

Appendix G. Hardness Slopes

As discussed in Section 5.1.1, EPA's earlier freshwater copper criteria recommendations were hardness-dependent values. Although characterized as "hardness-dependent," EPA recognized that these adjusted criteria not only reflected the influence of hardness on copper toxicity; hardness was also a surrogate for other covarying water quality parameters. In order to compare the new BLM-based criteria with updated hardness-dependent criteria an overall or "pooled slope" was needed to normalize the acute toxicity data to a standard hardness for calculating criteria. A pooled hardness slope was derived using all appropriate acute toxicity data, regardless of the quality rating assigned, according to the procedures in the 1985 Guidelines.

To account for the apparent relationship of copper acute toxicity to hardness, an analysis of covariance (Dixon and Brown 1979; Netter and Wasserman 1974) was performed using WINKS statistical software (WINKS ETC) to calculate the pooled slope for hardness using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. The pooled slope is a regression slope from a pooled data set, where every variable is adjusted relative to its mean. The species are adjusted separately, then pooled for a single conventional least squares regression analysis. The slope of the regression line is the best estimate of the all-species relationship between toxicity and hardness.

This analysis of covariance model was fit to the data contained in this appendix for the seven species for which definitive acute values are available over a range of hardness such that the highest hardness is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest. Other species either did not meet these criteria, the organisms were fed, or as with *D. pulex*, *D. pulicaria* and *H. azteca* did not show any hardness-toxicity trend, possibly due to differences in exposure methods such as unusual chemical composition of the dilution water.

A list of the species, acute toxicity and hardness values, and the slopes used to estimate the pooled hardness slope are included in this appendix. The slopes for the seven species ranged from 0.4349 to 0.8963, and the pooled slope for these seven species was 0.9584. An F-test was used to test whether a model with separate species slopes for each species gives significantly better fit to the data than the model with parallel slopes. This test showed that the separate slopes model is not significantly better, and therefore the slopes are not significantly different than the overall pooled slope ($P=0.39$).

Appendix G. Hardness Slopes

Results of Covariance Analysis of Freshwater Acute Toxicity Versus Hardness

Species	n	Slope	R2 Value	95% Confidence Limits		Degrees of Freedom
<i>Ceriodaphnia dubia</i>	27	0.8821	0.6063	0.5893	1.1749	25
<i>Daphnia magna</i>	46	0.7495	0.6174	0.5702	0.9288	44
<i>Oncorhynchus clarki</i>	11	0.6461	0.4184	0.0717	1.2204	9
<i>Oncorhynchus mykiss</i>	56	0.6245	0.6557	0.5010	0.7480	54
<i>Oncorhynchus tshawytscha</i>	12	0.8963	0.6064	0.3875	1.4051	10
<i>Pimephales promelas</i>	159	0.4349	0.4447	0.3583	0.5116	157
<i>Lepomis macrochirus</i>	6	0.7282	0.8499	0.3033	1.1531	4
All of the above	317	0.9584	0.5098	0.8542	1.0625	303

(p = 0.389)

