APPENDIX 8.IV

DERIVATION OF CHRONIC EFFECTS BENCHMARKS (AQUATIC HEALTH)

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8.IV.1 INTRODUCTION

As part of the aquatic health assessment outlined in the Gahcho Kué Project Environmental Impact Statement (EIS), predicted water quality concentrations of various substances in the Kennady Lake watershed (Section 8.9) and in downstream lakes (Section 9.9) were screened in the direct waterborne exposure assessment to identify substances of potential concern (SOPCs). The SOPCs were substances for which the modelled concentrations were higher than those observed under baseline conditions and that were also higher than relevant and applicable water quality guidelines for the protection of aquatic life.

Chronic effects benchmarks (CEBs) were developed for each of the SOPCs based on a review of current toxicological literature, with the exception of selenium. Consistent with the current state of the science of selenium toxicology, and recognizing that selenium elicits effects on reproduction due to maternal transfer (Chapman et al. 2010), the potential for effects to aquatic health due to predicted selenium concentrations were assessed through predicted tissue concentrations in the indirect exposure – changes to fish tissue quality assessment (EIS Section 8.9.3.1.2). For total dissolved solids (TDS), which is a mixture of substances[1], the CEB took the form of a range of concentrations, which were derived based on a review of the applicable literature (summarized in EIS Section 8.9.3.1.1).

This appendix describes the derivation of CEBs for the remaining SOPCs. The benchmarks were used to evaluate how projected changes in water quality could affect aquatic health, as discussed in EIS Sections 8.9 and 9.9. Where sufficient data were available (i.e., toxicity test results for at least five different species), species sensitivity distributions (SSDs) (Posthuma et al. 2002) were used to derive the CEB. The term “CEB” is used herein to define a benchmark water concentration of a substance beyond which detrimental effects to aquatic health may occur.

For parameters where fewer data were available, the lowest recorded chronic toxicity test result was used to define the CEB. A more detailed description of the methodology used to identify the SOPCs and their associated CEBs is provided in Section 8.IV.2. The results of the identification process are outlined in Section 8.IV.3. A summary of the selected CEBs that were used in the aquatic health assessment of the EIS is provided in Section 8.IV.4.

[1] Total dissolved solids concentration (TDS) is a measurement of inorganic salts (e.g., sodium, potassium, calcium, magnesium, chloride, sulphate, and bicarbonate), organic matter, and other dissolved materials in water (Weber-Scannell and Duffy 2007).

8.IV.2 METHODS

8.IV.2.1 SELECTION OF SUBSTANCES OF POTENTIAL CONCERN

The screening procedure used to identify an SOPC was a three-step process. The first step (Step 1) in the process involved assessing which of the modelled parameters had the potential to detrimentally affect aquatic health and which parameters could be excluded from further consideration for one of the following reasons:

- the parameter in question has been shown to have limited potential to affect aquatic health (i.e., innocuous substances);
- potential effects related to the parameter in question are assessed elsewhere in the EIS; and/or
- the parameter in question is a component of another parameter, which is a more suitable focus point for the analysis.

Parameters excluded during the first step of the screening process consisted of:

- sodium, based on work by Mount et al. (1997), which indicates that this substance has low toxicity to aquatic life;
- phosphorus and nitrogen compounds as nutrients, because potential effects related to eutrophication are assessed in Section 8.10.2.1 (however note that nitrate and ammonia were also screened for toxicity effects using water quality guidelines for the protection of aquatic life);
- calcium, chloride, magnesium, sulphate, and potassium, because they are individual ions for which Canadian protection of aquatic life guidelines have not yet been established and they are components of total dissolved solids (TDS), another modelled parameter included in the assessment; and
- the dissolved form of metals, metalloids, and non-metals[2], because they are a component of the corresponding total metal concentrations and total metal measurements are a more conservative basis for assessment than dissolved metals measurements.

[2] Henceforth, metals, metalloids (e.g., arsenic), and non-metals (e.g., selenium) will be referred to as metals.

The remaining substances, which included total metals, total suspended solids (TSS), and TDS, were subjected to a screening process, which involved comparing predicted maximum concentrations with:

- baseline water quality concentrations (Step 2); and,
- Canadian water quality guidelines for the protection of aquatic life (CCME 1999) (Step 3).

Step 2 recognized that existing concentrations may also exceed water quality guidelines. If the predicted concentration was less than or within 10 percent (%) of the long-term average concentration under baseline conditions, then the parameter was excluded from the assessment, because no incremental impact on aquatic health would be expected. A difference of less than or equal to 10% was not considered to be a change that would represent a potential effect to water quality, because:

- analytical uncertainty can be as high as, or higher than, 10%, depending on the individual parameter in question;
- a difference of less than 10% is unlikely to be statistically significant; for example, with a sample size of less than 200, the 95% confidence interval of the mean of a normally distributed variable with a typical coefficient of variation of 0.6 will be greater than 10%; and,
- effects to aquatic organisms are unlikely to be detectable for a change in a substance concentration of less than 10%.

Step 3 involved a comparison to water quality guidelines to determine whether parameters with guidelines have the potential to affect aquatic health. For SOPCs with guidelines that were dependent on pH (i.e., aluminum) or hardness (i.e., cadmium, copper, lead, nickel), the predicted pH or hardness associated with those SOPC concentrations were used in the screening. For chromium, which has a guideline that is dependent on speciation, the most conservative guideline was used (i.e., hexavalent chromium) although it is assumed that most of the chromium will be present as trivalent chromium (see Section 8.8.4.1.1).

Water quality guidelines represent levels that, if met in any surface water, will provide a high level of protection to aquatic life. In this assessment, the *Canadian Water Quality Guidelines for the Protection of Aquatic Life* were used; these conservative guidelines are intended to ”protect all forms of aquatic life and all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term” (CCME 1999). That is, exceedance of a water quality guideline indicates the possibility of adverse effects, but not necessarily a likelihood. At this stage in the screening process, parameters without guidelines were identified as SOPCs, with the exception of those specifically excluded above.

