal embryonic development.

- The authors reported that fertilization and/or embryonic development in rainbow trout exhibited 25 percent inhibition (IC25) over a 7-day exposure period at a TDS concentration of about 1,200 mg/L. The IC25 for the 15-d test exposure from fertilization to the eyed stage was about 600 mg TDS/L.

- Chum salmon were more sensitive, with IC25 estimates (based on the results of two different tests) of about 300 mg TDS/L.

- The authors speculate that inhibition may result from effects to sperm motility; however, subsequent researchers (e.g. Steckel et al. 2001) have examined sperm motility and report that it is not a controlling factor in successful egg fertilization and development.

LIMITATIONS OF THE STUDY

The controls had high mortality rates that should be taken into consideration when evaluating results from this study.

Holtz, W., J. Stoss and S. Buyujhatipoglu. 1977. Observations on the Activation of Trout Spermatozoa with Coelomic Fluid Water from an Uncontaminated Stream and Distilled Water. Zuchthyg 12(1977): 82-88. (Abstract and summary translated).

SUMMARY OF RESEARCH

- The researchers investigated the process of trout sperm activation occurring from dilution. They observed the reaction of freshly collected trout spermatozoa after mixing with coelomic fluid from females, water from an uncontaminated stream, and double distilled water at different rations.
- The finding most pertinent to this review was that the duration of sperm motility was longest in solutions with a sodium-to-calcium ratio of 20:1.
- Duration of sperm motility was greatest in amniotic fluid, followed by stream water, activation in distilled water resulted in the shortest duration of sperm motility.
- The concentration of metal ions seemed to affect sperm motility the most.
- Activation solutions with a sodium-calcium ratio of 20:1 resulted in the longest activation period.

LIMITATIONS OF THE STUDY

Total dissolved solids concentrations were not measured, nor were there any measurements of calcium sulfate. Because this is an incomplete translation from German to English, it was not possible to review the methods and results.

Hoke, R.A., W.R. Gala, J.B. Drake, J.P. Geisy, and S. Fleger. 1992. Bicarbonate as a potential confounding factor in cladoceran toxicity assessments of pore water from contaminated sediments. Can. J. Fish. Aquat. Sci. 49:1633-1640.

SUMMARY OF RESEARCH

- Organisms likely receive most of their exposure to toxic substances in sediments through contact with the pore water. Therefore, pore water is often used as a surrogate in toxicity tests for bulk sediment exposures.

- The authors observed that toxicity assessments of sediments might have been controlled by chemical properties of the pore waters. Elevated pore water alkalinity values, gas bubble formation, white crystalline residue on the inside of test chambers, and increases in pore water pH in test vessels during cladoceran toxicity tests suggested that the test results might be driven by the toxicity of bicarbonate to cladocerans.

- The researchers conducted 48-hr acute tests to establish the toxicity of HCO_3^- and Na^+ to *Daphnia magna* and *Cerodaphnia dubia*. Their results are summarized in the table below. The values for 48-hr LC50 were presented as mmol/L so we converted the values to mg/L and rounded to the nearest whole number to maintain consistency with other values reported in this review.

Species	Life Stage at testing	TDS Component	48-hr, LC50
D. magna	<24 hr	NaCl	5015
D. magna	<24 hr	NaCl	5000
D. magna	4th instar	NaCl	4000
C. dubia	<24 hr	NaCL	835
C. dubia	<24 hr	NaCL	735
D. magna	<24 hr	$NaHCO_3$	1400
D. magna	<24 hr	$NaHCO_3$	1150
D. magna	6 day	$NaHCO_3$	1780
D. magna	7 day	$NaHCO_3$	2200
D. magna	7 day	$NaHCO_3$	1250
C. dubia	<24 hr	$NaHCO_3$	1160
C. dubia	<24 hr	$NaHCO_3$	1000

LIMITATIONS OF THE STUDY

The tests were limited to Na^+ and HCO_3^- and did not address the cations and anions of concern in this study. The results are useful in consideration of other components of total dissolved solids.

Ketola, H.G., D. Longacre, A. Greulich, L. Phetterplace, and R. Lashomb. 1988. High Calcium Concentration in Water Increases Mortality of Salmon and Trout Eggs. Progressive Fish-Culturist 50(3): 129-135.

Summary of Research

- The authors report on several experiments to investigate effects of water chemistry during water hardening on survival of Atlantic salmon (*Salmo salar*), rainbow trout (*Onchorhynchus mykiss*), and brook trout (*Salvelinus fontinalis*) eggs. They found low survival (about 38%) when eggs were exposed to hard water containing high concentrations of calcium associated with gypsum in the water supply. Low survival occurred at 520 mg Ca/L. The value of 520 mg Ca/L corresponds to total dissolved solids (as $CaSO_4$) of about 1750 mg/L.

- The authors identified high concentrations of calcium as the causative agent by conducting experiments with both $CaSO_4$ and CaCl. Toxic responses to eggs hardened in both waters were similar.

- The authors summarize their results: "Our data show that water hardening eggs in water containing high concentrations of calcium (522 mg/L or more) significantly reduced survival of eggs of Atlantic salmon, brook trout, and rainbow trout. Very hard water rich in calcium sulfate (as in watershed rich in gypsum deposits) seems to be of special concern. Gypsum is more highly soluble than is limestone (calcium carbonate). Calcium sulfate is soluble to the extent of about 2 g/L, equivalent to about 580 mg calcium/L."

