

TECHNICAL MEMORANDUM

March 2005

UPDATED ACUTE AND CHRONIC ZINC CRITERIA

As part of the recent South Platte River Basin water quality hearing (July 2004), Chadwick Ecological Consultants, Inc. (CEC), on behalf of Climax Molybdenum Company, Inc., developed site-specific zinc standards for West Fork Clear Creek (CEC 2004a, b, c, d). These site-specific standards were approved by the Colorado Water Quality Control Commission and adopted for this stream segment (Clear Creek Segment 5). Development of the site-specific zinc standard was based on the recalculation procedure (U.S. EPA 1994) following deletion of non-resident taxa from the U.S. EPA zinc toxicity database. However, prior to the recalculation, CEC conducted a literature review and updated the existing zinc toxicity database. As a result, it was possible to derive new acute and chronic zinc criteria as well (see Table 7, CEC 2004a). For our update of zinc criteria, CEC reviewed the zinc criteria in the "1995 Updates" (U.S. EPA 1995) and its precursor "1987 Ambient Water Quality Criteria for Zinc (U.S. EPA 1987). Our reviews consisted of an evaluation of data used by the U.S. EPA for criteria derivation and updating the database with suitable data recently published, which resulted in revised criteria for zinc (CEC 2004a).

The revised acute and chronic databases presented by CEC (2004a,b,c) were subsequently revised with new data on the toxicity of zinc to *Oncorhynchus mykiss* and *Oncorhynchus clarki pleuriticus* in December 2004 (CEC 2004d). Since that last revision, a considerable amount of additional acute toxicity data were located. Fish data on the acute toxicity of zinc to *Salmo trutta*, *Thymallus arcticus*, *Gila elegans* and the Colorado native fish species *Xyrauchen texanus* and *Ptychocheilus lucius* were located in the scientific literature (Table 1). Furthermore, new invertebrate data on the acute toxicity of zinc to *Chironomus plumosus*, and *Daphnia magna* were also found. Lastly, we incorporated results from recent acute toxicity tests using Colorado native macroinvertebrates, including *Drunella grandis*, *Isoperla* sp., and *Lepidostoma* sp. (Table 1), that were conducted by CEC on behalf of Climax Molybdenum Company, Inc. (CEC 2005). These new EPT zinc data were previously provided to the WQCD and U.S. EPA. Many of these fish and invertebrate species are Colorado residents. Therefore, we determined it essential to include these new data in criteria derivation for the state of Colorado.

TABLE 1: New acute zinc data added to the revised database since December 2004.

Species	Common Name	Method	Hardness	Time (hr)	Adjusted		Reference
					LC ₅₀	LC ₅₀ *	
<i>Chironomus plumosus</i>	Midge	S, U	80	96	32,600	21,849	Fargašová 2003
<i>Ceriodaphnia dubia</i>	Cladoceran	S, M	190	48	500	160	Magliette <i>et al.</i> 1995
<i>Daphnia magna</i>	Cladoceran	S,M	46.1	48	259	278	Barata <i>et al.</i> 1998
<i>Daphnia magna</i>	Cladoceran	S,M	90.7	48	1,060	638	Barata <i>et al.</i> 1998
<i>Daphnia magna</i>	Cladoceran	S,M	179	48	962	325	Barata <i>et al.</i> 1998
<i>Daphnia magna</i>	Cladoceran	S,M	46.1	48	131	140	Barata <i>et al.</i> 1998
<i>Daphnia magna</i>	Cladoceran	S,M	90.7	48	457	275	Barata <i>et al.</i> 1998
<i>Daphnia magna</i>	Cladoceran	S,M	179	48	601	203	Barata <i>et al.</i> 1998
<i>Daphnia magna</i>	Cladoceran	S,M	490	48	1,220	175	Magliette <i>et al.</i> 1995
<i>Drunella grandis</i>	Mayfly	S, M	50.6	96	>1,560	1,544	CEC 2005
<i>Drunella grandis</i>	Mayfly	S, M	54.2	96	>3,050	2,848	CEC 2005
<i>Drunella grandis</i>	Mayfly	S, M	172	96	>2,190	765	CEC 2005
<i>Drunella grandis</i>	Mayfly	S, M	175	96	>3,050	1,050	CEC 2005
<i>Drunella grandis</i>	Mayfly	S, M	260.7	96	>3,270	802	CEC 2005
<i>Drunella grandis</i>	Mayfly	S, M	277.7	96	>6,290	1,461	CEC 2005
<i>Gila elegans</i>	Bonytail (larvae)	S,U	199	96	5,350	1,650	Buhl and Hamilton 1996
<i>Gila elegans</i>	Bonytail (larvae)	S,U	199	96	8,010	2,471	Buhl and Hamilton 1996
<i>Isoptera</i> sp.	Stonefly	S,U	182.2	96	>27,000	8,979	CEC 2005
<i>Lepidostoma</i> sp.	Caddisfly	S, M	62.1	96	26,200	21,785	CEC 2005
<i>Lepidostoma</i> sp.	Caddisfly	S, M	189.4	96	>38,800	12,485	CEC 2005
<i>Lepidostoma</i> sp.	Caddisfly	S, M	308.8	96	>81,700	17,339	CEC 2005
<i>Ptychocheilus lusius</i>	Colorado pikeminnow (larvae)	S,U	199	96	3,340	1,030	Buhl and Hamilton 1996
<i>Ptychocheilus lusius</i>	Colorado pikeminnow (juvenile)	S,U	199	96	8,620	2,659	Buhl and Hamilton 1996
<i>Ptychocheilus lusius</i>	Colorado pikeminnow (larvae)	S,U	150	96	9,800	3,846	Hamilton and Buhl 1997b
<i>Salmo trutta</i>	Brown Trout	F, M	206.7 (alk = 37.5)	96	2,267	677	Davies and Brinkman, 1999
<i>Salmo trutta</i>	Brown Trout	F, M	54.4 (alk = 37.4)	96	1,033	961	Davies and Brinkman, 1999
<i>Salmo trutta</i>	Brown Trout	F, M	54.0 (alk = 139.6)	96	690	646	Davies and Brinkman, 1999
<i>Salmo trutta</i>	Brown Trout	F, M	207.2 (alk = 141.4)	96	>2,660	793	Davies and Brinkman, 1999
<i>Thymallus arcticus</i>	Artic grayling (0.34g)	S, U	41.3	96	112	132	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (0.2g)	S, U	41.3	96	142	167	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (0.85g)	S, U	41.3	96	166	195	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (0.97g)	S, U	41.3	96	168	198	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (1.85g)	S, U	41.3	96	168	198	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (fry)	S, U	41.3	96	315	371	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (alevin)	S, U	41.3	96	1,580	1,859	Buhl and Hamilton 1990
<i>Thymallus arcticus</i>	Artic grayling (alevin)	S, U	41.3	96	2,920	3,436	Buhl and Hamilton 1990
<i>Xyrauchen texanus</i>	Razorback sucker (larvae)	S,U	199	96	4,100	1,265	Buhl and Hamilton 1996
<i>Xyrauchen texanus</i>	Razorback sucker (juvenile)	S,U	199	96	2,920	901	Buhl and Hamilton 1996

* Adjusted LC₅₀ determined using revised slope (0.8514) from Table 4.