Based on the screening process described above, the SOPCs in the direct waterborne exposure assessment were:

- total dissolved solids
- antimony
- barium
- beryllium
- chromium
- cobalt
- copper
- iron
- manganese
- selenium
- strontium
- uranium
- vanadium

8.IV.2.1 GENERAL APPROACH TO DERIVATION OF CHRONIC EFFECTS BENCHMARKS

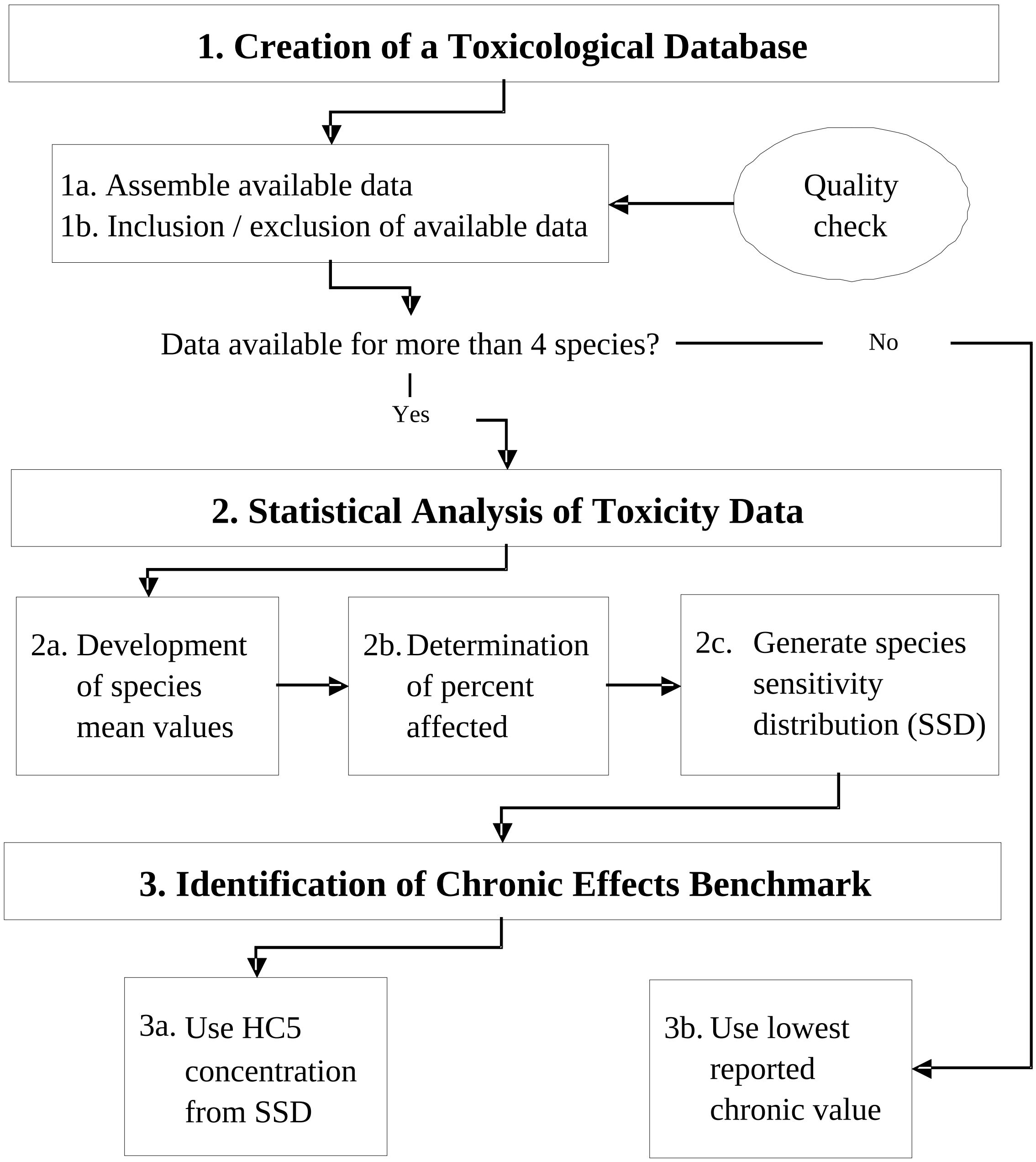
For each SOPC, predicted concentrations were compared to chronic effects benchmarks (CEBs). The CEBs represent substance concentrations above which changes to aquatic health could occur on the scale of individual organisms. The benchmarks are less conservative (i.e., more realistic) than water quality guidelines, but retain a level of conservatism for the evaluation of population-level effects, which would require concentrations to be higher than the CEBs described herein. Consequently, the CEBs are considered to be conservative thresholds by which potential effects to aquatic health can be assessed.

The SSD approach was selected as a preferred method to derive a CEB in acknowledgement that there are biological differences amongst species and that the variation amongst species sensitivities can be described by a statistical distribution to yield a species sensitivity distribution. The distribution can then be used to define an environmental quality criterion, expressed as a concentration that is expected to be safe for the majority of species (Posthuma et al. 2002). The most commonly used criterion is referred to as the HC5 value, which denotes a hazardous concentration to no more than 5 percent (%) of species. A comparison of chronic, single species and experimental ecosystem data for metals, pesticides, surfactants and other organic and inorganic compounds has shown that the HC5 is a conservative threshold for effects to aquatic ecosystems (Versteeg et al. 1999).

An SSD-type approach has been used to derive most of the current US EPA water quality criteria for the protection of aquatic life. It has also been used by several European nations for deriving environmental quality criteria and has been recommended as a standard ecological risk assessment technique by Suter and Barnthouse (1993), the Aquatic Risk Assessment and Mitigation Dialog Group (Baker et al. 1994) and the Water Environmental Research Foundation (Parkhurst et al. 1994). The Canadian Council of Ministers of the Environment (CCME) has used an SSD approach to develop the Canadian water quality guidelines for ammonia and boron for the protection of aquatic life (CCME 2009; CCME 2010) and recommends use of this approach for the development of other Canadian water quality guidelines for the protection of aquatic life (CCME 2007a).

The application of the SSD approach to the current assessment allowed for more recent studies to be included in the toxicity database and for the exclusion of non-resident species, which improved the relevance of the CEB to the Project area. The SSD approach for this assessment followed a three-step process, which is outlined in Figure 8.IV.2-1. The process involved creating a toxicological database for each SOPC, analyzing the available data, and deriving an HC5 value or, where insufficient data were available, conservatively using the lowest reported chronic toxicity test results. Each step in this process is discussed in more detail below.