- Experiment 1: The water quality did not affect survival of eggs during incubation if eggs were hardened in water with low concentrations of hardness (particularly if calcium sulfate concentrations were low). Percent eye-up of rainbow trout eggs incubated in: Cedar Springs (1604 mg/L TDS) was 50%, Caledonia (613 mg/L) was 52%. But, for those eggs then hardened in waters high in minerals, % eye-up of rainbow trout eggs was significantly lower: Keuka Lake (101 mg/L) was 76%, compared to Caledonia (613 mg/L) at 46% and Cedar Springs (1604 mg/L) at 30%.

- Experiment 2: The percent survival of Atlantic salmon eggs to the eye-up stage significantly decreased with increasing concentrations of calcium and/or sulfate in the hardening waters. Percent eye-up for eggs hardened in the Tunison laboratory water (125 mg/L TDS) was 68% compared to 33% eye-up in eggs hardened in TL water with additional salts (CaSO4, Na2SO4, KCl, MgCO3, NaCl and/or MnSO4 in amounts to mimic the ionic composition of Cedar Springs water – 1604 mg/L).

- Experiment 3: High concentrations of calcium in hardening water decreased survival of Atlantic salmon eggs during the hardening process. Calcium levels were measured at 522 mg/L in the treatments that exposed eggs to calcium

(Treatments 2 and 3). The concentration of 522 mg Ca/ L is equivalent to TDS (as calcium sulfate) of 1770 mg/L.

- Experiment 4: Hatchery waters (Van Hornesville) with high levels of calcium (554 mg/L) and sulfate (1,675 mg/L) resulted in lower percentages of eyed eggs from brook trout and statistically significant (lower) rates of hatchability. Percent swim-up of hatched brook trout eggs was lower for those eggs hardened in hatchery waters higher in calcium and sulfate, but the differences were not significant.

- Experiment 5: Results from this experiment were variable with survival among all treatments much lower than the previous experiments. The authors infer that increased calcium, but not sodium, was detrimental during water hardening of rainbow trout eggs.

LIMITATIONS OF THE STUDY

The authors tested the effects of elevated TDS to fish eggs after fertilization and before hardening. Their results cannot be used to predict effects that may result from exposure during the fertilization period. Low survival (in the range of 68-72% probably reflect effects of the tests and should be viewed as no effects concentrations.

Koel, T.M. and J. J. Peterka. 1995. Survival to Hatching of Fishes in Sulfate-Saline Water, Devils Lake, North Dakota. . Canadian Journal of Fisheries and Aquatic Sciences 52: 464-469.

SUMMARY OF RESEARCH

The authors report survival to hatching of different fish species at various concentrations of TDS:

Fish Species	TDS 200 mg/L	TDS 1100 mg/L	TDS 2400 mg/L	TDS 4250 mg/L	TDS 6350 mg/L
Walleye	41	38	7	1	0
Northern Pike	92	68	33	2	0
Yellow Perch	88	70	73	0	0
White Sucker	87	95	66	0	0
Carp	71	69	49	63	25

- According to their data, decreases in survival occurred for walleye and northern pike between 200 and 1100 mg TDS/L, and continued to decline with increasing TDS. Northern pike occur in Alaska. The authors did not define the point between 200 and 1100 at which effects occurred.

- Survival for yellow perch declined between 2400 and 4250 mg TDS/L.

- Survival for white sucker declined between 1100 and 2400 mg TDS/L.

- It is not possible from the information presented to determine more precise TDS concentrations that caused effects.

- Survival to hatching of several fish species was significantly lower in sodium-sulfate waters with TDS of >2400 mg/L compared to freshwater TDS of 200 mg/L.

- Walleye (*Stizostedion vitreum*) survival to hatching was 41% at 200 mg/L TDS, 38% at 1150 mg/L, and 7% at 2400 mg/L TDS. The low survival at 200 mg/L may have resulted from test protocol.

- Northern pike (*Esox lucius*) survival to hatching was 92% at 200 mg/L, 68% at 1150 mg/L, and 33% at 2400 mg/L.

- Yellow perch (*Perca flavescens*) survival to hatching was 88% at 200 mg/L, 70% at 1150 mg/L, 73% at 2400 mg/L and 0% at 4250 mg/L.

- White sucker (*Catostomus commersoni*) survival to hatching was 87% at 200 mg/L, 95% at 1150 mg/L, 66% at 2400 mg/L, and 0% at 4250 mg/L.

- Common carp (*Cyprinus carpio*) survival to hatching was 71% at 200 mg/L, 69% at 1150 mg/L, 49% at 2400 mg/L, 63% at 4250 mg/L and 25% at 6350 mg/L.

- Poorer hatching was found in common carp during this study with sodium-sulfate waters than in other studies using sodium-chloride. The authors believe depressed hatching rates were due to ionic properties rather than osmotic effects.

LIMITATIONS OF THE STUDY

The authors thought that % survival to hatching did not account for additional mortality that could be expected in nature because eggs became softer and lost their adhesiveness. Although common carp embryos successfully hatched, the sac fry were poorly developed, could not swim, and lacked an eye pigment.

