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Derivation of a Colorado State Manganese Table Value Standard For The Protection of Aquatic Life

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ABSTRACT

Manganese is a common constituent of fresh waters, often present at concentrations in the mg/L range. Increases in the ambient concentrations of manganese above naturally occurring levels in receiving streams can result from point source discharges from mining and smelting activities, as well as non-point discharges resulting from natural runoff in mineralized areas. Previously, little information was available regarding the acute and chronic toxicity of manganese to aquatic organisms. National ambient water quality criteria (AWQC) do not exist for manganese and in some instances, states have relied upon limited data in establishing water quality compliance limits. Through the effort presented herein, we have attempted to assemble all of the available freshwater aquatic toxicity data for manganese and, using the USEPA's procedures for deriving AWQC [USEPA 1985], propose revised values for Colorado's existing Table Value Standard (TVS) that reflects our current scientific understanding of manganese toxicity.

Acute toxicity data were available for twelve freshwater species and median lethal concentrations (LC50) ranged from a low of 5,322 µg/L for the rainbow trout to a high of 274,431 µg/L for the toad, *Bufo boreas* (data normalized to a hardness of 50 mg/L as $CaCO_3$ for comparative purposes). Manganese acute toxicity decreases with increasing water hardness; the slope for this relationship is 0.3331. Chronic toxicity data were available for six species of fish and aquatic invertebrates. Hardness normalized (i.e., 50 mg/L as $CaCO_3$) chronic effects concentrations for all of the tested species were remarkably consistent, ranging from 1,859 µg/L for rainbow trout to 4,246 µg/L for *Daphnia magna*. Manganese chronic toxicity decreases also with increasing water hardness; the slope for this relationship is 0.2706. Using the EC10 as the endpoint for evaluating chronic toxicity, the final acute-to-chronic ratio (ACR) for manganese is 3.6196.

National AWQC consist of two values: the criterion maximum concentration (CMC, acute) and the criterion continuous concentration (CCC, chronic). Using USEPA procedures for deriving AWQC [USEPA 1985] the following equations were developed. These equations describe manganese concentrations that should be protective of aquatic life in Colorado's waters:

$$CMC\ TVS_{(at\ hardness)} = e^{0.3331[\ln hardness] + 6.4676}$$

$$CCC\ TVS_{(at\ hardness)} = e^{0.3331[\ln hardness] + 5.8743}$$

Based on the above equations, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the criteria continuous concentrations (CCC) of manganese are 1310, 1650, and 2078 µg/L, respectively, and the criteria maximum concentrations (CMC) are 2370, 2985, and 3761 µg/L, respectively.

Introduction

Manganese is ubiquitously distributed throughout surface soils, aquatic sediments, ground waters, and surface waters of the United States. Concentrations in fresh waters vary widely, ranging from below detection to several hundred milligrams per liter [National Academy of Science 1973]. Manganese often is elevated in surface waters near metal mining operations, as it is a common constituent of point source discharges from mining and smelting activities, as well as from non-point discharges resulting from natural runoff in mineralized areas. In Colorado, manganese concentrations in surface waters also vary widely, from a few µg/L to several mg/L.

Prior to this effort, few acute or chronic toxicity studies have been reported with manganese and no USEPA national ambient water quality criteria (AWQC) have been promulgated. To derive enforceable standards, several states have relied on the recommendation of McKee and Wolf [1963] and adopted a manganese standard of 1,000 µg/L for the protection of aquatic life. This value is based on little toxicity data and does not consider potential modifying factors such as water hardness. Previously, Colorado had a Table Value Standard (TVS) of 1,000 µg/L. This value results from a recommendation from the Colorado Division of Wildlife [Davies and Goettl 1976], but again is based on limited toxicity data. In 1997, the Colorado Water Control Commission accepted a joint proposal from Climax Molybdenum and the Colorado Division of Wildlife that proposed a revised manganese Table Value Standard that considered a greatly increased database of acute and chronic toxicity data for manganese, as well as the relationship between manganese toxicity and water hardness. The chronic TVS is based on the following equation:

$$TVS_{(at\ hardness)} = e^{0.5434[\ln hardness]+4.7850}$$

Since that time additional acute and chronic toxicity tests have been conducted, e.g., Davies and Brinkman [1998]. The current effort is intended to revise the existing Table Value Standard, based on the most current toxicity data, so that it can be used throughout the waters of Colorado for minimizing potential environmental risk to Colorado's aquatic species resulting from manganese exposure. Toxicity test data considered in this evaluation were obtained from the open literature and from studies conducted in both the Colorado Division of Wildlife's toxicology laboratory and ENSR's laboratory. In addition, a search of the USEPA's environmental toxicity database, AQUIRE, was conducted to identify additional data. This report summarizes the results of acute and chronic toxicity tests conducted with a variety of freshwater aquatic species; a detailed discussion of the test procedures and study results is available in the individual study reports.