While updating these latest acute and chronic databases, a few data points that were previously thought suitable for criteria derivation were now determined inappropriate or duplication of existing datapoints. Six data points were removed from the acute database and 5 data points were removed from the chronic database (Table 2). All data included in the finalized updated acute database can be found in Appendix A.

TABLE 2: Data deleted from the updated acute and chronic databases.

Common Name	Species	Hardness as CaCO ₃	LC ₅₀ (µg/L)	Reference
Acute				
Cladoceran	<i>Daphnia</i> sp.	60	282	ERA, U.S. EPA 2002
Rainbow trout	<i>Oncorhynchus mykiss</i>	60	534	referenced in ERA, U.S. EPA 2002
Rainbow trout	<i>Oncorhynchus mykiss</i>	60	534	referenced in ERA, U.S. EPA 2002
Brook trout	<i>Salvelinus fontinalis</i>	60	1,458	referenced in ERA, U.S. EPA 2002
Brown trout	<i>Salmo trutta</i>	100	1,000	Marr 1994
Brown trout	<i>Salmo trutta</i>	50	454	Marr 1994
Chronic				
Brown trout	<i>Salmo trutta</i>	39	457	Davies and Brink man 1994a
Rainbow trout	<i>Oncorhynchus mykiss</i>	60	825	referenced in ERA, U.S. EPA 2002
Caddisfly	Caddisfly	60	9,046	ERA, U.S. EPA 2002
Cladoceran	<i>Daphnia</i> spp.	60	59	ERA, U.S. EPA 2002
Brook trout	<i>Salvelinus fontinalis</i>	60	1,049	referenced in ERA, U.S. EPA 2002

The final updated acute database contains 57 genera (increased from 51 presented in our June 2004 document). The resulting species and genus mean acute values are presented in Table 3. New data were incorporated into revised and updated acute hardness slope (0.8514) and final acute-chronic ratio (2.5496) calculations.

TABLE 3: Final acute zinc GMAV and SMAV ranked from least sensitive to most sensitive (all modified by revised slope = 0.8404).

Rank	Species	Common Name	GMAV	SMAV	Code
57	<i>Argia</i> sp.	Damselfly	89,299	89,299	1, 2
56	Trichoptera	Caddisfly	58,100	58,100	1, 2
55	Zygoptera	Damselfly	26,200	26,200	1, 2
54	<i>Chironomus</i> sp.	Midge	19,941	18,200	1, 2
	<i>Chironomus plumosus</i>	Midge		21,849	1, 2
53	<i>Crangonyx pseudogracilis</i>	Amphipod	19,800	19,800	1, 2
52	<i>Xenopus laevis</i>	Frog	19,122	19,122	2
51	<i>Nais</i> sp.	Worm	18,400	18,400	1, 2
50	<i>Fundulus diaphanus</i>	Banded killifish	17,938	17,938	2

TABLE 3: Continued.

Rank	Species	Common Name	GMAV	SMAV	Code
49	<i>Aeolosoma headleyi</i>	Worm	17,358	17,358	1, 2
48	<i>Ammicola</i> sp.	Snail	16,817	16,817	1, 2
47	<i>Lepidostoma</i> sp.	Caddisfly	>16,770	>16,770	1, 2
45	<i>Anguilla rostrata</i>	American eel	13,629	13,629	2
45	<i>Tubifex tubifex</i>	Worm	11,129	11,129	1, 2
44	<i>Asellus bicrenata</i>	Isopod	10,637	5,696	1, 2
	<i>Asellus aquaticus</i>	Isopod		18,200	1, 2
	<i>Asellus communis</i>	Isopod		11,611	1, 2
43	<i>Lepomis gibbosus</i>	Pumpkinseed	10,561	18,781	2
	<i>Lepomis macrochirus</i>	Bluegill		5,939	2
42	<i>Carassius auratus</i>	Goldfish	10,265	10,265	2
41	<i>Lumbriculus variegatus</i>	Worm	9,732	9,732	1, 2
40	<i>Isoperla</i> sp.	Stonefly	>8,979	>8,979	1, 2
39	<i>Cyprinus carpio</i>	Common carp	7,241	7,241	2
38	<i>Dugesia tigrina</i>	Flatworm	7,003	7,003	1, 2
37	<i>Echinogammarus tibaldii</i>	Amphipod	6,812	6,812	1, 2
36	<i>Notemigonus crysoleucus</i>	Golden shiner	6,000	6,000	2
35	<i>Poecilia reticulata</i>	Guppy	5,919	5,919	2
34	<i>Corbicula fluminea</i>	Asiatic clam	4,895	4,895	1, 2
33	<i>Mesocyclops hyalinus</i>	Copepod	4,844	4,844	1, 2
32	<i>Stenocypris malcomsoni</i>	Ostracod	4,461	4,461	1, 2
31	<i>Xiphophorus maculatus</i>	Southern platyfish	4,341	4,341	2
30	<i>Gammarus</i> sp.	Amphipod	4,330	8,100	1, 2
	<i>Gammarus italicus</i>	Amphipod		2,315	1, 2
29	<i>Pimephales promelas</i>	Fathead minnow	3,816	3,816	2
28	<i>Ptychocheilus lusius</i>	Colorado pikeminnow	3,771	2,192	2
	<i>Ptychocheilus oregonensis</i>	Northern pikeminnow		6,485	2
27	<i>Lirceus alabamiae</i>	Isopod	3,250	3,250	1, 2
26	<i>Gila elegans</i>	Bonytail	2,020	2,020	2
25	<i>Lophopodella carteri</i>	Bryozoan	1,693	1,693	1, 2
24	<i>Salvelinus fontinalis</i>	Brook trout	1,693	1,693	1
23	<i>Jordanella floridae</i>	Flagfish	1,672	1,672	2
22	<i>Xyrauchen texanus</i>	Razorback sucker	1,636	1,636	2
21	<i>Plumatella emarginata</i>	Bryozoan	1,594	1,594	1, 2
20	<i>Helisoma campanulatum</i>	Snail	1,579	1,579	1, 2
19	<i>Cypris</i> sp.	Ostracod	1,487	1,487	1, 2
18	<i>Physa gyrina</i>	Snail	1,354	1,685	1, 2
	<i>Physa heterostropha</i>	Snail		1,087	1, 2
17	<i>Pectinatella magnifica</i>	Bryozoan	1,296	1,296	1, 2
16	<i>Drunella grandis</i>	Mayfly	>1267	>1,267	1, 2
15	<i>Limnodrilus hoffmeisteri</i>	Worm	>1,260	>1,260	1, 2
14	<i>Salmo salar</i>	Atlantic salmon	>1,190	2,187	1
	<i>Salmo trutta</i>	Brown trout		>647	1
13	<i>Ranatra elongata</i>	Water scorpion	832	832	1, 2
12	<i>Tilapia mossambica</i>	Mozambique tilapia	787	787	2
11	<i>Oncorhynchus mykiss</i>	Rainbow trout	750	583	1
	<i>Oncorhynchus kisutch</i>	Coho salmon		1,633	1
	<i>Oncorhynchus nerka</i>	Sockeye salmon		1,507	1
	<i>Oncorhynchus tshawytscha</i>	Chinook salmon		448	1
	<i>Oncorhynchus clarki</i>	Cutthroat trout		369	1

TABLE 3: Continued.