LeBlond, J.B. 2000. A Toxicity Assessment of Total Dissolved Solid Ions in Mine Effluent Using Two Common Bioassays: The 22-hr MicroTox® Assay and a *S. Capricornutum* Growth Assay. April 2000. M. S. Thesis, University of Alaska Fairbanks, Fairbanks, Alaska.

SUMMARY OF RESEARCH

- Water samples from Red Dog Mine Station 140 (TDS 94-361 mg/L) and Fort Knox IW#3 (289-380 mg/L) sometimes resulted in greater toxicity to the algae assay than in the bacterium assay.

- "Most samples from Red Dog Mine also exhibited non-toxic effects on the MicroTox® and algal assays, including all those taken from Station 001 [treated mine discharge or Outfall 001], Station 9, and Station 12." Outfall 001 is important because it represents the point discharge of mine effluent before it mixes with surrounding waters. TDS measurements for these stations included: Outfall 001(2990-3310 mg/L), Station 9 (28-396 mg/L), and Station 12 (133-370 mg/L).

- Samples taken in July from Station 140 from the Red Dog Mine (356 mg/L TDS) inhibited cell growth in MicroTox® and were also proven to be very toxic to the algal assay. "This was the only sample site for which the algal assay was consistently more sensitive than the MicroTox®." Note: Station 140 water is high in metals, particularly Cd, Pb, and Zn.

- "The 2500 mg/L synthetic TDS solution made in the laboratory demonstrated significantly different results than the field samples on both the MicroTox® and algal assays." "Samples concentrations between 1775 mg/L TDS to 2500 mg/L TDS led to inhibited cell growth [MicroTox® assay], and had a measured EC20 value of 1960 mg/L TDS. On the algal assay, however, all sample concentrations demonstrated toxic effects, with an EC20 value of 551.3 mg/L TDS."

- Potassium and chloride were identified as significant toxicants during MicroTox® assays and principal components analyses; in addition, TDS was recognized as a significant toxicant when data were log transformed. "Field samples contained TDS concentrations between 94 and 870 mg/L, while the standards varied between 267 and 4880 mg/L. Only at these high levels, and without the presence of other trace components, does TDS becomes a driving toxic factor."

- The fact that the two assays differed in response to TDS in field and lab samples may suggest that no one assay will be appropriate for detecting a response to elevated TDS. Metals present in the field samples stimulated bacterial growth and, in some instances, were highly toxic to the algal assay. Standardized TDS samples were toxic to both assays. If mining companies were to use one of these two assays to determine a site-specific criterion for TDS, results may be misleading.

LIMITATIONS OF THE STUDY

- The authors used a marine bacterium to assess toxicity effects to represent what would happen in a freshwater system. The marine bacterium also would not be representative in its sensitivity to TDS because it would be used to elevated TDS levels in the marine environment.

- Using field samples from Station 140 were not appropriate because of high concentrations of toxic components that occurred naturally.

- Results using EC_{20} values indicate field water samples were not appropriate solutions to use in place of TDS standard solutions with the same TDS concentration. The 22-h Microtox® test was more sensitive to nickel, ammonia, and chloride in the TDS solutions, but the focus of our research was to investigate response only to TDS, not heavy metals.

- EC_{20} Assay results were highly variable, resulting in poor reproducibility of test results and high standard deviations.

LeBlond, J.B. and L.K. Duffy. In Press. Toxicity assessment of total dissolved solids in effluent of Alaskan mines using 22-h chronic Microtox® and *Selenastrum capricornutum* assays. The Science of the Total Environment.

SUMMARY OF RESEARCH

Microtox® Assay-

- Assays were conducted for 22 hours with simple TDS standard solution and field water samples from Fort Knox and Red Dog.
- "All tailings pond (TP) samples from Fort Knox, and some Red Dog Station 140 samples elicited toxic responses on the Microtox® assay whereas, for these samples on the algal assay varied monthly."
- "…[synthetic TDS solution] samples between 156 and 1775 mg/l TDS demonstrated non-toxic effects. Sample concentrations between 1775 and 2500 mg/l TDS led to inhibited bacterial growth, with an EC20 value of 1960 mg/l TDS."

Selenastrum capricornutum Assay –

- The TDS standard solution resulted in toxic effects at all concentrations. "When tested on the algal assay, all synthetic TDS concentrations demonstrated toxic effects, with an EC20 value of 551.3 mg/l TDS."

LIMITATIONS OF THE STUDY

- The authors used a marine bacterium to assess toxicity effects to represent what would happen in a freshwater system. The marine bacterium also would not be representative in its sensitivity to TDS because it would be used to elevated TDS levels in the marine environment.
- Using field samples from Station 140 were not appropriate because high concentrations of toxic metals naturally occur in that particular receiving water.
- Results using EC20 values indicate field water samples were not appropriate solutions to use in place of TDS standard solutions with the same TDS concentration. The 22-h Microtox® test was more sensitive to nickel, ammonia, and chloride in the TDS solutions, but the focus of our research was to investigate response only to TDS, not toxic factors.

Lewis, M. 1976. Effects of low concentrations of manganous sulfate on eggs and fry of rainbow trout. Progressive Fish Culturist 38 (2): 63-65.

Summary of Research

- Manganese can occur as a minor component of the total dissolved solids of a water treatment effluent. Lewis reported that Pennsylvania waterways receive a daily influx of more than 1 billion gallons of treated mine effluent. Manganous and other metallic salts are normal constituents of this effluent.