Acute and chronic toxicity data

Acute data

The acute toxicity of manganese to a variety of aquatic organisms is presented in Table 1. Among the twelve species represented in the database, genus geometric mean acute values ranged from a low of 5,322 μg/L for the rainbow trout to a high of 274,431 μg/L for the toad, *Bufo boreas* (at a hardness of 50 mg/L). As indicated in Table 2 below, possible age sensitivity differences were noted in tests conducted with rainbow trout, brook trout and fathead minnows, with older organisms being less sensitive to the acute toxic effects of manganese. Because of this, only data for younger organisms were retained for subsequent calculation of the proposed TVS to ensure conservatism.

Table 2. Comparison of manganese acute toxicity as a function of organism size.

Species	LC50 (μg/L) age/size	LC50 (μg/L) age/size	Source
Rainbow trout	14,500 62 mm	30,000 121 mm	Davies [1980]
Fathead minnow	8,557 <7 d	197,315 101 d	ENSR [1996]
Brook trout	3,606 87 d	73,300 150 d	ENSR [1994, 1996]

All within species tests were conducted at a similar water hardness.

Table 1. Summary of acute toxicity data for manganese with fish and aquatic invertebrates.

Species	Genus geometric mean LC50 (µg Mn/L)[1]	LC50 (µg Mn/L)	Water hardness (as $CaCO_3$)	Organism Age/Size	Source
Rainbow trout (*Oncorhynchus mykiss*)	5,322	2,008 (1,697-2,377)	44	33d	ENSR [1990][4]
		2,490 (2,070-3,008)	48	24.5 mm, 0.123 g, 50 d	ENSR [1994][4]
		5,320 (3,110-5,970)	90	23.4 mm, 0.094 g, 50 d	ENSR [1994][4]
		11,149 (10,038-12,464)	170	23.5 mm, 0.097 g, 50 d	ENSR [1994][4]
		4,830 (4,180-5,580)	37.5	42 mm	Davies and Brinkman [1994]
		14,500 (8,500-24,800)	36	62 mm	Davies [1980]
		30,000 (19,000-47,300)[2]	36	121 mm	Davies [1980]
		116,000 (90,600-148,500)[2]	304	201 mm	Davies [1980]
		2,910 (2,600-3,230)[3]	100	embryo-larval	Birge et al. [1979]
		3,170 (2,900 - 3,470)	27.6	41 mm, 0.601 g, 70 d	Davies and Brinkman [1998]
		16,200 (1,400 - 18,700)	147.8	41 mm, 0.590 g, 70 d	Davies and Brinkman [1998]
Hyalella azteca	6,631	6,630 (4,893-9,018)	96	2-3 mm	ENSR [1996][4]
		10,169 (8,548-11,717)	94	2-3 mm	ENSR [1996b]

Species	Genus geometric mean LC50 (µg Mn/L)[1]	LC50 (µg Mn/L)	Water hardness (as $CaCO_3$)	Organism Age/Size	Source
Brook trout (*Salvelinus fontinalis*)	7,483	73,300 (48,250-111,340)[2]	28	74 mm, 5.2 g, 150 d	ENSR [1996a]
		3,606 (2,320-4,400)	48	26 mm, 0.168 g, 87 d	ENSR [1994][4]
		5,120 (4,600-5,700)	31.3	37 mm, 0.405 g, 70 d	Davies and Brinkman [1998]
		27,500 (23400-31,600)	148.1	37 mm, 0.418 g, 70 d	Davies and Brinkman [1998]
Fathead minnow (Pimehales promelas)	9,301	3,542 (2,967-4,228)	26	<7 d	ENSR [1992a]
		6,232 (5,680-6,830)	50	<7 d	ENSR [1992a]
		9,346 (8,029-10,879)	100	<7 d	ENSR [1992a]
		15,826 (12,311-20,344)	200	<7 d	ENSR [1992a]
		10,302 (9,182-11,621)	48	<7 d	ENSR [1990][4]
		17,279 (15,232-19,408)	92	<7 d	ENSR [1990][4]
		27,440 (24,742-31,269)	176	<7 d	ENSR [1990][4]
		>45,000	396	<7 d	ENSR [1990][4]
		8,557 (7,188-10,187)	28	<7 d	ENSR [1996][4]
		197,315 (99,951-389,522)[2]	28	0.4 g, 101 d	ENSR [1996][4]