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Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Ceriodaphnia dubia</i>	<4 h	S,M,T	52	19.00	Carlson et al. 1986
<i>Ceriodaphnia dubia</i>	<4 h	S,M,T	52	17.00	Carlson et al. 1986
<i>Ceriodaphnia dubia</i>	<4 h	S,M,T	36	20.00	Carlson et al. 1986
<i>Ceriodaphnia dubia</i>	<4 h	S,M,T	36	18.00	Carlson et al. 1986
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	26.04	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	17.71	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	31.25	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	25.00	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	29.17	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	33.33	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	23.96	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	20.83	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	45	19.79	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	94.1	27.08	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	94.1	21.88	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	94.1	28.13	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	94.1	38.54	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	94.1	35.42	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	179	69.79	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	179	39.58	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	179	81.25	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	179	84.38	Belanger et al. 1989
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	97.6	14.58	Belanger & Cherry 1990
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	97.6	29.17	Belanger & Cherry 1990
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	97.6	32.29	Belanger & Cherry 1990
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	182	58.33	Belanger & Cherry 1990
<i>Ceriodaphnia dubia</i>	<12 h	S,M,D	182	87.50	Belanger & Cherry 1990
<i>Daphnia magna</i>	<24 h	S,M,T,I	100	31.80	Borgmann & Ralph 1983
<i>Daphnia magna</i>	<24 h	S,M,I	100	35.60	Borgmann & Charlton 1984
<i>Daphnia magna</i>	1 d	S,M,T	39	9.10	Nebeker et al. 1986a
<i>Daphnia magna</i>	1 d	S,M,T	39	11.70	Nebeker et al. 1986a
<i>Daphnia magna</i>	<2 h	S,M,T	38	6.60	Nebeker et al. 1986a
<i>Daphnia magna</i>	<2 h	S,M,T	38	9.90	Nebeker et al. 1986a
<i>Daphnia magna</i>	1 d	S,M,T	39	11.70	Nebeker et al. 1986a
<i>Daphnia magna</i>	<4 h	S,M,T	39	6.70	Nebeker et al. 1986a
<i>Daphnia magna</i>	1 d	S,M,T	26	9.10	Nebeker et al. 1986a
<i>Daphnia magna</i>	<2 h	S,M,T	27	5.20	Nebeker et al. 1986a
<i>Daphnia magna</i>	<24 h	S,M,T	170	41.20	Baird et al. 1991
<i>Daphnia magna</i>	<24 h	S,M,T	170	10.50	Baird et al. 1991
<i>Daphnia magna</i>	<24 h	S,M,T	170	20.60	Baird et al. 1991
<i>Daphnia magna</i>	<24 h	S,M,T	170	17.30	Baird et al. 1991
<i>Daphnia magna</i>	<24 h	S,M,T	170	70.70	Baird et al. 1991
<i>Daphnia magna</i>	<24 h	S,M,T	170	31.30	Baird et al. 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	7.10	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	16.40	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	39.90	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	18.70	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	18.90	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	39.70	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	46.00	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	71.90	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	57.20	Meador 1991
<i>Daphnia magna</i>	<24 h	S,M,I	109.9	67.80	Meador 1991
<i>Daphnia magna</i>	<24 h	R,M,T	170	31.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	38.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	35.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	58.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	37.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	51.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	39.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	50.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	52.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	31.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	30.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	46.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	R,M,T	170	63.00	Lazorchak & Waller 1993
<i>Daphnia magna</i>	<24 h	S,M,T	52	26.00	Chapman et al. Manuscript
<i>Daphnia magna</i>	<24 h	S,M,T	105	30.00	Chapman et al. Manuscript