- Lewis evaluated the toxicity of three low manganous sulfate concentrations (1, 5, and 10 mg/L) to eggs of rainbow trout (*Salmo gairdneri*) during a normal incubation period and to two growth stages of fry.

- He found egg mortality progressively increased with increased concentrations of manganous sulfate. Toxic responses were greatest at two distinct stages – before and up to the eyed stage and at hatching.

- Over the 29-day test period, he reported 7% mortality in controls, 12% mortality in 1 mg manganous sulfate/L, 22% mortality in 22% mg manganous sulfate/L, and 30% mortality in the highest concentration, 10 mg manganous sulfate/L. He reported no statistically significant difference among treatment replicates.

LIMITATIONS OF THE STUDY

Ions of manganese are rarely found at concentrations above 1 mg/L and manganese is usually not considered to be a problem in fresh water (USEPA 1986). Manganese is not a priority pollutant (USEPA 1999); as a non-priority pollutant, there is no CMC (Criterion Maximum Concentration) or CCC (Criterion Continuous Concentration) for freshwater aquatic life.

Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison, and J.M. Evans. 1997. Statistical Models to Predict the Toxicity of Major Ions to *Ceriodaphnia dubia*, *Daphnia magna* and *Pimephales promelas* (Fathead Minnows). Environmental Toxicology and Chemistry 16(10): 2009-2019.

SUMMARY OF RESEARCH

- The authors developed a predictive tool to assess toxicity attributable to major ions by testing the toxicity of over 2,900 ion solutions using the daphnids, *Ceriodaphnia dubia* and *Daphnia magna*, and fathead minnows (*Pimephales promelas*). They reported that relative ion toxicity of $K^+ > HCO_3^- \approx MG^{2+} > Cl^- > SO_4^{2-}$. The Na^+ and Ca^{2+} ions were not significant variables in the regressions.

- Assays exposing *C. dubia* to calcium sulfate for 24 hr resulted in an LC50 of >2,430 mg/L TDS and for 48 hr was >1,910 mg/L.

- Assays exposing *D. magna* to calcium sulfate for 24 and 48 hr resulted in an LC50 of >1,970 mg/L.

- Assays exposing *P. promelas* to calcium sulfate for 24, 48 and 96 hr all resulted in an LC50 of >1,970 mg/L.

Pentec Environmental, Inc. 1992. Mining Related Elevation of Dissolved Solids – Potential Significance in Surface Waters. Project Number 48-006. Prepared for Cominco Alaska, Inc. Edmonds, WA 98020.

SUMMARY OF RESEARCH

- Pentec Environmental examined some of the published literature on total dissolved solids to determine the significance of high total dissolved solids (TDS) effluents containing calcium sulfate to natural riverine ecosystems. Their work focused on TDS and sulfates in the absence of significant concentrations of toxic elements.

- Based on their review of the literature, they provided the following ranges of TDS noted to cause effects to aquatic and other species. In all reported citings, the type of TDS and the end point (death, limited growth) were not provided.

Taxonomic group	**Range of TDS**	**Reported Effect**	**TDS Components**
Livestock watering	2,860 – 12,000	not given	not given
Ducklings, no species reported	550 – 1,740	"poisoning"	not given (salinity?)
Freshwater fish (no species reported)	5,000 – 10,000	?	not given

LIMITATIONS OF THE STUDY

- The authors incorrectly state: "Important resident and anadromous (amphidromous) species in Ikalukrok Creek in northwestern Alaska (Arctic grayling, *Thymallus arcticus* and Dolly Varden char, *Salvelinus malma*) are both capable of surviving in the marine coastal waters (Houghton 1983) and therefore are expected to be capable of osmoregulation in high levels of TDS." Dolly Varden undergo many physiological changes upon smolting that allow the fish to migrate to and rear in marine waters. There is no documentation of Dolly Varden spawning and rearing successfully in marine water.

- Arctic grayling are found seasonally in near shore waters, usually during spring freshets and other high water events. The Arctic grayling may use this time to migrate into a different waterway. However, this species of fish does not spawn and rear in marine water; their occurrence is incidental.

- The authors also erroneously report winter TDS concentrations in Red Dog Creek as part of the "natural" condition. High TDS in winter results from exclusion of ions with ice development; fish do not occupy Red Dog Creek during the winter. Therefore, winter high TDS concentrations for Red Dog Creek are not representative of natural conditions promoting growth and survival of fish.

Ruiquan Wu and C.E. Boyd. 1990. Evaluation of Calcium Sulfate for Use in Aquaculture Ponds. The Progressive Fish-Culturist 52:26-31.

SUMMARY OF RESEARCH

- Application of gypsum (calcium sulfate) to fish ponds resulted in reduction of pH, turbidity, phosphate, and phytoplankton abundance, while increasing levels of calcium.

- Concentrations used in this study were substantially lower than concentrations shown by other studies to cause toxic effects to aquatic life.

LIMITATIONS OF THE STUDY

- It isn't clear how many ponds were used for each treatment. The authors did not use statistics to analyze the results for levels of significance or correlation.

Schwartz, M.L. and R. C. Playle. 2001. Adding Magnesium to the Silver-Gill Binding Model for Rainbow Trout (*Oncorhynchus mykiss*). Environmental Toxicology and Chemistry 20(3): 467-472.