Species	Genus geometric mean LC50 (μg Mn/L)[1]	LC50 (μg Mn/L)	Water hardness (as $CaCO_3$)	Organism Age/Size	Source
Daphnia magna	10,150	9,800	45	12 h	Biesinger and Christensen [1972]
Brown trout (*Salmo trutta)*	11,715	15,973 (7,464-36,484)	48	23.3 mm, 0.103 g, 115 d	ENSR [1994]
		3,770	37.5	138 mm	Davies and Brinkman [1994]
		49,900 (43,600-57,400)	454	116 mm	Davies and Brinkman [1995]
Ceriodaphnia dubia	15,395	8,757 (7,330-10,470)	26	<24 h	ENSR [1992b]
		12,513 (11,480-13,630)	50	<24 h	ENSR [1992b]
		20,495 (17,865-23,513)	100	<24 h	ENSR [1992b]
		25,480 (22,600-28,730)	200	<24 h	ENSR [1992b]
		15,641 (14,073-17,437)	48	<24 h	ENSR [1990][4]
		28,849 (25,108-34,419)	176	<24 h	ENSR [1990][4]
		>45,000	396	<24 h	ENSR [1990][4]
		23,456 (20,734-26,552)	92	<24 h	ENSR [1990][4]
Mussel (*Anodonta imbecillus*)	30,954	36,200	80	6-8 d	Wade, Hudson, and McKinney [1989]

Species	Genus geometric mean LC50 (µg Mn/L)[1]	LC50 (µg Mn/L)	Water hardness (as $CaCO_3$)	Organism Age/Size	Source
Longfin dace (*Agosia chrysogaster*)	78,890	130,000 (100,000-169,000)	224	43 mm	Lewis [1978]
Northern squawfish (*Ptychocheilus oregonensis*)	83,766	130,465 (36,063- —)	347	Juvenile	Beleau and Bartosz [1982]
		189,482 (145,410-330,001)	316	Post-larval	Beleau and Bartosz [1982]
Chironomus tentans	263,811	327,832 (218,452-611,066)	96	11 d	ENSR [1996c]
Bufo boreus	274,431	339,842 (312,300-369,820)	95	tadpole	ENSR [1996d][4]

[1]Values adjusted to a hardness of 50 mg/L (as $CaCO_3$) using a hardness:toxicity slope factor of 0.7432.

[2] Data not included in the reference value calculation due to a concern regarding sensitivity of older test organisms.

[3] Data not included in the reference value calculation due insufficient data documentation and non-standard test procedures.

[4] ENSR unpublished in-house data. Study raw data are available.

Typically, within-species LC50 values were consistent (differing by less than a factor of 10—following elimination of high values thought to reflect age/size related sensitivity), while among species differences suggest greater variation (> than a factor of 100).

A clear relationship between manganese acute toxicity and water hardness was noted (Fig. 1). When all of the available acute toxicity data are considered, the water hardness:toxicity slope was shown to be 0.3331 (r^2=0.56); this slope was used in the derivation of the TVS.