Figure 8.IV.2-1 Outline of the Process Used to Identify Chronic Effects Benchmarks



8.IV.2.1.1 Step 1 - Creating a Toxicological Database

8.IV.2.1.1.1 Step 1a - Assemble Available Toxicity Data

Available chronic toxicological data for each SOPC were summarized, with a focus on data for algae, invertebrates and fish (as per the recommendations of the CCME [CCME 2007a]). The development of each toxicity database began with an examination of primary chronic toxicity data from fact sheets used to derive relevant *Canadian Water Quality Guidelines* (CCME 1999a). The toxicity database was then expanded by querying the AQUIRE and ECOTOX databases, and by searching for other available peer-reviewed scientific literature from journal databases (e.g., Cambridge Scientific Abstracts).

The resulting database contained data with various test endpoints, such as mortality, reduced survival, growth, or reproduction, derived from chronic studies. All life-stages were included in the toxicity database, which consists of primary and secondary data that generally meet the requirements of United States Environmental Protection Agency (US EPA) and CCME guideline development protocols (Stephan et al. 1985; CCME 2007a).

8.IV.2.1.1.2 Step 1b - Inclusion or Exclusion of Selected Data

Once the available data were assembled, test species were screened for inclusion or exclusion based on rules put forth by the CCME on developing site-specific water quality objectives (CCME 2003). The applicable rules were as follows:

- toxicity data on species that are known to occur or may occur at the site cannot be excluded;
- toxicity data on species that are known not to occur or are not likely to occur at the site can be excluded;
- if a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family are maintained in the database;
- if a member of a family of amphibians may occur at the site, then toxicity data from any amphibian species within that family are maintained in the database;
- if a member of a class of freshwater invertebrates may occur at the site, then toxicity data from that invertebrate class are retained in the toxicity database; and,
- if a member of a phylum of freshwater algae may occur at the site, then toxicity data from that phylum are retained in the database.

Other criteria used to screen data included the following:

- Non-traditional endpoints, such as pathological changes or swimming speed, were excluded, because the ecological relevance of these endpoints is uncertain.
- Tests greater than 96 hours in duration were considered to be chronic for most species, with the exception of the nematode *Caenorhabditis elegans*. For this organism, tests 96 hours in duration were considered to be chronic because of their relatively short life span (Carleton-Dodds 2010, pers. comm.).
- Tests using field-collected organisms were excluded, as the life history of these organisms and their rate of exposure to the substance in question is not generally clearly defined.
- Experiments in which test organisms were injected with the substance in question were excluded, as the type of exposure is not reflective of what would occur in the receiving environment (i.e., the focus was on concentrations in water, not doses injected).
- Tests were also excluded if the original publication or report could not be located, since this prevented a review of the test methodology and verification of the test results.

If a study yielded multiple results for a single endpoint, then the results were reduced to a single measurement to avoid biasing the database toward the results of a single study. For example, if inhibition concentrations (ICs) to 10%, 25%, and 50% of the test population were reported for the growth of fathead minnow exposed to vanadium, then only one of the three values (i.e., the IC10, IC25 or IC50 value) was included in the database. The order of priority by which the endpoints were selected was as follows:

- IC10 or effects concentration (EC)[3] to 10% of the test population (i.e., EC10);
- IC11-25 or EC11-25;
- maximum allowable toxicant concentration (MATC), which was estimated using the geometric mean of the no observed effects concentration (NOEC) and the lowest observed effects concentration (LOEC) reported for a given test;
- NOEC;
- LOEC;
- IC26-49 or EC26-49; and
- IC50/EC50.

[3] "Effects concentrations" or EC*p*, include both lethal and sublethal effects.

Regression-based endpoints, such as IC or EC values, were given preference over hypothesis-based endpoints, such as LOEC and NOEC values, because regression-based endpoints are independent of the dilution series used to formulate the toxicity test. They are also the endpoints favoured by the US EPA (2007) and CCME (2007a). The IC10/EC10 results were given first priority because these represent a conservative threshold for no negative effect, and are derived by regression analysis.

Generally, effects on more than 20% of exposed individuals is considered to be an acceptable threshold level for negative effects (CCME 2007a), and current risk assessment guidance recommended the use of IC20/EC20 as permissible level of effects (Suter et al. 1995). However, IC25/EC25s are commonly reported in the literature. A 20-25% difference in response to a test is widely considered to be within the range of natural variability often observed in the field among normal, unexposued populations. Therefore, in the absence of an IC10/EC10 result, IC11-25 or EC11-25 values were used.

As previously noted, MATCs were calculated by taking the geometric mean of the NOEC and LOEC reported for a given test. The procedure can yield results that are comparable to IC25 results, as discussed for example in US EPA (2007). However, the ability to do so is influenced by the dilution series used to complete the toxicity test and the associated statistical power to differentiate between control and exposure samples.

Unbounded NOECs--that is, NOECs obtained from a test for which a LOEC could not be calculated--were used with caution. Given the limitations of NOEC and LOEC data as described in the previous paragraph, an unbounded NOEC does not provide sufficient information to assess whether the value is at or near the no-effects threshold, and hence may be overly conservative. Any IC1-9 or EC1-9 results were excluded, as these estimates are generally overly conservative, and IC10-25/EC10-25 values provide more reliable estimates of no-effect thresholds.

This order of priority for endpoints allows the guidance provided by CCME (2007a) for the derivation of long-term exposure guidelines. Using this approach, the resulting benchmarks are conservative and represent no-effect thresholds beyond which effects may occur.

The resulting toxicity databases are summarized in Attachment 8.IV.1, Tables 8.IV.1-1 to 8.IV.1-8 for all parameters except cobalt, copper, and uranium. A different approach was adopted to derive chronic effects benchmarks for these parameters, as outlined in Section 8.IV.2.1.3.

8.IV.2.1.2 Step 2 - Statistical Analysis of Available Data

Following the compilation of the toxicological databases, a statistical analysis of the assembled data was undertaken if data were available for five or more species. This occurred for three SOPCs: chromium, which had data from 14 species; manganese, which had data from five species; and strontium, which had data from nine species. The statistical analysis consisted of:

- developing species mean values;
- ranking the species mean values to determine percent affected; and,
- fitting a statistical distribution to the available dataset, if appropriate.