SUMMARY OF RESEARCH

- Schwartz and Playle investigated some of the protective effects of increased ions in water. Rainbow trout (Oncorhynchus mykiss) were exposed to about 0.1 µM silver as AgNO3 for 3 to 4 hours in synthetic, ion-poor water to which was added Mg, Ca, or thiosulfate. Gills were extracted and assayed for Ag.

- Authors found that competition by Na+2 and complexation by Cl- and dissolved organic matter (DOM) working together give the most protection against Ag adsorption to fish gills of rainbow trout. Mg, even at up to three times the concentrations found in sea water, did not reduce accumulation of Ag by trout gills.

- Silver accumulated on or in the gills of trout in water containing up to 8.6 mM CaCO4. No decrease in gill Ag was seen as the Ca concentration increased, indicating that even at a concentration similar to that in seawater, Ca2+ is not a strong, competing cation against Ag+ accumulation by trout gills.

- Although this study does not include tests of detrimental effects from elevated TDS, it brings into question the degree of protection from metals absorption afforded by elevated calcium.

Seals, C., C. Kempton, and J. Tommasso. 1994. Environmental calcium does not affect production or selected blood characteristics of sunshine bass reared under normal culture conditions. Progressive Fish Culturist 56: 269-272.

SUMMARY OF RESEARCH

- The authors discuss previous studies that identify the stress-alleviating benefits of calcium and recognize that few, or no, studies have explored the effects of calcium ion under conditions of normal culture.

- The primary objective of their study was to determine the effects of environmental calcium on production characteristics of sunshine bass (Morone chrysops) under apparently non-stressful conditions.

- The authors report that elevated calcium concentrations offer no advantages for sunshine bass growth, food conversion, condition factor, hematocrit, plasma osmolity, or plasma calcium concentrations during apparently non-stressful periods. Calcium (as CaCl) was tested at concentrations of 5, 10, 20, 40, and 80 mg/L; no tests were done on high concentrations.

- The authors reported that previous studies have indicated that environmental calcium is advantageous under stressful conditions; however, their study indicated that elevated calcium levels offer no advantages during apparently non-stressful periods.

Sorensen, D.L., M. M. McCarthy, E. J. Middlebrooks, and D. B. Porcella. 1977. Suspended and Dissolved Solids Effects on Freshwater Biota: A Review. . US Environmental Protection Agency Report, EPA-600/3-77-042.

SUMMARY OF RESEARCH

- The authors present a review of literature from late 1960's to mid-1970's. Many of the results are of tests conducted on warm-water species. Tests on some fish species show effects on egg development, but not when eggs are hardened in fresh water.

- The authors present a curve showing a precipitous decrease in biomass of organic matter (phytoplankton) with about 1200 mg/L TDS.

- Sorensen et al. also discuss studies of the use of additions of calcium sulfate to reduce nutrient availability, and primary production.

- This review covered a variety of responses by aquatic biota at all levels – blue green algae, phytoplankton, zooplankton, invertebrates, and embryonic and juvenile fish. Because the review occurred in the 1970's, the referenced materials are primarily from the 70's and earlier.

Algae

- Reported decreasing taxonomic richness beginning at 35 g/L (35,000 mg/L) salt concentration (Ruttner 1952).

- Inhibition of Selanastrum at salinities greater than 9 ppt (9,000 mg/L) (Specht 1975), and between 250 and 500 mg/L (Cleave et al. 1976).

- Concentrations of TDS that led to maximum productivity occurred at 1400 ppm (1400 mg/L); continued increase in TDS resulted in a decline in productivity (Kerekes and Nursall 1966).

- Maximum standing crop of algae occurred at 8200 ppm (8200 mg/L), beyond that increased concentrations of TDS become osmotically limiting (Topping 1975).

- Salt concentrations (NaCl) of 1 mg/L were necessary for growth of blue green algae, but concentrations above this amount led to inhibition of growth (Batterton and van Baalen 1971).

Zooplankton

- Chronic toxicity of nitrilotriacetate (NTA) to *Daphnia magna* was reduced with increasing hardness until 438 mg/L total hardness was reached (Biesinger et al. 1974).

- Polyelectrolytes used as flocculants were toxic to mysids and *Daphnia* at concentrations between 0.06 mg/L to 16.5 mg/L (Biesinger et al. 1976).

Aquatic Invertebrates

- References to studies on TDS effects to aquatic invertebrates were not used if: 1) concentrations were substantially higher than the 1500 mg/L concentration of interest to this review, 2) did not include conclusive information on concentrations that were detrimental to invertebrates, or 3) the invertebrate fauna studied were not typically found in freshwater.

Salmonid Fishes

- Oxygen consumption by rainbow trout was reduced in salinities of 7.5 ppt (7500 mg/L), while fish activity was no different than in freshwater when salinities were held at 15 ppt (15,000 mg/L), and maximum oxygen consumption occurred at 30 ppt (30,000 mg/L) salinity (Rao 1971).

Other Fishes

- Salinities greater than 1,000 ppm (1,000 mg/L) TDS greatly reduced egg survival of striped bass (*Morone saxitalis*) unless they are hardened in fresh water (Turner and Farley 1971).