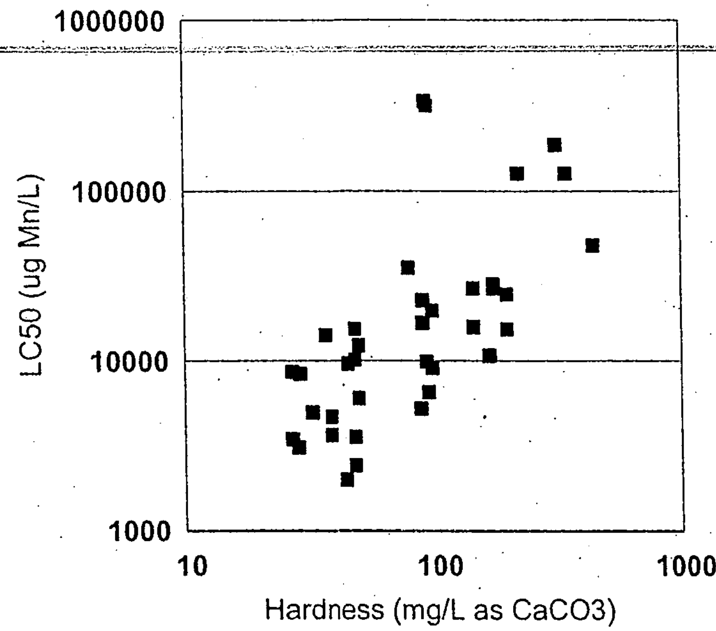

Figure 1. Relationship between water hardness and manganese acute toxicity (all species).

Chronic/Short-term chronic toxicity tests

The available chronic toxicity test data are summarized in Table 3[1]. Data are available for six test species, *Daphnia magna*, *Ceriodaphnia dubia*, brown trout, brook trout, rainbow trout and fathead minnows. Test results suggest that both fish and invertebrate species are similarly sensitive to the chronic toxic effects of manganese. Geometric mean genus chronic effects values (normalized to a hardness of 50 mg/L as $CaCO_3$) for all of the tested species were remarkably consistent, ranging from 1,859 µg/L for rainbow trout to 4,246 µg/L for *Daphnia magna*.

Both short-term chronic (i.e., 7 d) and early-life-stage (ca. 35 d) toxicity tests were conducted with fathead minnows. Results from these studies were similar, with the 7-d test EC20 values (normalized to a hardness of 50 mg/L) being 0.57 to 1.8 times that determined

[1] Data presented for chronic toxicity tests are based on a calculation of the 20% and 10% Effect Concentration (EC20 and EC10). This approach is based on regression analysis using a log-logistic model. The selection of this approach was based on its recent use by USEPA in analyzing data for the revision of the ambient water quality criteria document for ammonia (USEPA 1998).

Table 3. Summary of chronic toxicity data for manganese with fish and aquatic invertebrates.

Species	Genus geometric mean chronic value (µg Mn/L)[1]	Effect Concentration (µg Mn/L)[2]	Water hardness (as $CaCO_3$)	Test type	Source
Rainbow trout	1,859	EC20: 1,398 (967-2,022) EC10: 1,201 (765-1,887) NOEC: 760	29	Early-life-stage	Davies and Brinkman [1998]
		EC20: 4,259 (3,703-4,898) EC10: 3,477 (2,961-4,082) NOEC: 3,390	151	Early-life-stage	Davies and Brinkman [1998]
		LOEC: 1,530[3] NOEC: 770	34	33d	Goettl and Davies [1978]
		LOEC: 1,000[3] NOEC: <1000	5	Early-life-stage	Lewis [1978]
Brook trout	1,962	EC20: 2,104 (1,379-3,209) EC10: 1,699 (1,033-2,795) NOEC: 550	32	Early-life-stage	Davies and Brinkman [1998]
		EC20: 3,695 (2,846-4,796) EC10: 2,826 (2,060-3,875) NOEC: 3,530	156	Early-life-stage	Davies and Brinkman [1998]

Species	Genus geometric mean chronic value (µg Mn/L)[1]	Effect Concentration (µg Mn/L)[2]	Water hardness (as $CaCO_3$)	Test type	Source
Fathead minnow	3,444 (2,289)[4]	EC20: 2,550 (2,074-3,135) EC10: 2,289 (1,806-2,902) NOEC: 1,410 [based on survival]	30	Early-life-stage	ENSR [1996e]
		EC20: 1,338 (641-2,792) EC10: 1,152 (932-2,696) NOEC: 980	26	Short-term chronic	ENSR [1992d]
		EC20: 5,490 (NC) EC10: 5,183 (NC) NOEC: 5,040	50	Short-term chronic	ENSR [1992d]
		EC20: 5,120 (3,758-6,974) EC10: 4,397 (3,022-6,399) NOEC: 4,560	100	Short-term chronic	ENSR [1992d]
		EC20: 13,152 (10,093-17,140) EC10: 11,614 (8570-15,776) NOEC: 7,860	200	Short-term chronic	ENSR [1992d]
		EC20: 3,417 (3,091-3,777) EC10: 3,164 (2,818-3,552) NOEC: 4,700	46	Short-term chronic	ENSR [1989b]