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Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Daphnia magna</i>	<24 h	S,M,T	106	38.00	Chapman et al. Manuscript
<i>Daphnia magna</i>	<24 h	S,M,T	207	69.00	Chapman et al. Manuscript
<i>Daphnia magna</i>	<24 h	S,M,T,D	7.1	4.80	Long's MS Thesis
<i>Daphnia magna</i>	<24 h	S,M,T,D	20.6	7.40	Long's MS Thesis
<i>Daphnia magna</i>	<24 h	S,M,T,D	23	6.50	Long's MS Thesis
<i>Oncorhynchus clarki</i>	larval, 0.34 g	S,M,T	169	80.00	Dwyer et al. 1995
<i>Oncorhynchus clarki</i>	larval, 0.57 g	S,M,T	169	60.00	Dwyer et al. 1995
<i>Oncorhynchus clarki</i>	7.4 cm, 4.2 g	F,M,T,D	205	398.91	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	6.9 cm, 3.2 g	F,M,T,D	69.9	197.87	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	8.8 cm, 9.7 g	F,M,T,D	18	41.35	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	8.1 cm, 4.4 g	F,M,T,D	204	282.93	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	6.8 cm, 2.7 g	F,M,T,D	83	186.21	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	7.0 cm, 3.2 g	F,M,T,D	31.4	85.58	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	8.5 cm, 5.2 g	F,M,T,D	160	116.67	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	7.7 cm, 4.4 g	F,M,T,D	74.3	56.20	Chakoumakos et al. 1979
<i>Oncorhynchus clarki</i>	8.9 cm, 5.7 g	F,M,T,D	26.4	21.22	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	larval, 0.67 g	S,M,T	169	110.00	Dwyer et al. 1995
<i>Oncorhynchus mykiss</i>	larval, 0.48 g	S,M,T	169	50.00	Dwyer et al. 1995
<i>Oncorhynchus mykiss</i>	larval, 0.50 g	S,M,T	169	60.00	Dwyer et al. 1995
<i>Oncorhynchus mykiss</i>	swim-up, 0.25 g	R,M,T,D	44.1	46.70	Cacela et al. 1996
<i>Oncorhynchus mykiss</i>	swim-up, 0.25 g	R,M,T,D	44.6	24.20	Cacela et al. 1996
<i>Oncorhynchus mykiss</i>	swim-up, 0.20-0.24 g	R,M,T,D	38.7	3.54	Welsh et al. 2000
<i>Oncorhynchus mykiss</i>	swim-up, 0.20-0.24 g	R,M,T,D	39.3	8.44	Welsh et al. 2000
<i>Oncorhynchus mykiss</i>	swim-up, 0.20-0.24 g	R,M,T,D	89.5	17.92	Welsh et al. 2000
<i>Oncorhynchus mykiss</i>	swim-up, 0.20-0.24 g	R,M,T,D	89.67	33.33	Welsh et al. 2000
<i>Oncorhynchus mykiss</i>	12-16 cm	F,M	300	890.00	Calamari & Marchetti 1973
<i>Oncorhynchus mykiss</i>	alevin	F,M,T	23	28.00	Chapman 1975, 1978
<i>Oncorhynchus mykiss</i>	swim-up, 0.17 g	F,M,T	23	17.00	Chapman 1975, 1978
<i>Oncorhynchus mykiss</i>	parr, 8.6 cm, 6.96 g	F,M,T	23	18.00	Chapman 1975, 1978
<i>Oncorhynchus mykiss</i>	smolt, 18.8 cm, 68.19 g	F,M,T	23	29.00	Chapman 1975, 1978
<i>Oncorhynchus mykiss</i>	1.2-7.9 g	F,M,T,D	335	106.25	Fogels & Sprague 1977
<i>Oncorhynchus mykiss</i>	juvenile, 3.9 g	F,M,T	125	200.00	Spear 1977, Anderson & Spear 1980b
<i>Oncorhynchus mykiss</i>	juvenile, 29.1 g	F,M,T	125	190.00	Spear 1977, Anderson & Spear 1980b
<i>Oncorhynchus mykiss</i>	adult, 176 g	F,M,T	125	210.00	Spear 1977, Anderson & Spear 1980b
<i>Oncorhynchus mykiss</i>	1.1 g	F,M,T,D	32	23.33	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	2.2 g	F,M,T,D	31	30.10	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.4 g	F,M,T,D	31	31.25	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	2.7 g	F,M,T,D	30	31.25	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	3.2 g	F,M,T,D	101	41.67	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	0.71 g	F,M,T,D	99	34.48	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	0.80 g	F,M,T,D	102	31.98	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.5 g	F,M,T,D	101	48.23	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.6 g	F,M,T,D	99	49.90	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.5 g	F,M,T,D	100	50.10	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	10 g	F,M,T,D	100	84.48	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.0 g	F,M,T,D	98	89.48	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.0 g	F,M,T,D	366	72.92	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.7 g	F,M,T,D	371	85.63	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	6.6 g	F,M,T,D	361	310.42	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1.8 g	F,M,T,D	371	537.50	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	0.90 g	F,M,T,D	360	321.88	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	3.1 g	F,M,T,D	364	115.63	Howarth & Sprague 1978
<i>Oncorhynchus mykiss</i>	1 g	F,M,T,D	194	176.04	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	4.9 cm	F,M,T,D	194	88.85	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	6.0 cm, 2.1 g	F,M,T,D	194	86.77	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	6.1 cm, 2.5 g	F,M,T,D	194	107.29	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	2.6 g	F,M,T,D	194	285.42	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	4.3 g	F,M,T,D	194	133.33	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	9.2 cm, 9.4 g	F,M,T,D	194	230.21	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	9.9 cm, 11.5 g	F,M,T,D	194	171.88	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	11.8 cm, 18.7 g	F,M,T,D	194	205.21	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	13.5 cm, 24.9 g	F,M,T,D	194	535.42	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	13.4 cm, 25.6 g	F,M,T,D	194	253.13	Chakoumakos et al. 1979
<i>Oncorhynchus mykiss</i>	6.7 cm, 2.65 g	F,M,T	9.2	2.80	Cusimano et al. 1986
<i>Oncorhynchus mykiss</i>	134 g	F,M,T	120	80.00	Seim et al. 1984
<i>Oncorhynchus mykiss</i>	parr	F,M,T,D,I	31	90.00	Mudge et al. 1993