- Most spawning by striped bass occurred within the Sacramento-San Joaquin Delta where salinities were below 200 mg/L TDS with an occasional 1,500 mg/L because of seawater intrusion. Although this concentration did not harm the eggs, the author speculates that over the long-term, differences in survival and migratory preferences may result in reduced spawning in areas with high TDS (Turner 1976).

- Using an empirical factor of 0.55 to 0.9, conductivity measurements (µmhos/cm) can be converted to mg/L TDS (APHA 1992). Choice of which empirical factor to use is based on the soluble components of the water and on the temperature of measurement. Because most papers do not include the necessary information to choose an empirical factor, a range will be presented for the purposes of estimating TDS concentrations for this review. Hatching success and sac fry survival was the greatest for fathead minnow (*Pimephales promelas*) eggs fertilized in water with a TDS concentration from 715–1170 mg/L (1300 µmhos/cm x 0.55 and 0.9 to estimate possible range) and then held in water with TDS values of 275-450 mg/L (500 µmhos/cm), 715-1170 mg/L (1300 µmhos/cm), 2,200–3,600 mg/L (4,000 µmhos/cm), and 6,600 – 10,800 mg/L (12,000 µmhos/cm). Lower fertilization rates were seen for eggs held in water with 275-450 mg/L (500 µmhos/cm) or 2,200-3,600 mg/L (4,000 µmhos/cm) and then held in the previous concentrations (500, 1300, 4000, and 6000 µmhos/cm). There was no hatch of walleye (*Stizostedion vitreum vitreum*), about a 1% hatch of northern pike (*Esox lucius*), and a 22 – 93 % hatch of fathead minnow eggs exposed in TDS concentrations of 2,200-3,600 mg/L (4,000 µmhos/cm). There were no northern pike sac fry that survived the TDS concentration of 3,300-5,400 mg/L (6,000 µmhos/cm), although roughly 1% of the fathead minnow sac fry survived a TDS concentration of 6,600-10,800 mg/L (12,000 µmhos/cm) (all surviving fry had physical abnormalities). (Peterka 1972).

- A literature review by Peterka (1972) revealed that ionic composition is more important for tolerance by fathead minnow than TDS. Levels of >2,000 mg/L TDS in NaHCO3, Na2CO3, and K2CO3 lakes were toxic to fathead minnow, while a 15,000 mg/L TDS concentration in Na2SO4 and MgSO4 lakes were not toxic. In another instance, a TDS concentration of 7,000 mg/L was not detrimental to reproduction or growth of fathead minnow. And in another study, fathead minnows grew faster in lake waters with TDS concentrations of 3,250 mg/L when compared to growth rates in waters where TDS was measured at 1,060 mg/L.

- Black buffalo (*Ictiobus niger*) and bigmouth buffalo (*Ictiobus cyprinellus*) were reported to successfully spawn in waters with salinities of 1600-1800 mg/L (1.6-1.8 ppt) and 1400-2000 mg/L (1.4-2.0 ppt), respectively (Perry 1976).

- Marine fish species such as bairdiella (*Bairdiella icistia*) were successfully introduced to the Salton Sea, CA, but with increasing salinities, this species' egg and larval survival was greatly reduced (Lasker et al. 1972 and May 1976). The author's explanation was that the harmful effects of the water might be due to the higher proportion of calcium and sulfate that are typically 3 times higher than that found in seawater. Sorensen et al. suggest that the divalent cations may be responsible for adverse physiological effects (May 1976).

Stekoll, M., W. Smoker, I. Wang, and B. Failor. 2001. Fourth Quarter 2000 Report for ASTF Grant #98-012, Project: Salmon as a Bioassay Model of Effects of Total Dissolved Solids. 17 January 2001.

SUMMARY OF RESEARCH

Acute Assays

- Chum fertilization: Eggs fertilized in and remaining in assay solution showed a significant decrease in fertilization rates with increasing concentration of total dissolved solids (TDS). Fertilization rates dropped from 97% in 0 mg/L TDS to 21% average fertilization in 2500 mg/L TDS. Eggs fertilized in assay solution and immediately moved to freshwater also showed this trend; 97% fertilized in 0 mg/L TDS to 77% fertilized in 2500 mg/L. Eggs fertilized in freshwater and then placed into assay solution showed no significant trend.

Coho sperm motility trials

- Increasing TDS concentrations resulted in faster time to 50% motility in coho sperm. Average time to 50% motility in 2500 mg/L was 14.15 sec. compared to time to 50% motility in process water. Although there was a slightly significant difference seen, it is not believed to be the cause of the decreased fertilization rates in chum salmon eggs.

96-hr assays

- Coho fertilization: "For eggs fertilized in and exposed to and incubated in TDS solutions (and controls) during the 96-hour assay, a trend of decreasing fertilization rates with increasing concentration at a highly significant P-value of 8.5×10^{-5} was seen. Mortality during the 96-hour assay showed statistical significance at P-value of 0.19. For eggs fertilized in process water and moved immediately to a TDS solution no clear trend in fertilization or mortality rates were seen. There was 100% fertilization except one replicate at 250 mg/l had one egg that was not fertilized and one replicate at 1875 had two eggs that were not fertilized."
- Coho between fertilization and epiboly: Results were inconclusive, but may indicate a trend in decreased mortality rate with increased TDS concentration, or more likely, the high rates of mortality are peculiar to this particular stage of development when embryos are vulnerable to any mechanical disturbances. "A 96-hour bioassay at a developmental stage between epiboly and fertilization (BEF) shows a possible, but not significant, trend of increased mortality rte with increased TDS concentration

Chronic Assays

Fish hatched in 1999 and exposed to chronic levels of TDS have not exhibited significant differences in length or weight.