Species	Genus geometric mean chronic value (µg Mn/L)[1]	Effect Concentration (µg Mn/L)[2]	Water hardness (as $CaCO_3$)	Test type	Source
Brown trout	3,719	EC20: 4,705 (NC) EC10: 4,330 (NC) NOEC: 3,940	31	Early-life-stage	Stubblefield et al. [1997]
		EC20: 5,148 (4,179-6,342) EC10: 4,133 (3,249-5,257) NOEC: 2,780	152	Early-life-stage	Stubblefield et al. [1997]
		EC20: 8,209 (7,110-9,478) EC10: 7,365 (6,227-8,710) NOEC: 4,550	450	Early-life-stage	Stubblefield et al. [1997]
Ceriodaphnia dubia	3,820	EC20: 3,314 (2,630-4,175) EC10: 2,922 (2,237-3,819) NOEC: 1,980	26	7-d chronic	ENSR [1992c]
		EC20: 4,885 (4,225-5,649) EC10: 4,370 (3,698-5,165) NOEC: 2,010	50	7-d chronic	ENSR [1992c]
		EC20: 6,052 (4,349-8,422) EC10: 5,281 (3,607-7,732) NOEC: 4,460	100	7-d chronic	ENSR [1992c]

Species	Genus geometric mean chronic value (µg Mn/L)[1]	Effect Concentration (µg Mn/L)[2]	Water hardness (as $CaCO_3$)	Test type	Source
		EC20: 7,809 (6,317-9,654) EC10: 6,910 (5,430-8,792) NOEC: 7,540	200	7-d chronic	ENSR [1992c]
		EC20: 3,317 (2,692-4,089) EC10: 2,731 (2,105-3,544) NOEC: 2,900	46	7-d chronic	ENSR [1989a]
Daphnia magna	4,246	16% repro impair.: 4,100	45	3 wk	Biesinger and Christensen [1972]

[1]Genus geometric mean values are based on EC10 values and have been adjusted to a hardness of 50 mg/L (as $CaCO_3$) using the pooled acute slope (0.3331) to allow interspecies comparison—individual study values are reported as presented, i.e., not hardness adjusted.

[2] EC20 and EC10 values based on biomass endpoint for fish tests except where noted.

[3] Data not included in the reference value calculation due to insufficient data documentation and/or non-standard test procedures.

[4] Genus geometric mean chronic value reported for the fathead minnow includes results for 7-d short-term chronic toxicity tests. This value, however, was not used in the derivation of the fathead minnow acute-chronic ratio because the short-term test is not recognized by the USEPA as an acceptable chronic test for criteria derivation purposes. The value used in deriving the acute-chronic ratio is provided in parenthesis and is based only on the fathead early life stage test which is a USEPA recognized chronic test.

NC - Confidence intervals could not be calculated.

from the early-life-stage study. Because of the similarity between the results for the two test types, all test data were included in evaluating the effect of water hardness on manganese chronic toxicity. However, because the short-term chronic test is not recognized by the US EPA as an acceptable chronic toxicity test for purposes of criterion development only the results from the early life stage test were included in deriving the fathead acute-chronic ratio presented in Table 4.

As was noted in the acute toxicity tests, water hardness and manganese chronic toxicity was inversely correlated (Fig. 2). Manganese chronic toxicity decreased with increasing water hardness at a slope of 0.2706 (r^2=0.70).