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Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Oncorhynchus mykiss</i>	swim-up, 0.29 g	F,M,T,D	36.1	19.60	Cacela et al. 1996

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Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Oncorhynchus mykiss</i>	swim-up, 0.25 g	F,M,T,D	36.2	12.90	Cacela et al. 1996
<i>Oncorhynchus mykiss</i>	swim-up, 0.23 g	F,M,T,D	20.4	5.90	Cacela et al. 1996
<i>Oncorhynchus mykiss</i>	swimup, 0.23 g	F,M,T,D	45.2	37.80	Cacela et al. 1996
<i>Oncorhynchus mykiss</i>	swim-up, 0.26 g	F,M,T,D	45.4	25.10	Cacela et al. 1996
<i>Oncorhynchus mykiss</i>	swim-up, 0.23 g	F,M,T,D	41.9	17.20	Cacela et al. 1996
<i>Oncorhynchus tshawytscha</i>	alevin, 0.05 g	F,M,T	23	26.00	Chapman 1975, 1978
<i>Oncorhynchus tshawytscha</i>	swim-up, 0.23 g	F,M,T	23	19.00	Chapman 1975, 1978
<i>Oncorhynchus tshawytscha</i>	parr, 9.6 cm, 11.58 g	F,M,T	23	38.00	Chapman 1975, 1978
<i>Oncorhynchus tshawytscha</i>	smolt, 14.4 cm, 32.46 g	F,M,T	23	26.00	Chapman 1975, 1978
<i>Oncorhynchus tshawytscha</i>	3 mo, 1.35 g	F,M,T,I	13	10.20	Chapman & McCrady 1977
<i>Oncorhynchus tshawytscha</i>	3 mo, 1.35 g	F,M,T,I	46	24.10	Chapman & McCrady 1977
<i>Oncorhynchus tshawytscha</i>	3 mo, 1.35 g	F,M,T,I	182	82.50	Chapman & McCrady 1977
<i>Oncorhynchus tshawytscha</i>	3 mo, 1.35 g	F,M,T,I	359	128.40	Chapman & McCrady 1977
<i>Oncorhynchus tshawytscha</i>	swim-up, 0.36-0.45 g	F,M,T,D	36.6	7.71	Welsh et al. 2000
<i>Oncorhynchus tshawytscha</i>	swim-up, 0.36-0.45 g	F,M,T,D	34.6	13.02	Welsh et al. 2000
<i>Oncorhynchus tshawytscha</i>	swim-up, 0.36-0.45 g	F,M,T,D	38.3	14.90	Welsh et al. 2000
<i>Oncorhynchus tshawytscha</i>	swim-up, 0.36-0.45 g	F,M,T,D	35.7	19.06	Welsh et al. 2000
<i>Pimephales promelas</i>	adult, 40 mm	S,M,T	103	310.00	Birge et al. 1983
<i>Pimephales promelas</i>	adult, 40 mm	S,M,T	103	120.00	Birge et al. 1983
<i>Pimephales promelas</i>	adult, 40 mm	S,M,T	262	390.00	Birge et al. 1983; Benson & Birge 1985
<i>Pimephales promelas</i>	---	S,M,T	52	55.00	Carlson et al. 1986
<i>Pimephales promelas</i>	---	S,M,T	52	85.00	Carlson et al. 1986
<i>Pimephales promelas</i>	---	S,M,T	36	180.00	Carlson et al. 1986
<i>Pimephales promelas</i>	---	S,M,T	36	95.00	Carlson et al. 1986
<i>Pimephales promelas</i>	<24 h	S,M,T	290	15.00	Schubauer-Berigan et al. 1993
<i>Pimephales promelas</i>	<24 h	S,M,T	290	44.00	Schubauer-Berigan et al. 1993
<i>Pimephales promelas</i>	<24 h	S,M,T	290	200.00	Schubauer-Berigan et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	19	4.82	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	19.5	8.20	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	16.5	31.57	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	17	21.06	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	19	35.97	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	17	59.83	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	17	4.83	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	17.5	70.28	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	18.5	83.59	Welsh et al. 1993
<i>Pimephales promelas</i>	<24 h, 0.68 mg	S,M,T	18.5	182.00	Welsh et al. 1993
<i>Pimephales promelas</i>	larval, 0.32 g	S,M,T	173	290.00	Dwyer et al. 1995
<i>Pimephales promelas</i>	larval, 0.56 g	S,M,T	173	630.00	Dwyer et al. 1995
<i>Pimephales promelas</i>	larval, 0.45 g	S,M,T	173	400.00	Dwyer et al. 1995
<i>Pimephales promelas</i>	larval, 0.39 g	S,M,T	173	390.00	Dwyer et al. 1995
<i>Pimephales promelas</i>	3.2-5.5 cm, 0.42-3.23 g	S,M,T	165	450.00	Richards & Beitinger 1995
<i>Pimephales promelas</i>	2.8-5.1 cm, 0.30-2.38 g	S,M,T	159	297.00	Richards & Beitinger 1995
<i>Pimephales promelas</i>	1.9-4.6 cm, 0.13-1.55 g	S,M,T	168	311.00	Richards & Beitinger 1995
<i>Pimephales promelas</i>	3.0-4.8 cm, 0.23-1.36 g	S,M,T	167	513.00	Richards & Beitinger 1995
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.540586	62.23	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.540586	190.50	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	44.539694	68.58	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	44.539694	168.91	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	44.539694	94.62	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.540586	143.51	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.04014	120.65	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.04014	196.85	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	138.123096	133.35	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	151.134692	184.15	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	138.123096	304.80	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	139.123988	292.10	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	47.041924	133.35	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	37.033004	92.71	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	60.05352	152.40	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	76.067792	177.80	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	103.091876	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	103.091876	190.50	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	107.095444	196.85	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	134.119528	234.95	Erickson et al. 1996a,b