Rank	Species	Common Name	GMAV	SMAV	Code
10	<i>Heliodiaptomus viduus</i>	Copepod	637	637	1, 2
9	<i>Catostomus latipinnis</i>	Flannelmouth sucker	601*	601	2
	<i>Catostomus commersoni</i>	White sucker		5,250	1,2
8	<i>Moina irrasa</i>	Cladoceran	319	664	1, 2
	<i>Moina macrocopa</i>	Cladoceran		153	1, 2
7	<i>Daphnia magna</i>	Cladoceran	269	285	1, 2
	<i>Daphnia pulex</i>	Cladoceran		253	1, 2
6	<i>Hyalella azteca</i>	Amphipod	242	242	1, 2
5	<i>Agrosia chrysogaster</i>	Longfin dace	226	226	2
4	<i>Thymallus arcticus</i>	Arctic grayling	199	199	1
3	<i>Cottus bairdi</i>	Mottled sculpin	160	160	1
2	<i>Morone saxatilis</i>	Striped bass	119*	119	2
	<i>Morone americana</i>	White perch		13,442	2
1	<i>Ceriodaphnia dubia</i>	Cladoceran	92	167	1, 2
	<i>Ceriodaphnia reticulata</i>	Cladoceran		51	1, 2

1 - coldwater species

2 - warmwater species

* - only most sensitive species used

The updated criteria are still calculated from the four most sensitive genera (*Thymallus*, *Cottus*, *Morone*, and *Ceriodaphnia*). From these values, a final acute value of 155.6 : g/L was calculated resulting in a revised updated final dissolved zinc acute equation of $0.978 e^{0.8514 [\ln (\text{hardness})]+1.0239}$. Using the new acute-chronic ratio (2.5496), the resulting revised and updated dissolved zinc chronic equation would be $0.986 e^{0.8514 [\ln (\text{hardness})]+0.7811}$. Table 4 presents a summary of these revised and updated acute and chronic zinc criteria at varying hardness levels.

TABLE 4: Summary of existing and revised zinc criteria at varying hardness levels using the updated acute toxicity database, revised pooled-hardness slope, and updated acute-to-chronic ratio.

Equations	Mean Hardness in mg/L CaCO ₃									
	25	50	75	100	150	200	250	300	350	400
Current Standards										
Acute = $0.978 * e^{0.8473 [\ln (\text{hardness})]+0.8840}$	36.20	65.13	91.84	117.19	165.23	210.83	254.71	297.26	338.70	379.32
Chronic = $0.986 * e^{0.8473 [\ln (\text{hardness})]+0.8840}$	36.50	65.66	92.58	118.14	166.57	212.55	256.78	299.68	341.49	382.40
Updated/Revised Standards										
Acute = $0.978 * e^{0.8514 [\ln (\text{hardness})]+1.0239}$	42.19	76.12	107.51	137.35	193.97	247.80	299.65	349.97	399.05	447.10
Chronic = $0.986 * e^{0.8514 [\ln (\text{hardness})]+0.7811}$	33.37	60.20	85.02	108.62	153.40	195.98	236.98	276.77	315.59	353.59

Literature Cited

- Barata, C., D.J. Baird, and S.J. Markich. 1998. Influence of genetic environmental factors on the tolerance of *Daphnia magna* Straus to essential and non-essential metals. *Aquatic Toxicology* 42:115-137.
- Buhl, K.F., and S.J. Hamiton. 1990. Comparative toxicity of inorganic contaminants released by Placer Mining to early life stages of salmonids. *Ecotoxicology and Environmental Safety* 20:325-342.
- Buhl, K.J., and S.J. Hamilton. 1996. Toxicity of inorganic contaminants, individually and in environmental mixtures, to three endangered fishes (Colorado squawfish, ponytail, and razorback sucker). *Archives of Environmental Contamination and Toxicology* 30:84-92.
- Chadwick Ecological Consultants, Inc. 2004a. *Development of Site-specific Zinc Standards for West Fork Clear Creek (Clear Creek Segment 5), Clear Creek County, Colorado*. Report prepared for Climax Molybdenum Company, Inc.
- Chadwick Ecological Consultants, Inc. 2004b. *Development of Site-specific Zinc Standards for West Fork Clear Creek (Clear Creek Segment 5), Clear Creek County, Colorado*, Revised May 2004. Report prepared for Climax Molybdenum Company, Inc.
- Chadwick Ecological Consultants, Inc. 2004c. *Details related to Revision of Proposed West Fork Clear Creek Site-Specific Zinc Standards*. Technical Memorandum dated May 27, 2004, prepared for Climax Molybdenum Company, Inc.
- Chadwick Ecological Consultants, Inc. 2004d. *Draft Revised Zinc Criteria*. Technical Memorandum dated December 2004 prepared for Climax Molybdenum Company, Inc.
- Chadwick Ecological Consultants, Inc. 2005. *Native Aquatic Insect Zinc Toxicity Testing*. Technical Memorandum prepared for Climax Mining Company, CO.
- Davies, P.H., and S. Brinkman. 1994. *Toxicity of Cadmium and Zinc to Wild Brown Trout*. Water Pollution Studies, Federal Aid Project F-33. Colorado Division of Wildlife, Fort Collins, CO.
- Davies, P.H., and S. Brinkman. 1999. *Toxicity of Zinc to Brown Trout under Conditions of Embryonic Exposure (Acclimated), Non-exposure (Unacclimated) and Following 2 and 3 Weeks Deacclimation*. Water Pollution Studies, Federal Aid Project F-243-R-6. Colorado Division of Wildlife, Fort Collins, CO.
- Fargašová, A. 2003. Cd, Cu, Zn, Al and their binary combinations, acute toxicity for *Chironomus plumosus* larvae. *Fresenius Environmental Bulletin* 12(8):830-834.
- Magliette, R.J., F.G. Doherty, D. McKinney, and E.S. Venkataramani. 1995. Need for environmental quality guidelines based on ambient freshwater quality criteria in natural waters - case study "zinc." *Bulletin of Environmental Contamination and Toxicology* 54(4):626-632.

- Marr, C.A. 1994. *Effects of Acclimation and Pulsed Exposure on the Lethal and Sub-lethal Responses of Brown and Rainbow Trout Exposed to a Metals Mixture*. Ph.D. Dissertation. Department of Zoology and Physiology. University of Wyoming, Laramie, WY.
- U.S. EPA. 1987. *1987 Ambient Water Quality Criteria for Zinc*. EPA-440/5-87-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- U.S. Environmental Protection Agency. 1994. *EPA Interim Guidance on Determination and Use of Water-Effect Ratios for Metals*. EPA-823-B-94-001. Office of Water, Washington, DC.
- U.S. EPA. 1995. *1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water*. EPA-820-B-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- U.S. Environmental Protection Agency. 2002. *Ecological Risk Assessment for French Gulch/Wellington-Oro Mine Site, Breckinridge, CO*. U.S. Environmental Protection Agency, Denver, CO.