Species means were calculated by taking the geometric mean of the individual test results. The geometric mean, as opposed to the arithmetic mean, was used to minimize bias toward high test results. Species mean values were then ranked from lowest to highest, and the percent of species affected was calculated based on dividing the rank assigned to each species mean by the total number of species. An example of this process is illustrated in Table 8.IV.2-1 using toxicity data for manganese.

Table 8.IV.2-1 Summary of Available Chronic Aquatic Toxicity Data for Manganese

Test Species	Common Name	End point	Chronic Toxicity Value (µg/L)	Species Mean (µg/L)	Rank	Percent Affected (%)
Oncorhynchus mykiss	Rainbow trout	LC10	958	2,806	1	20
Oncorhynchus mykiss	Rainbow trout	LC50	8,220			
Pimephales promelas	Fathead minnow	MATC	1,775	3,535	2	40
Pimephales promelas	Fathead minnow	MATC	1,775			
Pimephales promelas	Fathead minnow	MATC	14,025			
Daphnia magna	Water flea	MATC	1,100	5,463	3	60
Daphnia magna	Water flea	EC16	4,100			
Daphnia magna	Water flea	MATC	5,480			
Daphnia magna	Water flea	LC50	5,700			
Daphnia magna	Water flea	LC50	8,990			
Daphnia magna	Water flea	LC50	21,000			
Tubifex tubifex	Aquatic worm	EC50	26,800	82,214	4	80
Tubifex tubifex	Aquatic worm	EC50	42,700			
Tubifex tubifex	Aquatic worm	EC50	85,900			
Tubifex tubifex	Aquatic worm	EC50	464,750			
Asellus aquaticus	Isopod	LC50	333,000	333,000	5	100

µg/L = micrograms per litre; % = percent; LC = lethal concentration; MATC = maximum allowable toxicant concentration; EC = effects concentration

Once the species mean values were ranked and the percent of species affected was calculated, the data were plotted, and a best-fit curve was identified using a statistical software pakage (e.g., SigmaPlot 11.0 [SYSTAT Software 2008]).

Since SSDs typically follow a sigmoidal pattern, the data were assessed using a logistic function. As noted above, SSDs were only developed for substances with chronic toxicity data available for five or more species. Minimum data requirements for SSDs that have been recommended by various authorities range from three to more than 20 (Suter et al. 2002). CCME (2007a) specifies a minimum of seven species, but other jurisdictions differ (e.g., Danish soil quality criteria require a minimum of five species [Suter et al. 2002]). SSDs developed with more species are likely more robust. However, the benefit of basing the CEB on all relevant and available toxicity data (i.e., in an SSD) was considered to outweigh the potential increase in uncertainty arising from having relatively few data.

8.IV.2.1.3 Step 3 - Identification of Chronic Effects Benchmark

8.IV.2.1.3.1 Step 3a – Derivation of the HC5 Concentration

Following the development of an appropriate regression model, the HC5 value was calculated using the model equation. The HC5 value was then used as the CEB for the parameter in question. Species sensitivity distribution-based CEBs were derived for chromium, manganese, and strontium.

8.IV.2.1.3.2 Step 3b - Selection of the Lowest Reported Chronic Value

For most SOPCs (excepting chromium, manganese, and strontium), toxicity data were available for fewer than five species. Chronic effects benchmarks for the remaining substances for which toxicity databases were developed were based on the lowest chronic toxicity result present in the parameter-specific toxicity database.

8.IV.2.2 ADDITIONS/ALTERATIONS TO GENERAL METHODS

For three SOPCs, namely copper, cobalt, and uranium, the general methods outlined above were modified to take advantage of recent, existing data summaries, as outlined below.

8.IV.2.2.1 Copper

The US EPA revised their recommended copper criteria in 2007 (US EPA 2007). The revised criteria were developed using the Biotic Ligand Model (BLM) to account for the influence of dissolved organic carbon (DOC), pH and hardness on copper toxicity. The CEB for copper was initially intended to be set to the revised chronic criterion, adjusted to on-site conditions. However, an accurate adjustment could not be achieved, because conditions in and around Kennady

Lake were outside of the range of those considered in the development of the revised criterion. Thus, the Canadian copper guideline for the protection of aquatic life (CCME 2007b) was carried forward as the chronic effects benchmark for copper.

8.IV.2.2.2 Cobalt

The British Columbia Ministry of Water, Land and Air Protection (BC MWLAP) recently evaluated the toxicological literature for cobalt (BC MWLAP 2004). Thus, the lowest chronic toxicity value reported by BC MWLAP (2004) for species relevant to the Project area was used to define the chronic effects benchmark for cobalt.

8.IV.2.2.3 Uranium

The National Guidelines and Standards Office of Environment Canada recently evaluated the toxicological literature for uranium and derived a long-term exposure guideline for the protection of freshwater aquatic life (Environment Canada 2010). This guideline was developed using the SSD approach. This draft Canadian uranium guideline was carried forward as the CEB for uranium.

8.IV.3 RESULTS

8.IV.3.1 ANTIMONY

Two forms of antimony can exist in the dissolved phase (ATSDR 1997); however, most antimony released into waterways is associated with particulate matter. Dissolved antimony (III) occurs under moderately oxidizing conditions, whereas dissolved antimony (V) predominates in highly oxidizing environments (NWQMS 2000). The toxicity of antimony depends largely upon its chemical form and oxidation state, with antimony (III) exerting greater toxicity than antimony (V) (Hou and Narasaki 1999). Consequently, most toxicity studies focus on antimony (III).

Surface waters in the Project area tend to contain high levels of dissolved oxygen during the open water season, although periodic anoxia could occur in deeper water during winter (under ice cover). Dissolved antimony would be expected to exist predominantly as antimony (V).

Insufficient data were available to create an SSD for antimony (Attachment 8.IV.1, Table 8.IV.1-1). The lowest reported toxicity value was a 30-d NOEC of 7.5 µg/L for survival and growth of fathead minnow embryos (LeBlanc and Dean 1984); however, this NOEC was unbounded (i.e., a LOEC could not be calculated in the study). It was also very low in comparison to other toxicity estimates. Therefore, the next lowest reported toxicity value of 157 micrograms per litre (µg/L) wasselected for use as the CEB for antimony. This value is based on a 28-day LC10 test result generated using rainbow trout (Birge et al. 1979) and is considered to be conservative, because it is based on the more toxic form (i.e., antimony [III]).