Stoss, J., S. Buyujhatipoglu and W. Holtz. 1977. The Influence of Certain Electrolytes on the Induction of Sperm Motility in Rainbow Trout (*Salmo gairdneri*). Zuchthyg 12 (1977): 178-184. (Abstract and summary translated).

SUMMARY OF RESEARCH

- This study is a continuation of the study by Holz et al. 1977. The present study investigates the effect of the addition of different combinations of ions on the activation of freshly collected trout milt.

- The authors tested water with sodium chloride, potassium chloride, calcium chloride, and magnesium chloride at different concentrations. The effects of the anions were determined by testing potassium and sodium salts as carbonates and as chlorides.

- Spermatozoa activity normally seen during dilution was inhibited when small quantities of potassium chloride (19.2 mg/L) or potassium carbonate (106.2 mg/L) were added.

- Greater amounts of sodium chloride (16,010 mg/L), calcium chloride (15,229 mg/L) or magnesium chloride (11,749 mg/L) were needed to result in the same inhibition.

LIMITATIONS OF THE STUDY

- The paper is a translation from German and the translation is incomplete. Therefore, it is not possible to thoroughly review methods and analysis of results.

Teitge, J.E. and J.R. Hockett. 1996. Major Ion Toxicity of Six Produced Waters to Three Freshwater Species: Application of Ion Toxicity Models and TIE Procedures. Environmental Toxicology and Chemistry 16(10): 2002-2008.

SUMMARY OF RESEARCH

- Of the six produced waters tested (PW-1 through PW-4 and PW-6: 34,452 mg/L; 58,138 mg/L; 2,771 mg/L; 6,021 mg/L; and 5,704 mg/L respectively), only the PW-5 sample had a TDS concentration within the range considered by this literature review. The total salinity or TDS concentration of PW-5 was 1,692 mg/L, comprised mostly of sodium (95%) and bicarbonate ions. The LC50s for *C. dubia, D. magna*, and *P. promelas* exposed to PW-5 were >100%, >100%, and 71%, respectively.

LIMITATIONS OF THE STUDY

- Total salinities reported in Table 1 do not agree with discussion of the results.
- Discrepancies were found between the model predictions for ion toxicity and the assay results with *Daphnia magna, Ceriodaphnia dubia*, *Pimephales promelas*.

U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Mid-Continent Ecology Division. 1999. Technical Memorandum from Dave Mount, ORD/MED, to Mike Letourneau, EPA Region 10, presenting laboratory data associated with results presented in June 9, 1999, memorandum.

SUMMARY OF RESEARCH

- Under the direction of Dr. Dave Mount, the US EPA National Health and Environmental Effects Research Laboratory conducted toxicity tests on laboratory water reconstituted to approximate the reported chemistry of effluent from the Red Dog Mine in Alaska.

- Three experiments were conducted using larvae of the midge, Chironomous tentans. Tests 1 and 2 were conducted using <24-h old larvae. Test 3 was conducted using 10-d old larvae. Tests 2 and 3 were conducted concurrently using the same test solutions.

- Survival and growth were determined after 10 days exposure. Survival was determined as the number of recovered organisms divided by the number added at the beginning of exposure. For the 10-d old larvae, growth was indexed by dry weight of the recovered organisms. The mass of the organisms at test termination was too small to weigh reliably, so length was used as a surrogate measure.

- In Test 1, control survival was relatively low (72.9 %), though above the 70% minimum suggested by USEPA. Survival declined consistently with increasing TDS concentration. The 10-d LC50 for Test 1 was set at 2035 mg/L (range of 1244 to 3309 mg/L).

- In Test 3, survival was high in all treatments, but mean dry weight was significantly reduced at the highest TDS concentration relative to the dilution water (DW) control. The estimated IC0 was 1598 mg/L TDS.

- In Test 2, the DW and Lake Superior Water Controls had survivals that were less than the acceptable levels; therefore, results of Test 2 are not considered.

LIMITATIONS OF THE STUDY

Chironomous tentans is used in many laboratory toxicity tests, but it does not occur naturally in Alaska. There have been no studies that compare the sensitivity of this species to species that occur naturally in Alaska.

Wilkie, M.P. and C. M. Wood. 1994. The Effects of Extremely Alkaline Water (pH 9.5) on Rainbow Trout Gill Function and Morphology. Journal of Fish Biology 45: 87-98.

SUMMARY OF RESULTS

- The authors recognize that numerous eutrophic lakes and ponds experience diurnal and seasonal rises in water pH as a result of high rates of algal photosynthesis.

- Earlier studies had reported persistent, sometimes lethal, reductions in plasma Cl^- and Na^+ concentrations in rainbow trout exposed to alkaline water. Longer-term studies showed that rainbow trout are capable of surviving at high pH for days or weeks.

- The authors investigated the possible changes in the exposed surface area of branchial chloride cells when fish were exposed to Cl^- and Na^+ at elevated pH.