APPENDIX A

Acute Toxicity Database

Common Name	Species	Method	Chemical	Hardness as CaCO ₃ (mg/L)	Test Duration	LC ₅₀ (µg/L)	Adjusted LC ₅₀ * (µg/L)	SMAV (µg/L)	Reference
Worm	<i>Lumbricius variegatus</i>	S, U	Zinc chloride	30	--	6,300	9,732	9,732	Bailey and Liu 1980**
Tubificid worm	<i>Limnodrilus hoffmeisteri</i>	S, U	Zinc sulfate	100	96-hr	>2,274	>1,260	>1,260	Wurtz and Bridges 1961**
Tubificid worm	<i>Tubifex tubifex</i>	--	--	224	96-hr	130,000	36,261		Qureshi <i>et al.</i> 1980
Tubificid worm	<i>Tubifex tubifex</i>	--	--	34.2	96-hr	2,570	3,551		Brkovic-Popovic and Popovic 1977
Tubificid worm	<i>Tubifex tubifex</i>	--	--	261	96-hr	60,200	14,,743		Brkovic-Popovic and Popovic 1977
Tubificid worm	<i>Tubifex tubifex</i>	--	--	0.1	96-hr	110	21842		Brkovic-Popovic and Popovic 1977
Tubificid worm	<i>Tubifex tubifex</i>	--	--	34.2	96-hr	2,980	4,118	11,129	Brkovic-Popovic and Popovic 1977
Worm	<i>Nais sp.</i>	S, M	--	50	--	18,400	18,400	18,400	Rehwoldt <i>et al.</i> 1973**
Worm	<i>Aeolosoma headleyi</i>	--	--	45	48-hr.	18,100	19,799		Cairns <i>et al.</i> 1978
Worm	<i>Aeolosoma headleyi</i>	--	--	45	48-hr.	17,600	19,252		Cairns <i>et al.</i> 1978
Worm	<i>Aeolosoma headleyi</i>	--	--	45	48-hr.	15,600	17,064		Cairns <i>et al.</i> 1978
Worm	<i>Aeolosoma headleyi</i>	--	--	45	48-hr.	15,000	16,408		Cairns <i>et al.</i> 1978
Worm	<i>Aeolosoma headleyi</i>	--	--	45	48-hr.	13,500	14,767	17,358	Cairns <i>et al.</i> 1978
Flat worm	<i>Dugesia tigrina</i>	--	--	50	96-hr	7,400	7,400		See <i>et al.</i> 1994
Flat worm	<i>Dugesia tigrina</i>	--	--	40	96-hr	5,480	6,627	7,003	See 1976
Snail (embryo)	<i>Amnicola sp. (embryo)</i>	S, M	--	50	--	20,200	20,200		Rehwoldt <i>et al.</i> 1973**
Snail (adult)	<i>Amnicola sp. (adult)</i>	S, M	--	50	--	14,000	14,000	16,817	Rehwoldt <i>et al.</i> 1973**
Snail (adult)	<i>Helisoma campanulatum</i>	S, U	Zinc sulfate	20	--	870	1,898		Wurtz 1962**
				(@12.8°C)					
Snail (adult)	<i>Helisoma campanulatum</i>	S, U	Zinc sulfate	20	--	1,270	2,771		Wurtz 1962**
				(@22.8°C)					
Snail (adult)	<i>Helisoma campanulatum</i>	S, U	Zinc sulfate	100	--	3,030	1,679		Wurtz 1962**
				(@12.8°C)					
Snail (adult)	<i>Helisoma campanulatum</i>	S, U	Zinc sulfate	100	--	1,270	704	1,579	Wurtz 1962**
				(@22.8°C)					
Snail (adult)	<i>Physa gyrina</i>	F, M	Zinc chloride	36	--	1,274	1,685	1,685	Nebeker <i>et al.</i> 1986**
Snail	<i>Physa heterostropha</i>	S, U	Zinc chloride	45	--	1,800	1,969		Cairns and Scheler 1958b; Academy of Natural Sciences 1960**
				(@20°C)					
Snail	<i>Physa heterostropha</i>	S, U	Zinc chloride	45	--	1,000	1,094		Cairns and Scheler 1958b; Academy of Natural Sciences 1960**
				(@30°C)					

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Snail	<i>Physa heterostropha</i>	S, U	Zinc chloride	170 (@20°C)	--	6,200	2,187		Cairns and Scheler 1958b; Academy of Natural Sciences 1960**
Snail	<i>Physa heterostropha</i>	S, U	Zinc chloride	170 (@30°C)	--	7,100	2,505		Cairns and Scheler 1958b; Academy of Natural Sciences 1960**
Snail (adult)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	20	--	1,110	2,422		Wurtz and Bridges 1961; Wurtz 1962**
Snail (adult)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	100	--	3,160	1,751		Wurtz and Bridges 1961; Wurtz 1962**
Snail (young)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	20 (@10.6°C)	--	303	661		Wurtz 1962**
Snail (young)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	20 (@12.8°C)	--	434	947		Wurtz 1962**
Snail (young)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	20 (@32.2°C)	--	350	764		Wurtz 1962**
Snail (young)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	100 (@10.6°C)	--	434	241		Wurtz 1962**
Snail (young)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	100 (@12.8°C)	--	1,390	770		Wurtz 1962**
Snail (young)	<i>Physa heterostropha</i>	S, U	Zinc sulfate	100 (@32.2°C)	--	1,110	615	1,087	Wurtz 1962**
Asiatic clam (10-21 mm)	<i>Corbicula fluminea</i>	S, M	Zinc sulfate	64	--	6,040	4,895	4,895	Cherry <i>et al.</i> 1980; Rodgers <i>et al.</i> 1980**
Copepod	<i>Haplodiptomus viduus</i>	--	--	37.6	48-hr.	500	637	637	Sharma and Selverai 1994
Copepod	<i>Mesocyclops hyalinus</i>	--	--	37.6	96-hr	3,800	4,844	4,844	Sharma and Selverai 1994
Cladoceran	<i>Ceriodaphnia dubia</i>	R, M	Zinc chloride	52	<24-hr.	180	174	167	Carlson <i>et al.</i> 1986**
Cladoceran	<i>Ceriodaphnia dubia</i>	S, M	Zinc bromide	190	48	500	160		Magliette <i>et al.</i> 1995
Cladoceran	<i>Ceriodaphnia reticulata</i>	S, U	--	45	--	76	83		Mount and Norberg 1984**
Cladoceran	<i>Ceriodaphnia reticulata</i>	S, U	Zinc chloride	45	48-hr.	41	45		Carlson and Roush 1985**
Cladoceran	<i>Ceriodaphnia reticulata</i>	S, M	Zinc chloride	45	--	32	35	51	Carlson and Roush 1985**
Cladoceran	<i>Daphnia magna</i>	S, M		46.1	48	259	278		Barata <i>et al.</i> 1998
Cladoceran	<i>Daphnia magna</i>	S, M		90.7	48	1,060	638		Barata <i>et al.</i> 1998
Cladoceran	<i>Daphnia magna</i>	S, M		179	48	962	325		Barata <i>et al.</i> 1998
Cladoceran	<i>Daphnia magna</i>	S, M		46.1	48	131	140		Barata <i>et al.</i> 1998
Cladoceran	<i>Daphnia magna</i>	S, M		90.7	48	457	275		Barata <i>et al.</i> 1998
Cladoceran	<i>Daphnia magna</i>	S, M		179	48	601	203		Barata <i>et al.</i> 1998