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.04014	146.05	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	46.041032	171.45	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.04014	152.40	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.04014	184.15	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	44.039248	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	45.04014	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	46.041032	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	189.168588	222.25	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	46.041032	146.05	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	75.0669	139.70	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	46.041032	139.70	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	74.066008	152.40	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	133.118636	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	76.067792	196.85	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	134.119528	266.70	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	52.046384	99.06	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	51.045492	111.13	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	50.0446	78.74	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	51.045492	92.71	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	51.045492	85.09	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	53.047276	123.19	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	53.047276	165.10	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	52.046384	190.50	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	47.041924	165.10	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	47.041924	127.00	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	47.041924	92.08	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	47.041924	66.68	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	140.12488	393.70	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	88.078496	317.50	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	59.052628	107.95	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	41.036572	67.95	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	27.024084	45.72	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	43.038356	177.80	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	25.0223	13.97	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	107.095444	304.80	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	87.077604	71.12	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	85.07582	83.82	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	88.078496	104.78	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	87.077604	139.70	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	87.077604	152.40	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	87.077604	260.35	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	87.077604	488.95	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	87.077604	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	251.223892	704.85	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	252.224784	952.50	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	252.224784	1244.60	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	251.223892	1485.90	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	200.1784	781.05	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	140.12488	476.25	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	90.08028	273.05	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	19.016948	22.23	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	34.030328	24.13	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	51.045492	36.83	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	29.025868	27.94	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	30.02676	26.67	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	27.024084	20.32	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	27.024084	26.67	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	90.08028	190.50	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	60.05352	109.86	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	120.10704	203.20	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	180.16056	209.55	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	91.081172	146.05	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	90.08028	165.10	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	93.082956	254.00	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	92.082064	311.15	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	91.081172	165.10	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	144.128448	920.75	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	292.260464	1073.15	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	440.39248	1003.30	Erickson et al. 1996a,b