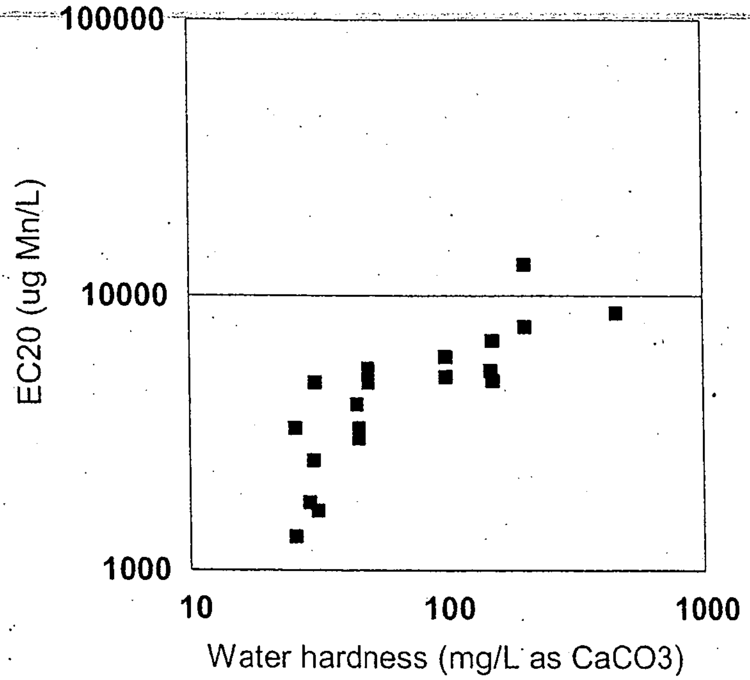

Figure 2. Relationship between water hardness and manganese chronic toxicity (all species).

TVS Derivation

Typically, surface water pollutant concentrations are regulated by state water quality standards, often derived from U.S. Environmental Protection Agency (USEPA) national ambient water quality criteria (AWQC). These criteria apply nationally to all freshwater and marine surface water bodies and are recommended as maximum chemical concentrations below which adverse effects to aquatic life and their uses are not expected to occur. However, a national criterion has not yet been promulgated for manganese. Several states have relied on the recommendation of McKee and Wolf [1963], thereby adopting a manganese standard of 1,000 µg/L. Colorado has adopted the same value, i.e., 1,000 µg/L, based on a recommendation from the Colorado Division of Wildlife (CDOW) [Davies and Goettl 1976]. Both the McKee and Wolf

Table 4. Summary of acute-chronic ratio data used for manganese final chronic value calculation.

Species	Water hardness (as $CaCO_3$)	LC50 (µg Mn/L)	EC10 (µg Mn/L)	Acute/Chronic ratio (ACR)	Genus geometric mean ACR
Fathead minnow	30	8,557	2,289	3.7383	3.7383
Ceriodaphnia dubia	26	8,757	2,922	2.9969	
	50	12,513	4,370	2.8634	
	100	20,495	5,281	3.8809	
	200	25,480	6,910	3.6874	
	48	15,641	2,731	5.7272	3.7103
Daphnia magna	45	9,800	4,100	2.3902	2.3902
Brown trout	48/31	15,973	4,330	3.6889	3.6889
Brook trout	31	5,120	1,699	3.0135	
	150	27,500	2,826	9.7311	5.4156
Rainbow trout	28	3,170	1,201	2.6395	
	150	16,200	3,477	4.6592	3.5064
Geometric mean ACR					**3.6196**

and the CDOW recommendations are based on limited toxicity data and do not consider toxicity modifying factors such as water hardness.

Calculation of proposed TVS

Acute equation: Calculation of a national numeric AWQC for a given chemical requires empirical data from both acute and chronic toxicity tests. The minimum database requirements stipulate that acceptable acute toxicity data must be available for one species of freshwater animal in at least eight different families as described below:

- the family *Salmonidae* in the class *Osteichthyes*;
- a second family of fish in the class *Osteichthyes* (preferably a warm water species);
- a third family in the phylum *Chordata* (may be a fish, amphibian, etc.);
- a planktonic crustacean (e.g., cladoceran, copepod);
- a benthic crustacean (e.g. ostracod, isopod, amphipod, crayfish);
- an insect (e.g., mayfly, caddisfly, midge);
- a family in a phylum other than *Arthropoda* or *Chordata* (e.g., *Rotifera*, *Mollusca*);
- a family in any order of insect or any phylum not already represented.

The current database for manganese satisfies the minimum database requirements for acute data. A Final Acute Value (FAV) is calculated from the acute testing database as the concentration of the material corresponding to a cumulative probability of effect of 0.05 [USEPA 1988]. Table 1 presents all of the acute toxicity data and associated species mean acute values (SMAV) used in deriving the FAV for manganese Using these cummulative probability calculations (USEPA 1985), the FAV for manganese, at a hardness of 50 mg/L, was determined to be 4,740 µg/L (Appendix A). To calculate the proposed TVS, and in accordance with the AWQC derivation procedures, the FAV is divided by two and this value (i.e., 2,370) is used in deriving the final acute equation (discussed in a later section).

Chronic equation: In addition to the acute toxicity data requirements previously discussed, freshwater chronic toxicity data are required so that chronic toxicity can be assessed for at least three different families as described below:

- at least one family is represented by a fish species;
- at least one family is represented by an invertebrate species;

- at least one family is represented by an acutely sensitive freshwater species.