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Cladoceran	<i>Daphnia magna</i>	S, M	Zinc bromide	190	48	1,220	392		Magliette et al. 1995
Cladoceran	<i>Daphnia magna</i>	R, M	--	300	96-hr	1,100	239		Berglind and Dave 1984***
Cladoceran	<i>Daphnia magna</i>	S, U	Zinc chloride	45.3	--	100	109 ^f		Biesinger and Christensen 1972**
Cladoceran	<i>Daphnia magna</i>	S, M	Zinc sulfate	45	--	280	306		Cairns et al. 1978**
Cladoceran	<i>Daphnia magna</i>	S, U	--	45	--	68	74 ^f		Mount and Norberg 1984**
Cladoceran	<i>Daphnia magna</i>	S, M	--	54	--	334	313		Chapman et al. Manuscript**
Cladoceran	<i>Daphnia magna</i>	S, M	--	105	--	525	279		Chapman et al. Manuscript**
Cladoceran	<i>Daphnia magna</i>	S, M	--	196	--	655	205		Chapman et al. Manuscript**
Cladoceran	<i>Daphnia magna</i>	F, M	--	130	--	799	354	285	Attar and Maly 1982**
Cladoceran	<i>Daphnia pulex</i>	--	--	45	--	500	547		Cairns et al. 1978**
Cladoceran	<i>Daphnia pulex</i>	--	--	45	--	107	117	253	Mount and Norberg 1984**
Cladoceran	<i>Moina irrasa</i>	--	--	5	48-hr.	77	550		Zou and Bu 1994**
Cladoceran	<i>Moina irrasa</i>	--	--	5	48-hr.	153	1,083		Zou and Bu 1994**
Cladoceran	<i>Moina irrasa</i>	--	--	5	48-hr.	205	1,458		Zou and Bu 1994**
Cladoceran	<i>Moina irrasa</i>	--	--	5	48-hr.	50	355		Zou and Bu 1994**
Cladoceran	<i>Moina irrasa</i>	--	--	5	48-hr.	93	660		Zou and Bu 1994**
Cladoceran	<i>Moina irrasa</i>	--	--	5	48-hr.	59	421	664	Zou and Bu 1994**
Cladoceran	<i>Moina macrocopa</i>	--	--	37.6	48-hr.	120	153	153	Sharma and Selverai 1994
Isopod	<i>Asellus aquaticus</i>	S, U	--	50	96-hr	18,200	18,200	18,200	Martin and Holdich 1986
Isopod (3-7 mm)	<i>Asellus bicrenata</i>	F, M	Zinc sulfate	220	--	20,110	5,696	5,696	Bosnak and Morgan 1981**
Isopod	<i>Asellus communis</i>	S, U	Zinc sulfate	20	96-hr	12,734	27,782		Wurtz and Bridges 1961**
Isopod	<i>Asellus communis</i>	S, U	Zinc sulfate	100	96-hr	8,755	4,852	11,611	Wurtz and Bridges 1961**
Isopod (3-7 mm)	<i>Lirceus alabamae</i>	F, M	Zinc sulfate	152	--	8,375	3,250	3,250	Bosnak and Morgan 1981**
Amphipod	<i>Crangonyx pseudogracilis</i>	R, U	Zinc sulfate	50	--	19,800	19,800	19,800	Martin and Holdich 1986**
Amphipod	<i>Echinogammarus tibaldii</i>	--	--	240	96-hr	25,900	6,812	6,812	Pantani et al. 1997
Amphipod	<i>Gammarus sp.</i>	S, M	--	50	--	8,100	8,100	8,100	Rehwoldt et al. 1973**
Amphipod	<i>Gammarus italicus</i>	--	--	240	96-hr	8,800	2,315	2,315	Pantani et al. 1997
Amphipod	<i>Hyalella azteca</i>	--	--	100	96-hr	436	242	242	Eisenhauer et al. 1999
Ostracod	<i>Cypris sp.</i>	--	--	114	48-hr.	3,000	1,487	1,487	Qureshi et al. 1980
Ostracod	<i>Stenocypris malcomsoni</i>	--	--	37.6	96-hr	3,500	4,461	4,461	Sharma and Selverai 1994
Damselfly	<i>Argia sp.</i>	S, U	Zinc sulfate	20	--	40,930	89,299	89,299	Wurtz and Bridges 1961**
Damselfly	<i>Zygoptera</i>	--	--	50	96-hr	26,200	26,200	26,200	Rehwoldt et al. 1973
Mayfly	<i>Drunella grandis</i>	S, M	zinc sulfate	50.6	96-hr	>1,560	>1,544	>1,267	CEC 2005
Mayfly	<i>Drunella grandis</i>	S, M	zinc sulfate	54.2	96-hr	>3,050	>2,848		CEC 2005
Mayfly	<i>Drunella grandis</i>	S, M	zinc sulfate	172	96-hr	>2,190	>765		CEC 2005

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Mayfly	<i>Drunella grandis</i>	S, M	zinc sulfate	175	96-hr	>3,050	>1,050		CEC 2005
Mayfly	<i>Drunella grandis</i>	S, M	zinc sulfate	260.7	96-hr	>3,270	>802		CEC 2005
Mayfly	<i>Drunella grandis</i>	S, M	zinc sulfate	277.7	96-hr	>6,290	>1,461		CEC 2005
Stonefly	<i>Isoperla sp.</i>	S, U	Zinc sulfate	182.2	96-hr	>27,000	>8979	>8,979	CEC 2005
Water scorpion	<i>Ranatra elongata</i>	--	--	112.4	96-hr	1,658	832	832	Shukla <i>et al.</i> 1983
Caddisfly	<i>Lepidostoma sp.</i>	S, M	Zinc sulfate	62.1	96-hr	26,200	21,785	>16,769	CEC 2005
Caddisfly	<i>Lepidostoma sp.</i>	S, M	Zinc sulfate	189.4	96-hr	>38,800	12,485		CEC 2005
Caddisfly	<i>Lepidostoma sp.</i>	S, M	Zinc sulfate	308.8	96-hr	>81,700	17,339		CEC 2005
Caddisfly	<i>Trichoptera</i>	--	--	50	96-hr	58,100	58,100	58,100	Rehwoldt <i>et al.</i> 1973
Midge	<i>Chironomus plumosus</i>	S, U	Zinc sulfate	80	96hr	32,600	21,849	21,849	Fargasova 2003
Midge	<i>Chironomus sp.</i>	--	--	50	96-hr	18,200	18,200	18,200	Rehwoldt <i>et al.</i> 1973
Bryozoan	<i>Pectinatella magnifica</i>	S, U	--	205 (190-220)	--	4,310	1,296	1,296	Perdue and Wood 1980**
Bryozoan	<i>Lophopodella carteri</i>	S, U	--	205 (190-220)	--	5,630	1,693	1,693	Perdue and Wood 1980**
Bryozoan	<i>Plumatella emarginata</i>	S, U	--	205 (190-220)	--	5,300	1,594	1,594	Perdue and Wood 1980**
American eel	<i>Anguilla rostrata</i>	S, M	--	55	--	14,500	13,370		Rehwoldt <i>et al.</i> 1972**
American eel	<i>Anguilla rostrata</i>	S, M	Zinc nitrate	53	--	14,600	13,893	13,629	Rehwoldt <i>et al.</i> 1973**
Coho salmon (yearling)	<i>Oncorhynchus kisutch</i>	R, M	Zinc chloride	94	--	4,600	2,687 [†]		Lorz and McPherson 1976, 1977**
Coho salmon	<i>Oncorhynchus kisutch</i>	F, M	Zinc chloride	25	--	905	1,633	1,633	Chapman and Stevens 1978**
Sockeye salmon (parr)	<i>Oncorhynchus nerka</i>	F, M	Zinc chloride	22	--	749	1,507	1,507	Chapman 1975, 1978b**
Chinook salmon (juvenile)	<i>Oncorhynchus tshawytscha</i>	F, M	Zinc sulfate	21	--	84	176		Finlayson and Verrue 1982**
Chinook salmon (swim-up alevin)	<i>Oncorhynchus tshawytscha</i>	F, M	Zinc chloride	23	--	97	188		Chapman 1975, 1978b**
Chinook salmon (parr)	<i>Oncorhynchus tshawytscha</i>	F, M	Zinc chloride	23	--	463	897		Chapman 1975, 1978b**
Chinook salmon (smolt)	<i>Oncorhynchus tshawytscha</i>	F, M	Zinc chloride	23	--	701	1,358	448	Chapman 1975, 1978b**
Cutthroat trout	<i>Oncorhynchus clarki</i>	F, M	--	31.1	96-hr	140	210		Brinkman and Hansen 2004
Cutthroat trout	<i>Oncorhynchus clarki</i>	F, M	--	149.4	96-hr	1,645	648	369	Brinkman and Hansen 2004
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	330	--	7,210	1,446		Sinley <i>et al.</i> 1974**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	25	--	430	776		Sinley <i>et al.</i> 1974**
Rainbow trout (30.5 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	30	--	430	664		Goettl <i>et al.</i> 1974**
Rainbow trout (22.6 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	30	--	810	1,251		Goettl <i>et al.</i> 1974**
Rainbow trout (29.7 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	30	--	410	633		Goettl <i>et al.</i> 1974, 1976**