8.IV.3.2 BARIUM

The acetate, nitrate and halide salts of barium are soluble in water, but the carbonate, chromate, fluoride, oxalate, phosphate and sulphate salts are relatively insoluble. The aqueous solubility of barium compounds increases as pH decreases. Organometallic barium compounds are ionic and are hydrolyzed in water. The concentration of barium ions in natural aquatic systems is limited by naturally occurring anions, such as sulphates and carbonates, and by the possible adsorption of barium ions onto metal oxides and hydroxides.

Insufficient data were available to develop an SSD for barium (Attachment 8.IV.1, Table 8.IV.1-2). The lowest reported toxicity value of 5,800 µg/L was, therefore, conservatively selected for use as the CEB for barium. This value is based on an

EC16 reproduction test result generated using the water flea *Daphnia magna* (Biesinger and Christensen 1972).

8.IV.3.3 BERYLLIUM

Beryllium toxicity and speciation varies with pH changes in the environment. Formation of solid beryllium hydroxide ($Be[OH]_2$) occurs in most aquatic systems with ranges of pH 6 to 8. Beryllium can also form insoluble carbonates and soluble beryllium sulphates in aquatic environments.

There were insufficient data for beryllium to develop an SSD (Attachment 8.IV.1, Table 8.IV.2-3). The lowest reported toxicity value of 5.3 µg/L was, therefore, conservatively selected for use as the CEB for beryllium. This value is based on a 28-d MATC for reproduction in *Daphnia magna* (Kimball 1978).

8.IV.3.4 CADMIUM

Cadmium is usually found as a mineral combined with other elements, such as oxygen (cadmium oxide), chlorine (cadmium chloride) or sulphur (cadmium sulphate, cadmium sulphide). It may exist in water as a hydrated ion, as inorganic complexes (such as carbonates, hydroxides, chlorides or sulphates) or as organic complexes with humic acids (OECD 1994). Cadmium may enter aquatic systems through weathering and erosion of soils and bedrock, atmospheric deposition, direct discharge from industrial operations, leakage from landfalls and contaminated sites and the dispersive use of sludge and fertilizers in agriculture. The predominant dissolved form of cadmium in freshwater is the cadmium ion (Cd^{2+}), which is the form that is most bioavailable to aquatic biota (Wright and Welbourn 1994). Upon entry to the aquatic ecosystem, cadmium tends to partition to particulate matter and dissolved organic matter, reducing concentrations of the free ion in the water column, thereby lowering its bioavailability (Jonnalagadda and Rao 1993).

Modifying factors, such as hardness, salinity, pH and dissolved oxygen levels, can have a profound effect on cadmium toxicity to aquatic plants and animals. Ions, such as hydrogen and calcium, may compete with cadmium, resulting in reduced cadmium uptake and toxicity (Wright and Welbourn 1994). The toxicity of cadmium to fish is strongly affected by hardness, mainly due to competition for anionic binding sites at the gills between cadmium ions and ions responsible for hardness (i.e., calcium and magnesium) (Parametrix 1995).

The US EPA revised their recommended criteria for cadmium in 2001 (US EPA 2001). This revision included an extensive review of the available toxicological literature and their revised criterion included a hardness correction factor. It was deemed to be unnecessary to repeat this work. Instead, the species mean chronic toxicity values from US EPA (2001) were used as the basis for the toxicological database for this appendix (Table 8.IV.3-1).

Table 8.IV.3-1 Summary of Available Chronic Aquatic Toxicity Data for Cadmium, Summarized to Species

Species	Common Name	Species Mean Chronic Toxicity Value [(a)] (µg/L)	Included/ Excluded	Reason
Hyalella azteca	amphipod	0.27	Included	-
Daphnia magna	cladoceran	0.38	Included	-
Oncorhynchus mykiss	rainbow trout	1.31	Included	-
Oncorhynchus tshawytscha	chinook salmon	2.61	Included	-
Salvelinus fontinalis	brook trout	2.64	Included	-
Chironomus tentans	midge	2.80	Included	-
Oncorhynchus kisutch	coho salmon	4.27	Included	-
Aplexa hypnorum	snail	4.82	Included	-
Salmo trutta	brown trout	5.00	Included	-
Daphnia pulex	cladoceran	6.17	Included	-
Catostomus commersoni	white sucker	7.80	Included	-
Salmo salar	Atlantic salmon	7.92	Included	-
Salvelinus namaycush	lake trout	8.09	Included	-
Esox lucius	northern pike	8.09	Included	-
Pimephales promelas	fathead minnow	16.4	Included	-
Aeolosoma headleyi	oligochaete	20.7	Included	-
Ceriodaphnia dubia	cladoceran	27.2	Included	-
Jordanella floridae	flagfish	5.32	Excluded	Non-resident species
Micropterus dolomieu	smallmouth bass	8.12	Excluded	Non-resident species
Lepomis macrochirus	Bluegill	17.4	Excluded	Non-resident species
Oreochromis aurea	blue tilapia	23.6	Excluded	Non-resident species

Source: Table 3c in US EPA (2001).
(a) Toxicity values were corrected to a hardness of 50 mg/L as $CaCO_3$.