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Pimephales promelas</i>	<24 h	S,M,T,D	217.193564	933.45	Erickson et al. 1996a,b

Appendix G. Hardness Slopes

Species	Lifestage	Method	Hardness (mg/L as CaCO ₃)	LC50 or EC50 Total (ug/L)	Reference
<i>Pimephales promelas</i>	<24 h	S,M,T,D	218.194456	742.95	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	212.189104	1879.60	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	S,M,T,D	92.082064	266.70	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	adult	F,M,T	198	470.00	Mount 1968
<i>Pimephales promelas</i>	---	F,M,T	31	75.00	Mount & Stephan 1969
<i>Pimephales promelas</i>	5.6 cm, 1.6 g	F,M,T	200	440.00	Geckler et al. 1976
<i>Pimephales promelas</i>	4.7 cm	F,M,T	200	490.00	Geckler et al. 1976
<i>Pimephales promelas</i>	fry, 6 wk, 2.2 cm	F,M,T	202	490.00	Pickering et al. 1977
<i>Pimephales promelas</i>	subadult, 6 mo, 5.5 cm	F,M,T	202	460.00	Pickering et al. 1977
<i>Pimephales promelas</i>	---	F,M,T	48	114.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	45	121.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	46	88.50	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	30	436.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	37	516.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	87	1586.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	73	1129.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	84	550.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	---	F,M,T	66	1001.00	Lind et al. Manuscript (1978)
<i>Pimephales promelas</i>	30 d, 0.15 g	F,M,T,D	43.9	96.00	Spehar & Fiandt 1986
<i>Pimephales promelas</i>	60-90 d, 3.3 cm, 0.7 g	S,M,T	101	252.00	Bennett et al. 1995
<i>Pimephales promelas</i>	<24 h	F,M,T,D	47.041924	31.75	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	243.216756	117.48	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	255.727906	48.26	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	47.041924	73.03	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.04014	59.06	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.04014	78.74	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.540586	22.23	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	49.043708	6.99	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.04014	22.23	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	43.038356	107.32	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.540586	292.10	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.04014	81.28	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.04014	298.45	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.540586	241.30	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	45.04014	133.35	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	44.039248	93.98	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	44.039248	67.95	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	22.52007	4.76	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	24.021408	13.97	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	23.020516	29.85	Erickson et al. 1996a,b
<i>Pimephales promelas</i>	<24 h	F,M,T,D	21.519178	59.69	Erickson et al. 1996a,b
<i>Lepomis macrochirus</i>	3.58 cm, 0.63 g	R,M,D	85	2291.67	Blaylock et al. 1985
<i>Lepomis macrochirus</i>	12 cm, 35 g	F,M,T	45	1100.00	Benoit 1975
<i>Lepomis macrochirus</i>	10.3 cm, 18.6 g	F,M,T	200	8300.00	Geckler et al. 1976
<i>Lepomis macrochirus</i>	10.1 cm, 19.2 g	F,M,T	200	10000.00	Geckler et al. 1976
<i>Lepomis macrochirus</i>	2.8-6.8 cm	F,M,T	25.9	1000.00	Cairns et al. 1981
<i>Lepomis macrochirus</i>	3.58 cm, 0.63 g	F,M,D	85	1354.17	Blaylock et al. 1985

Appendix G. Hardness Slopes

SUMMARY OUTPUT						
			Overall Slope			
Regression Statistics						
Multiple R	0.714033268					
R Square	0.509843507					
Adjusted R Square	0.508287455					
Standard Error	0.744214128					
Observations	317					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	181.4715328	181.4715328	327.651897	1.05959E-50	
Residual	315	174.4642206	0.553854669			
Total	316	355.9357534				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-1.34057E-15	0.04179923	-3.20717E-14	1	-0.082240968	0.082240968
X Variable 1	0.958366107	0.052945018	18.10115734	1.05959E-50	0.854195537	1.062536676