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Rainbow trout (18.3 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	312	--	4,520	951		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (2.0 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	312	--	1,190	250		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (34.6 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	23	--	560	1085		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (4.9 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	22	--	240	483		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (52.1 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	30	--	830	1,282		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (15.4 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	314	--	7,210	1,509		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (72 g)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	102	--	1,000	545		Goettl <i>et al.</i> 1974, 1976**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	R, U	Zinc sulfate	5	--	280	1,989		McLeay 1976**
Rainbow trout (alevin)	<i>Oncorhynchus mykiss</i>	F, M	Zinc chloride	23	--	815	1,579		Chapman 1975, 1978b**
Rainbow trout (swim- up alevin)	<i>Oncorhynchus mykiss</i>	F, M	Zinc chloride	23	--	93	180		Chapman 1975, 1978b**
Rainbow trout (parr)	<i>Oncorhynchus mykiss</i>	F, M	Zinc chloride	23	--	136	263		Chapman 1975, 1978b**
Rainbow trout (adult male)	<i>Oncorhynchus mykiss</i>	F, M	Zinc chloride	83	--	1,755	1,140		Chapman and Stevens 1978**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	46.8	--	370	391		Holcombe and Andrew 1978**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	47	--	517	545		Holcombe and Andrew 1978**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	44.4	--	756	836		Holcombe and Andrew 1978**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	178	--	2,510	851		Holcombe and Andrew 1978**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	179	--	2,960	999		Holcombe and Andrew 1978**
Rainbow trout (juvenile)	<i>Oncorhynchus mykiss</i>	F, M	Zinc sulfate	170	--	1,910	674		Holcombe and Andrew 1978**
Rainbow trout (fingerling)	<i>Oncorhynchus mykiss</i>	S, M	Zinc sulfate	14	--	560	1,655 [†]		Spry and Wood 1984**
Rainbow trout (fry)	<i>Oncorhynchus mykiss</i>	F, M	Zinc chloride	9.2 (@pH=7.0)	--	66	279		Cusimano <i>et al.</i> 1986**
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	350	96-hr	4,520	862		Goettl <i>et al.</i> 1972
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	350	96-hr	1,190	227		Goettl <i>et al.</i> 1972
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	30	96-hr	560	865		Goettl <i>et al.</i> 1972
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	30	96-hr	240	371		Goettl <i>et al.</i> 1972
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	38	96-hr	105	133		Davies 1980
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	38	96-hr	186	235		Davies 1980
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	33.2	96-hr	125	177		Brinkman and Hansen 2004
Rainbow trout	<i>Oncorhynchus mykiss</i>	F, M	--	145.4	96-hr	588	237	583	Brinkman and Hansen 2004
Atlantic salmon (parr)	<i>Salmo salar</i>	F, M	Zinc sulfate	14	--	740	2,187	2,187	Carson and Carson 1972**

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Brown Trout	<i>Salmo trutta</i>	F, M	--	206.7 (alk = 37.5)	96-hr	2,267	677		Davies and Brinkman 1999
Brown Trout	<i>Salmo trutta</i>	F, M	--	54.4 (alk = 37.4)	96-hr	1,033	961		Davies and Brinkman 1999
Brown Trout	<i>Salmo trutta</i>	F, M	--	54.0 (alk = 139.6)	96-hr	690	646		Davies and Brinkman 1999
Brown Trout	<i>Salmo trutta</i>	F, M	--	207.2 (alk = 141.4)	96-hr	>2,660	>793		Davies and Brinkman 1999
Brown Trout (wild)	<i>Salmo trutta</i>	F, M	--	37.6	96-hr	642	818		Davies and Brinkman 1994
<i>Salmo trutta</i>	Brown Trout	F, M	Zinc sulfate	51.9	--	871	844		Davies and Brinkman, 2000
<i>Salmo trutta</i>	Brown Trout	F, M	Zinc sulfate	51.8 (2 wk de- acclimation)	--	392	380		Davies and Brinkman, 2000
Brown Trout	<i>Salmo trutta</i>	F, M	--	42.3	96-hr	476	549		Davies <i>et al.</i> 2000
Brown Trout	<i>Salmo trutta</i>	F, M	--	52.6	96-hr	484	464		Davies <i>et al.</i> 2000
Brown Trout	<i>Salmo trutta</i>	F, M	--	52.6	96-hr	603	578	647	Davies <i>et al.</i> 2000
Brook trout (juvenile)	<i>Salvelinus fontinalis</i>	F, M	Zinc sulfate	46.8	96-hr	1,550	1,640		Holcombe & Andrew 1978**
Brook trout (juvenile)	<i>Salvelinus fontinalis</i>	F, M	Zinc sulfate	47	--	2,120	2,235		Holcombe & Andrew 1978**
Brook trout (juvenile)	<i>Salvelinus fontinalis</i>	F, M	Zinc sulfate	44.4	96-hr	2,420	2,678		Holcombe & Andrew 1978**
Brook trout (juvenile)	<i>Salvelinus fontinalis</i>	F, M	Zinc sulfate	178	96-hr	6,140	2,083		Holcombe & Andrew 1978**
Brook trout (juvenile)	<i>Salvelinus fontinalis</i>	F, M	Zinc sulfate	179	--	6,980	2,357		Holcombe & Andrew 1978**
Brook trout (juvenile)	<i>Salvelinus fontinalis</i>	F, M	Zinc sulfate	170	--	4,980	1,757		Holcombe & Andrew 1978**
Brook trout	<i>Salvelinus fontinalis</i>	F, M	--	52.6	96-hr	738	707		Davies <i>et al.</i> 2000
Brook trout	<i>Salvelinus fontinalis</i>	F, M	--	52.6	96-hr	1,178	1,128	1,693	Davies <i>et al.</i> 2000
Artic grayling (0.34g)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	112	132	199	Buhl and Hamiltom 1990
Artic grayling (0.2g)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	142	167		Buhl and Hamiltom 1990
Artic grayling (0.85g)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	166	195		Buhl and Hamiltom 1990
Artic grayling (0.97g)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	168	198		Buhl and Hamiltom 1990
Artic grayling (1.85g)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	168	198		Buhl and Hamiltom 1990
Artic grayling (fry)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	315	371		Buhl and Hamiltom 1990
Artic grayling (alevin)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	1,580	1,859 [†]		Buhl and Hamiltom 1990
Artic grayling (alevin)	<i>Thymallus arcticus</i>	S, U	Zinc chloride	41.3	96-hr	2,920	3,436 [†]		Buhl and Hamiltom 1990