The current chronic database for manganese satisfies the minimum database requirements.

A variety of procedures exist for calculating chronic AWQC, and these are discussed in the AWQC derivation procedures [USEPA 1985]. The final chronic value (FCV) may be derived similarly to the FAV, if sufficient chronic test data are available; however, insufficient data are available for manganese. Alternatively, an acute-chronic ratio (ACR) is calculated to generalize the relationship between measured acute and chronic toxicity values. Thus, for those species for which chronic toxicity tests have been conducted, the mean ratio of chemical concentrations associated with acute and chronic effects (final ACR) is determined. The FCV is calculated by dividing the FAV by the final ACR. Implicit in generalizing the FCV from the final ACR is the assumption that the relationship between acutely toxic and chronically toxic concentrations of a given chemical is similar for the various species tested.

Table 4 presents the results of acute and chronic toxicity tests used in calculating the final ACR. All studies were conducted in the same laboratories and in waters of similar hardness. Geometric mean genus ACRs varied from 2.3902 to 5.4156; the geometric mean ACR was 3.6196. The final chronic value (FCV) is the quotient of the FAV and the final ACR; using the geometric mean ACR of 3.6196, the FCV for manganese was determined to be 1,310 µg/L.

Evaluation of the water hardness:toxicity relationship for the available chronic data confirms the relationship previously observed with the acute toxicity data; the slope for this relationship was 0.2706 (r^2=0.70; Appendix A). However, this value was not employed for subsequent TVS calculations; rather, because the acute and chronic slopes did not differ substantially (0.3331 vs. 0.2931), the acute slope was used in subsequent derivations. This is the approach recommended by the USEPA particularly when an ACR approach is employed (USEPA 1985).

Toxicity data also are required for a freshwater plant species (either an alga or vascular plant). Plant toxicity values are not available for manganese; however, manganese has been identified as an essential nutrient for plant growth and is recommended for incorporation in algal growth media at concentrations approximating the previously discussed FCV [ASTM 1997]. Therefore, it is anticipated that the proposed TVS would be protective of exposed aquatic plants; however, additional data would be necessary to verify this assumption.

Materials for which maximum permissible tissue concentrations are available (e.g., mercury), require additional testing to determine the bioconcentration potential of the material and to calculate a Final Residue Value (FRV) for concentrations in tissue. No such value exists for Mn, therefore, bioconcentration data are not required for AWQC derivation. Nonetheless, Rouleau et al. [1995] found that brown trout rapidly accumulated manganese to whole body steady-state concentrations by a factor of approximately 19. Manganese was found to sequester in specific tissues such that liver and viscera (minus liver and kidney) contained the highest manganese concentrations, while gills, kidneys, epidermal muscle, skin, fins, and bones contained lesser concentrations. Tissue concentrations do not appear to accumulate to levels that would represent a substantial risk to predatory organisms.

TVS values

A national AWQC consists of two concentrations: the criterion maximum concentration (CMC, calculated as one-half the final acute value) and the criterion continuous concentration (CCC, calculated as the lowest of the final chronic value, final plant value, final residue value, or final chronic equation, if applicable). These values may be thought of as the acute and chronic criteria, respectively. The criterion is defined by USEPA guidelines (USEPA 1985) as follows: "except where a locally important species is very sensitive, aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of the material of interest does not exceed the Criteria Continuous Concentration (CCC) more than once every 3 years, on the average, and if the 1-hour average concentration does not exceed the Criteria Maximum Concentration (CMC) more than once every 3 years, on the average."

Based upon USEPA procedures for deriving AWQC [USEPA 1985] and using the results of the toxicity tests described, the following equations describing TVS values were developed (see Appenix A for calculations:

$$CMC\ TVS_{(at\ hardness)} = e^{0.3331[\ln hardness]+6.4676}$$

$$CCC\ TVS_{(at\ hardness)} = e^{0.3331[\ln hardness]+5.8743}$$

Based on the preceding equations, the following table provides example values for the proposed TVS at four water hardness levels .

Table 5. Proposed acute and chronic manganese Table Value Standards over a range of water hardness.

Water hardness	CMC TVS (μg/L)	CCC TVS (μg/L)
50	2,370	1,310
100	2,986	1,650
200	3,760	2,078
400	4,738	2,618

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Appendix A
TVS Calculation Spreadsheets