- Rainbow trout held in water with a pH 9.5 were able to regulate their internal ionic concentration because the chloride and sodium levels were normal at the end of the 5-week study.

- The study showed that fish adapt to elevated pH, such as occurs with increased concentrations of TDS, at least when the TDS components are Na^+ and Cl^-.

LIMITATIONS OF THE STUDY

- TDS concentrations were not measured, nor were there any measurements of calcium sulfate.

Woodward, D.F., R. G. Riley, M. G. Henry, J. S. Meyer, and T. R. Garland. 1985. Leaching of Retorted Oil Shale: Assessing the Toxicity to Colorado Squawfish, Fathead Minnows, and Two Food-Chain Organisms. Transactions of the American Fisheries Society 114: 887-894.

SUMMARY OF RESULTS

- The authors tested leach water from retorted oil shale. Leach water contained low concentrations of total organics, background concentrations of nitrogen-containing aromatic hydrocarbons, and elevated concentrations of K, Li, Mg, Mo, Na, SO_4, and NO_3.

- In 96-hr exposures, the authors found the undiluted leachate was not toxic to fathead minnows (*Pimephales promelas*) or Colorado squawfish (*Ptychocheilus lucius*) and only slightly toxic to the mayfly *Hexagenia bilineata* and to *Daphnia magna*.

- However, in 30-day tests of different concentrations of leachate, the authors found reduced growth of fathead minnows and reduced survival of mayflies. The highest test concentration not causing toxic effects was 3:97. This dilution represented a conductivity of 1,080 µS/cm and total dissolved solids of 750 mg/L.

- The results highlighted here are those that resulted from a significant difference between treatment and control. After 15 days exposure, mayfly *Hexagenia bilineata*, had 80% survival in 2,270 mg/L, and 65% at 4,370 mg/L TDS. After 30 days exposure, *H. bilineata*, 70% survival in 1,230 and 2,270 mg/L TDS, and 40 % survival in 4,370 mg/L.

- There was no significant difference between the treatments and control for survival of fathead minnow, *Pimephales promelas*, after 15 days exposure. After 30 days exposure however, there was 88% survival in both 2,610 mg/L and 4,800 mg/L TDS.

- Colorado squawfish, *Ptychocheilus lucius*, after 15 days exposure, had 32% survival in 2,610 mg/L TDS, and 20% survival in 4,800 mg/L TDS. After 30 days exposure, *P. lucius* had 27% survival in 2,610 mg/L and 15% survival in 4,800 mg/L TDS.

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APPENDIX: NOTE 15 TO ALASKA WATER QUALITY CRITERION FOR TOTAL DISSOLVED SOLIDS

15. If a permit applicant proposes to raise the TDS levels in the receiving water to result in a concentration in the waterbody between 500 mg/l and 1,000 mg/l for all sources or above 110 mg/l for the potassium ion, the department will require a permit applicant to provide information that the department identifies as necessary to determine if the proposed TDS level will cause or can reasonably be expected to cause an adverse effect to aquatic life; based on its analysis, the department will limit the TDS level in the waterbody as necessary to prevent an adverse effect, and will set permit effluent limits accordingly; the burden of proof to demonstrate no adverse effect is on the permit applicant; implementation of the "no adverse effect" criterion is not subject to 18 AAC 70.235.

(c) Water quality will be analyzed according to

*(1) Standard Methods for the Examination of Water and Wastewate*r, 18th edition, 1992, published jointly by the American Public Health and American Water Works Associations, and the Water Environment Federation (publication office: American Public Health Association, 1015 15th Street NW, Washington, D.C. 20005);

(2) *Methods for Chemical Analysis of Water and Waste*s, March 1979, Technical Report No. EPA 600-4-79-020, Environmental Monitoring and Support Laboratory, Office of Research and Development, United States Environmental Protection Agency, Cincinnati, Ohio 45268 (available from the National Technical Information Service, United States Department of Commerce, Springfield, Virginia 22161, Order No. PB 297686);

(3) Guidelines Establishing Test Procedures for the Analysis of Pollutants; Final Rule and Interim Final Rule and Proposed Rule, Federal Register Part VIII, EPA, Friday, October 26, 1984, 40 C.F.R. Part 136, Vol. 49, No. 209;

(4) Guidelines Establishing Test Procedures for the Analysis of Pollutants; Final Rule and Interim Final Rule and Proposed Rule; Corrections, Federal Register Part VI, EPA, Friday, January 4, 1985, 40 C.F.R. Part 136, pages 690 through 697;

(5) *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewate*r, July 1982 Technical Report No. EPA 600 14-82-057, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268;

(6) methods cited in (b) of this section; or

(7) other methods of analysis approved by the department and EPA.

(d) In applying acute aquatic life criteria, a one-hour averaging period typically is used for ammonia and other fast-acting toxic substances; a 24-hour averaging period is used for all other toxic substances, unless otherwise specified by the department. (Eff. 11/1/97, Register 143; am 4/29/99, Register 150; am 5/27/99, Register 150)

Authority: AS 46.03.020 AS 46.03.050 AS 46.03.070

AS 46.03.080

Editor's note: Federally-promulgated water quality standards for the State of Alaska regarding toxic substances, including human health criteria and aquatic life criteria, are found at 40 C.F.R. 131.36.