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Longfin dace (juvenile)	<i>Agosia chrysogaster</i>	R, M	Zinc sulfate	217	--	790	226	226	Lewis 1978**
Goldfish	<i>Carassius auratus</i>	S, U	Zinc sulfate	50	--	7,500	7,500		Cairns <i>et al.</i> 1978**
Goldfish (1-2 g)	<i>Carassius auratus</i>	S, U	Zinc sulfate	20	--	6,440	14,051	10,265	Pickering and Henderson 1966**
Common carp (<20 cm)	<i>Cyprinus carpio</i>	S, M	Zinc nitrate	53	--	7,800	7,422		Rehwoldt <i>et al.</i> 1971**
Common carp	<i>Cyprinus carpio</i>	S, M	--	55	--	7,800	7,192		Rehwoldt <i>et al.</i> 1972**
Common carp (2.1 g)	<i>Cyprinus carpio</i>	R, U	Zinc sulfate	19	--	3,120	7,111	7,241	Khengarot <i>et al.</i> 1983**
Bonytail (larvae)	<i>Gila elegans</i>	S, U	Zinc chloride	199	96-hr	5,350	1,650	2,020	Buhl and Hamilton 1996
Bonytail (larvae)	<i>Gila elegans</i>	S, U	Zinc chloride	199	96-hr	8,010	2,471		Buhl and Hamilton 1996
Golden shinner	<i>Notemigonus crysoleucas</i>	S, U	Zinc sulfate	50	--	6,000	6,000	6,000	Cairns <i>et al.</i> 1969**
Fathead minnow (embryo)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	186	--	1,820	595		Pickering and Vigor 1965**
				(174-198)					
Fathead minnow (embryo)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	186	--	1,850	605		Pickering and Vigor 1965**
				(174-198)					
Fathead minnow (fry)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	186	--	870	284		Pickering and Vigor 1965**
				(174-198)					
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	20	--	2,550	5,563 [†]		Pickering and Henderson 1966**
				(@15°C)					
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	S, U	--	20	--	2,330	5,083 [†]		Pickering and Henderson 1966**
				(@15°C)					
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	20	--	770	1,680 [†]		Pickering and Henderson 1966**
				(@25°C)		(780)			
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	20	--	960	2,94 [†]		Pickering and Henderson 1966**
				(@25°C)					
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	360	--	33,400	6,220 [†]		Pickering and Henderson 1966**
				(@25°C)					
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	63	--	12,500	10,267		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	54	--	13,800	12,925		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	97	--	18,500	10,523		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	103	--	25,000	13,512		Mount 1966**

Common Name	Species	Method	Chemical	Hardness as CaCO ₃ (mg/L)	Test Duration	LC ₅₀ (µg/L)	Adjusted LC ₅₀ * (µg/L)	SMAV (µg/L)	Reference
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	212	--	29,000	8,477		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	208	--	35,500	10,547		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	54	--	13,700	12,831		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	63	--	6,200	5,093		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	100	--	12,500	6,928		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	99	--	12,500	6,988		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	186	--	19,000	6,209		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	195	--	13,600	4,269		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	54	--	4,700	4,402		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	49	--	5,100	5,188		Mount 1966**
Fathead minnow (1-2 g))	<i>Pimephales promelas</i>	F, M	Zinc sulfate	98	--	8,100	4,567		Mount 1966**
Fathead minnow (1-2 g))	<i>Pimephales promelas</i>	F, M	Zinc sulfate	102	--	9,900	5,395		Mount 1966**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	193	--	8,200	2,597		Mount 1966**
Fathead minnow (1-2 g))	<i>Pimephales promelas</i>	F, M	Zinc sulfate	216	--	15,500	4,459		Mount 1966**
Fathead minnow (44.6 mm)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	166	--	7,630	2,747 [†]		Rachlin and Perimutter 1968**
Fathead minnow (2-3 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	203	--	8,400	2,548		Brungs 1969**
Fathead minnow (2-3 g)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	203	--	10,000	3,033		Brungs 1969**
Fathead minnow (2-3 g)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	203	--	12,000	3,640 [†]		Brungs 1969**
Fathead minnow (2-3 g)	<i>Pimephales promelas</i>	S, U	Zinc sulfate	203	--	13,000	3,943 [†]		Brungs 1969**
Fathead minnow (4 wk)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	46	--	600	644		Benoit and Holcombe 1978**
Fathead minnow (1-2 g)	<i>Pimephales promelas</i>	S, M	Zinc sulfate	45	--	2,100	2,297 [†]		Judy and Davies 1979**
Fathead minnow (juvenile)	<i>Pimephales promelas</i>	F, M	Zinc sulfate	220	--	2,610	739		Broderius and Smith 1979**
Fathead minnow (larva)	<i>Pimephales promelas</i>	S, M	Zinc chloride	45	--	396	433 [†]		Carison and Roush 1985**
Fathead minnow (<24 hr)	<i>Pimephales promelas</i>	S, M	Zinc chloride	52	--	551	533 [†]	3,816	Carison <i>et al.</i> 1986**