Given that there were mean chronic values for 17 species, sufficient data were available to develop a site-specific SSD for cadmium. The logistic model provided a good fit to the data (r^2 = 0.97), and followed the form:

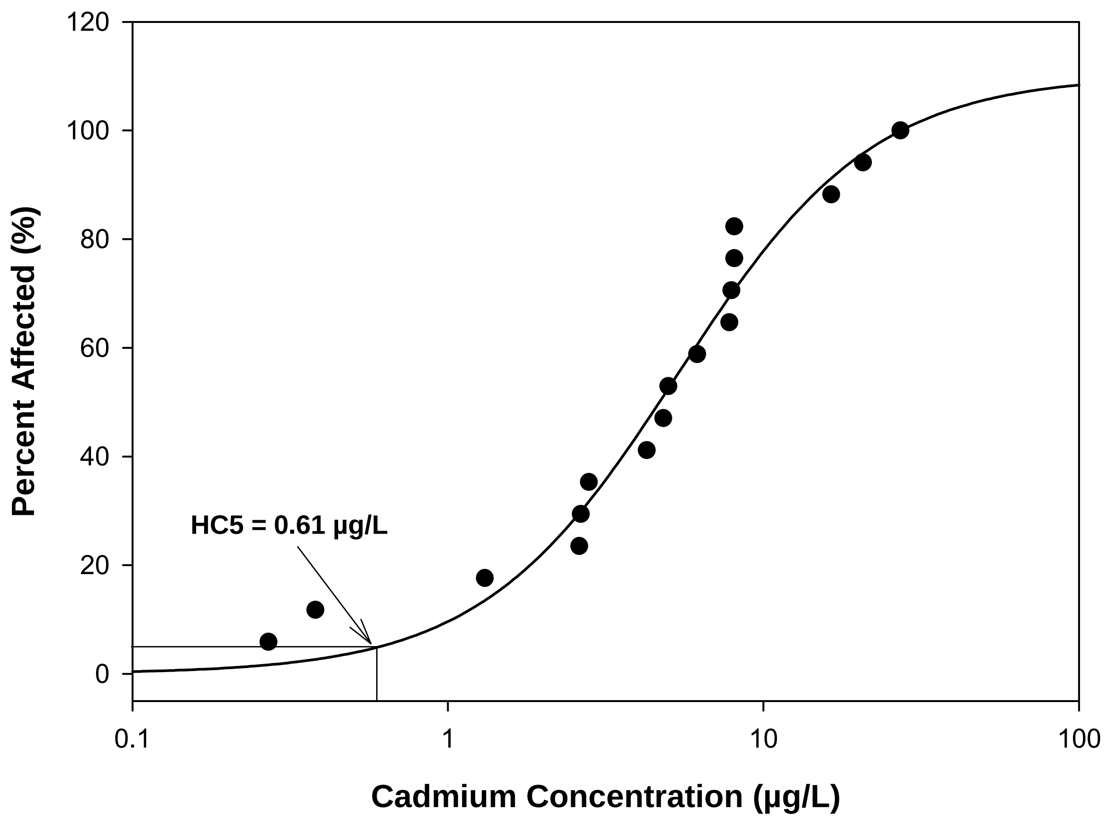
$$y = \frac{110.2}{1 + \left(\frac{x}{5.3}\right)^{-1.4}}$$

where: y = percent of aquatic community affected; and,

x = cadmium concentration (µg/L).

The resulting HC5 was 0.61 µg Cd/L based on a hardness of 50 mg/L (Figure 8.IV-2). This value was not considered sufficiently conservative for use as the CEB because it is higher than the species mean values reported for *Hyalella azteca* (0.27 µg/L) and *Daphnia magna* (0.38 µg/L), which represent 6 and 12% of the species included in the SSD. Instead, the CEB for cadmium was conservatively set to the species mean value reported for *Hyalella azteca*, which was the lowest in the available dataset (Table 8.IV.3-1).

Figure 8.IV.3-1 Species Sensitivity Distribution for Cadmium



The selected value of 0.27 µg/L corresponds to a hardness of 50 mg/L. It was adjusted to site-specific hardness levels using the equation outlined in U.S. EPA (2001):

$$y = \varepsilon^{(0.7409 \times \ln(hardness) - 4.21)}$$

where: y = hardness-adjusted benchmark.

8.IV.3.5 CHROMIUM

Chromium can exist in nine different oxidation forms; however, it is found most commonly in the chromium (III) and chromium (VI) states in the environment. In the current assessment, it is anticipated that most chromium will be present as chromium (III). The basis for this assumption is that the dominant sources of chromium to Kennady Lake are groundwater and seepage from fine PK and waste rock, and these are not highly oxidative systems that would generate chromium (VI). Chromium (III) oxidizes slowly to chromium (VI), although chromium (VI) is more soluble (US EPA 1984). As such, chromium (III) dominates in reducing environments such as sediments and wetlands, whereas chromium (VI) is the primary species found in surface water and aerobic soils (CCME 1999b). Chromium (VI) is more toxic to aquatic life than chromium (III), and thus is typically addressed separately in water quality guidelines (e.g., CCME 1999b). Chromium (III) is more toxic in soft water than in hard water, whereas hardness does not affect toxicity of chromium (VI) (US EPA 1984). Given the different toxicity profiles, separate CEBs were developed for chromium (III) and chromium (VI).

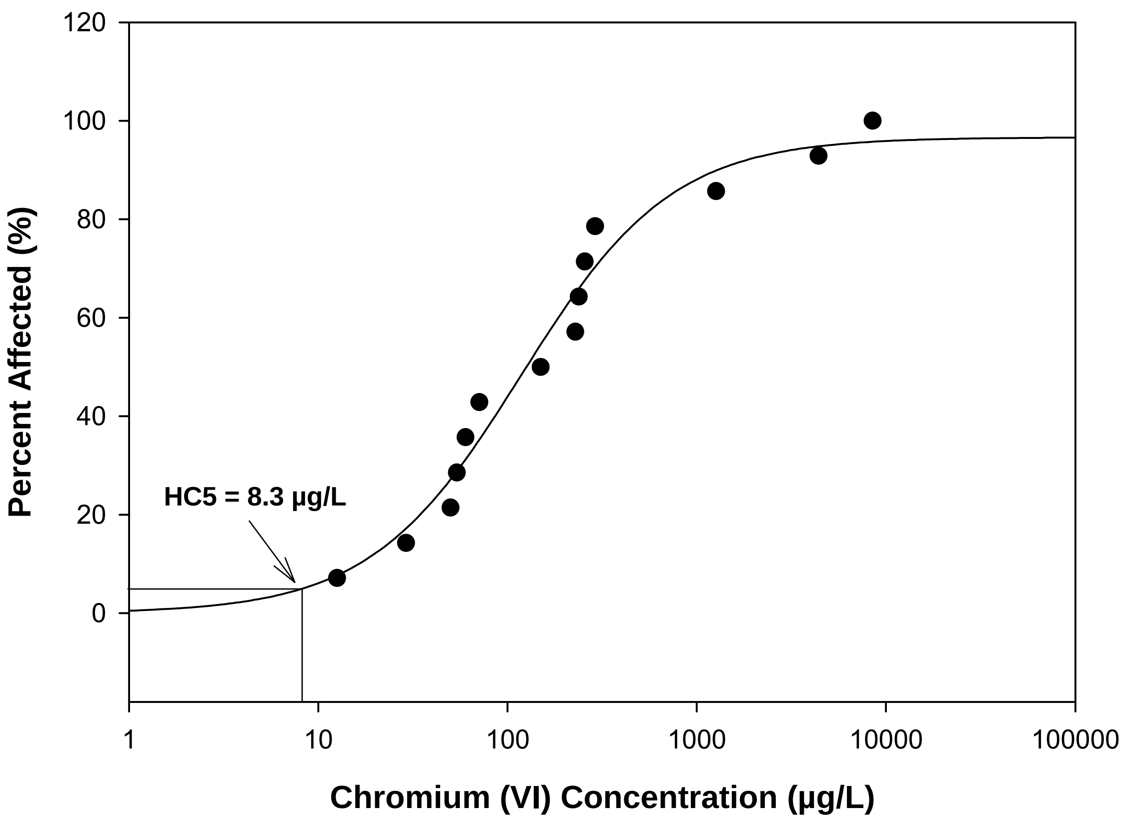
Sufficient data were available to develop an SSD for chromium (VI) (Attachment 8.IV.1, Table 8.IV.1-4). The logistic model provided a good fit to the data (r^2 = 0.97), and followed the form:

$$y = \frac{96.6}{1 + \left(\frac{x}{118.1}\right)^{-1.09}}$$

where: y = percent of aquatic community affected; and,
x = chromium (VI) concentration (µg/L).

The resulting HC5 based on the logistic regression model was 8.3 µg/L (Figure 8.IV.3-2). The SSD was derived using chronic toxicity data for 14 aquatic species (Attachment 8.IV.1, Table 8.IV.1-4).

Figure 8.IV.3-2 Species Sensitivity Distribution for Chromium (VI)



HC5 = hazardous concentration to 5%; % = percent; µg/L = micgrograms per litre

There were insufficient chronic toxicity data for chromium (III) to develop an SSD (Attachment 8.IV.1, Table 8.IV.2-3). The lowest reported toxicity value of 89 µg/L was therefore selected for use as the CEB for chromium (III). This value is based on a LOEC for survival of rainbow trout embryos exposed until 30-d post-swim-up (Stevens and Chapman 1984). This toxicity value is associated with a hardness of 25 mg/L as $CaCO_3$.

8.IV.3.6 COBALT

Cobalt can exist in six oxidation states; however, the most common states in the aquatic environment are cobalt (III) and cobalt (II), which form numerous organic and inorganic salts. Like most metals, the solubility of cobalt is highly dependant on its form. While cobaltous carbonate is highly insoluble in water, several salts, such as $CoCl_2$, are highly soluble. Cobalt is essential in trace amounts, and it forms part of the vitamin B-12.

The BC MWLAP recently evaluated the toxicological literature for cobalt (BC MWLAP 2004). It was deemed ineffective to repeat this work. Thus, the lowest chronic toxicity value reported by BC MWLAP (2004) for species relevant to the Project area was conservatively used to define the CEB for cobalt, excluding those data that were flagged in the original document as outliers. The resulting CEB was set to 9.3 µg/L. This value is based on a reproductive LOEC test result generated using the water flea *Daphnia magna* (Kimball 1978).

8.IV.3.7 COPPER

In natural waters, copper occurs primarily as the divalent cupric ion in free and complex forms. The cupric ion (Cu^{2+}) is the most readily available (Suedel et al. 1996), and is highly reactive, forming complexes and precipitates with organic and inorganic substances and suspended solids in the water column (US EPA 1985). Copper can be toxic to aquatic life, but at low concentrations it is an essential nutrient for both aquatic plants and animals (US EPA 1985).

Water quality can also affect the toxicity and bioavailability of copper to aquatic life. Generally, as water hardness increases, toxicity decreases. Water hardness in natural waters is controlled by the presence of calcium and magnesium, which compete with metal cations for binding sites on the gills of aquatic organisms (ICME 1995).

As noted in Section 8.IV.2.2.1, the Canadian copper guideline for the protection of aquatic life (CCME 2007b) was carried forward as the CEB for copper. Based on on-site conditions, the value of the guideline is 2 µg/L.

8.IV.3.8 IRON

Iron exists in two forms: soluble ferrous (Fe^{2+}) iron and insoluble ferric (Fe^{3+}) iron. Oxidation-reduction reactions determine the chemical behavior of iron in the aquatic environment. In aerobic systems, the vast majority of iron is present in water as insoluble ferric ion, which is largely non-toxic. Under anaerobic conditions, soluble ferrous iron can form. Although periodic anoxia has been observed in the Project area, dissolved oxygen levels tend to be high, and iron exists predominantly as insoluble ferric iron.

Insufficient data were available to develop an SSD for iron (Attachment 8.IV.1, Table 8.IV.1-5). The lowest reported toxicity value of 256 µg/L was, therefore, initially identified for use as the CEB for iron. This value is based on a 21-day reproduction test using the water flea *Daphnia magna* (Dave 1984). The identified value is effectively equivalent to the Canadian water quality guideline of 300 µg/L (CCME 2007b). Thus, the Canadian water quality guideline was carried forward as the CEB for iron.