Common Name	Species	Method	Chemical	Hardness as CaCO ₃ (mg/L)	Test Duration	LC ₅₀ (µg/L)	Adjusted LC ₅₀ * (µg/L)	SMAV (µg/L)	Reference
Colorado pikeminnow (juvenile)	<i>Ptychocheilus lusius</i>	S,U	Zinc chloride	199	96-hr	3,340	1,030		Buhl and Hamilton 1996
Colorado pikeminnow	<i>Ptychocheilus lusius</i>	S,U	Zinc chloride	199	96-hr	8,620	2,659		Buhl and Hamilton 1996
Colorado pikeminnow (juvenile)	<i>Ptychocheilus lusius</i>	S,U	Zinc sulfate	150	96-hr	9,800	3,846	2192	Hamilton and Buhl 1997b
Northern pikeminnow (juvenile)	<i>Ptychocheilus oregonensis</i>	F, M	Zinc chloride	25	--	3,498	6,311		Andros and Garton 1980**
				(20-30)					
Northern pikeminnow (juvenile)	<i>Ptychocheilus oregonensis</i>	F, M	Zinc chloride	25	--	3,693	6,663	6,485	Andros and Garton 1980**
				(20-30)					
White sucker (17.7 g)	<i>Catostomus commersoni</i>	F, M	Zinc chloride	18	--	2,200	5,250	5,250	Duncam and Klaverkamp 1983**
Flannelmouth Sucker	<i>Catostomus latipinnis</i>	--	--	144	96-hr	1,480	601	601	Hamilton and Buhl 1997
Razorback sucker (larvae)	<i>Xyrauchen texanus</i>	S,U	Zinc chloride	199	96-hr	4,100	1,265	1636	Buhl and Hamilton 1996
Razorback sucker (juvenile)	<i>Xyrauchen texanus</i>	S,U	Zinc chloride	199	96-hr	2,920	901		Buhl and Hamilton 1996
Razorback sucker (larvae)	<i>Xyrauchen texanus</i>	S,U	Zinc sulfate	150	96-hr	9,800	3,846		Hamilton and Buhl 1997b
Banded killifish (<20 cm)	<i>Fundulus diaphanus</i>	S, M	Zinc nitrate	53	--	19,100	18,176		Rewoldt <i>et al.</i> 1971**
Banded killifish	<i>Fundulus diaphanus</i>	S, M	--	55	--	19,200	17,704	17,938	Rewoldt <i>et al.</i> 1972**
Flagfish (juvenile)	<i>Jordanella floridae</i>	F, M	Zinc sulfate	44	--	1,500	1,672	1,672	Spehar 1976 a,b**
Guppy (6 mo)	<i>Poecilia reticulata</i>	S, U	Zinc sulfate	20	--	1,270	2,771 [†]		Pickering and Henderson 1966**
Guppy	<i>Poecilia reticulata</i>	S, U	Zinc sulfate	120	--	30,000	14,237 [†]		Cairns <i>et al.</i> 1969**
Guppy (fry)	<i>Poecilia reticulata</i>	S, M	Zinc sulfate	30	--	1,740	2,688		Pierson 1981**
Guppy (adult male)	<i>Poecilia reticulata</i>	S, M	Zinc sulfate	30	--	5,050	7,801		Pierson 1981**
Guppy (adult female)	<i>Poecilia reticulata</i>	S, M	Zinc sulfate	30	--	6,400	9,887		Pierson 1981**
Guppy (adult male)	<i>Poecilia reticulata</i>	S, U	Zinc sulfate	118	--	300,000	144,419 [†]		Sehgal and Saxena 1986**
Guppy (adult female)	<i>Poecilia reticulata</i>	S, U	Zinc sulfate	118	--	278,000	133,828 [†]	5,919	Sehgal and Saxena 1986**
Southern platyfish (20.8)	<i>Xiphophorus maculatus</i>	S, U	Zinc sulfate	166	--	12,000	4,320	4,320	Rachlin and Perimutter 1968**
White perch (<20 cm)	<i>Morone americana</i>	S, M	Zinc nitrate	53	--	14,300	13,608		Rehwoldt <i>et al.</i> 1971**
White perch	<i>Morone americana</i>	S, M	--	55	--	14,400	13,278	13,442	Rehwoldt <i>et al.</i> 1972**
Striped bass	<i>Morone saxatilis</i>	S, U	Zinc chloride	40	63-day	120	145		Palawski <i>et al.</i> 1985**
Striped bass	<i>Morone saxatilis</i>	S, U	Zinc chloride	285	63-day	430	98	119	Palawski <i>et al.</i> 1985**
Mottled Sculpin	<i>Cottus bairdi</i>	F, M	--	48.6	96-hr	156	160	160	Woodling <i>et al.</i> 2002
Pumpkinseed (<20 cm)	<i>Lepomis gibbosus</i>	S, M	Zinc nitrate	53		20,000	19,032		Rehwoldt <i>et al.</i> 1971**
Pumpkinseed	<i>Lepomis gibbosus</i>	S, M		55		20,100	18,533	18,781	Rehwoldt <i>et al.</i> 1972**

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Bluegill (3.5-3.9 g)	<i>Lepomis macrochirus</i>	S, U	Zinc chloride	45 (@18°C)		4,200	4,594		Cairns and Scheler 1957, 1968; Academy of Natural Sciences 1960**
Bluegill (3.5-3.9 g)	<i>Lepomis macrochirus</i>	S, U	Zinc chloride	45 (@30°C)		3,500	3,828		Cairns and Scheler 1957; Academy of Natural Sciences 1960**
Bluegill (3.5-3.9 g)	<i>Lepomis macrochirus</i>	S, U	Zinc chloride	170 (@18°C)		12,900	4,551		Cairns and Scheler 1957; Academy of Natural Sciences 1960**
Bluegill (3.5-3.9 g)	<i>Lepomis macrochirus</i>	S, U	Zinc chloride	170 (@30°C)		12,500	4,410		Cairns and Scheler 1957; Academy of Natural Sciences 1960**
Bluegill (2.5-3.9 g)	<i>Lepomis macrochirus</i>	S, U	Zinc chloride	45		8,020	8,773		Cairns and Scheler 1958a; Academy of Natural Sciences 1960**
Bluegill (0.96 g)	<i>Lepomis macrochirus</i>	F, M	Zinc chloride	45		3,573	3,908		Cairns and Scheler 1959**
Bluegill (2.80 g)	<i>Lepomis macrochirus</i>	F, M	Zinc chloride	45		3,453	3,777		Cairns and Scheler 1959**
Bluegill (54.26 g)	<i>Lepomis macrochirus</i>	F, M	Zinc chloride	45		3,314	3,625		Cairns and Scheler 1959**
Bluegill (1-2 g)	<i>Lepomis macrochirus</i>	S, U	Zinc sulfate	20 (@15°C)		6,440	14,051		Pickering and Henderson 1966**
Bluegill (1-2 g)	<i>Lepomis macrochirus</i>	S, U	Zinc sulfate	20 (@25°C)		5,460	11,912		Pickering and Henderson 1966**
Bluegill (1-2 g)	<i>Lepomis macrochirus</i>	S, U	Zinc sulfate	20 (@25°C)		4,850	10,582		Pickering and Henderson 1966**
Bluegill (1-2 g)	<i>Lepomis macrochirus</i>	S, U	Zinc sulfate	20 (@25°C)		5,820	12,698		Pickering and Henderson 1966**
Bluegill (1-2 g)	<i>Lepomis macrochirus</i>	S, U	Zinc chloride	20 (@25°C)		5,370	11,716		Pickering and Henderson 1966**
Bluegill (1-2 g)	<i>Lepomis macrochirus</i>	S, U	Zinc sulfate	360 (@25°C)		40,900	7,617		Pickering and Henderson 1966**
Bluegill	<i>Lepomis macrochirus</i>	F, M	Zinc sulfate	46		9,900	10,628		Cairns <i>et al.</i> 1971**
Bluegill	<i>Lepomis macrochirus</i>	F, M	Zinc sulfate	46		12,100	12,990		Cairns <i>et al.</i> 1971**
Bluegill	<i>Lepomis macrochirus</i>	F, M	Zinc sulfate	NR		3,200		5,939	Thompson <i>et al.</i> 1980
Mozambique tilapia (18 g)	<i>Tilapia mossambica</i>	S, U	Zinc chloride	115		1,600	787	787	Qureshi and Saksena 1980**

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Frog	<i>Xenopus laevis</i>	S, M	--	100		34,500	19,122	19,122	Dawson <i>et al.</i> 1988***

* acute values adjusted to hardness = 50 mg/L with revised slope of 0.8514

** as cited in U.S. EPA Zinc Document (1987)

*** as cited in U.S. EPA 1995 Updates (1996)

F = flow-through, S = static, R = renewal, M = measured, U = unmeasured

‡ Value not used in
criteria derivation