8.IV.3.9 MANGANESE

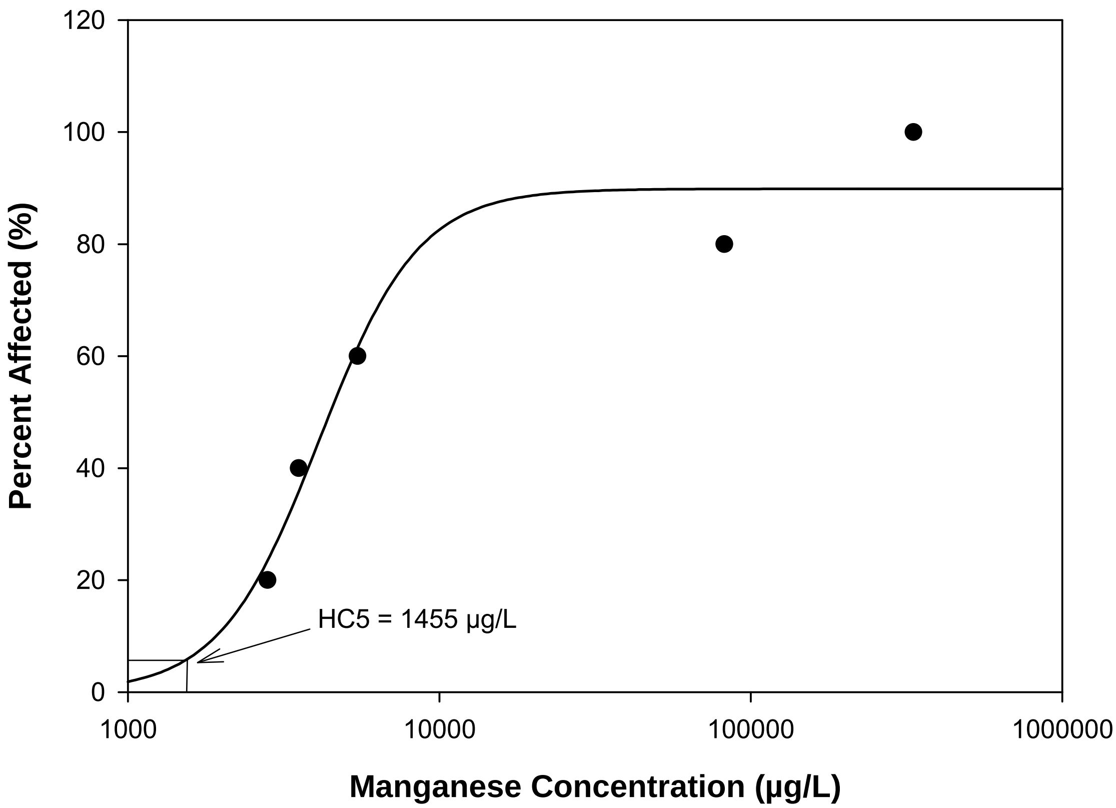
Manganese exists in oxidation states ranging from -3 to +7, of which divalent and trivalent manganese are the more important forms in aquatic systems (CCREM 1987). Sufficient data were available to develop an SSD for manganese, as there were chronic toxicity data for five species. The logistic model provided a good fit to the data ($r^2 = 0.94$), and followed the form:

$$y = \frac{89.9}{1 + \left(\frac{x}{4110}\right)^{-2.7}}$$

where: y = percent of aquatic community affected; and,
x = manganese concentration (µg/L).

The resulting HC5 based on the logistic regression model was 1,455 µg/L (Figure 8.IV.3-3). Data used in creating the SSD can be found in Attachment 8.IV.1, Table 8.IV.1-6.

Figure 8.IV.3-3 Species Sensitivity Distribution for Manganese



HC5 = hazardous concentration to 5%; % = percent; µg/L = micgrograms per litre

8.IV.3.10 STRONTIUM

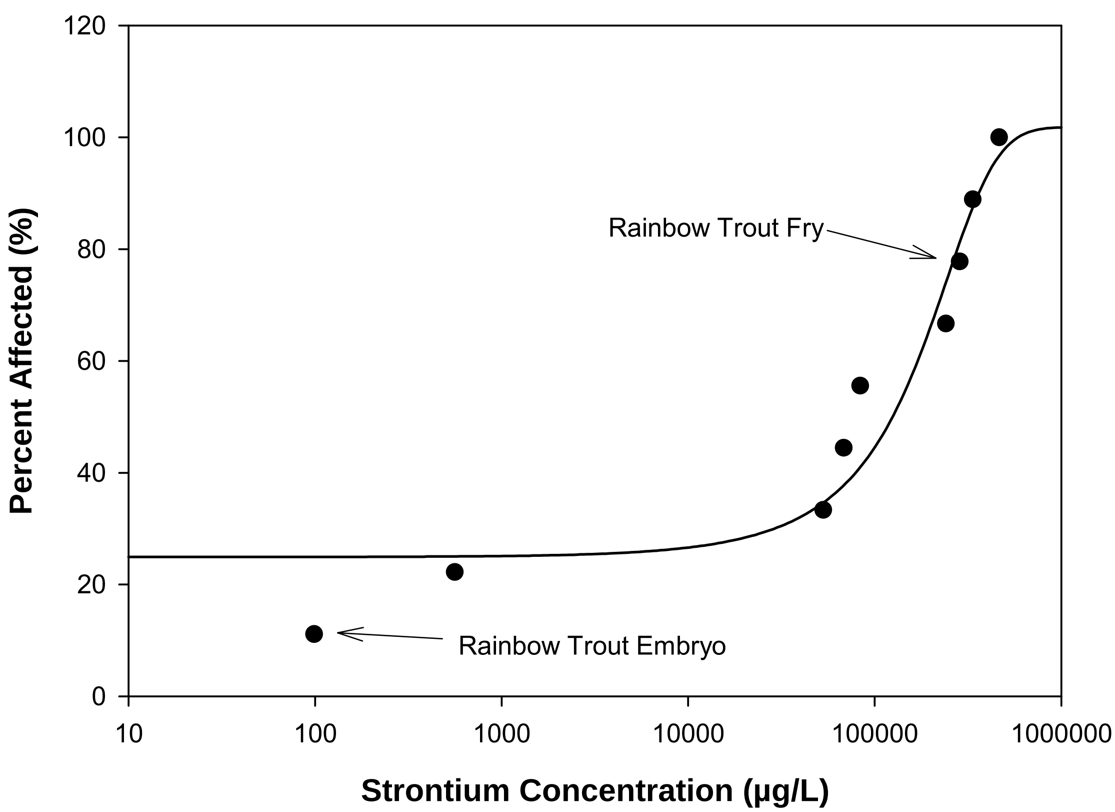
Strontium can exist in two oxidation states: 0 and +2. Under normal environmental conditions, only the +2 oxidation state is stable enough to be of practical importance, since strontium readily reacts with both water and oxygen (Cotton and Wilkinson 1980; Hibbins 1997). There are 26 isotopes of strontium, four of which occur naturally. Naturally occurring strontium is not radioactive and is either referred to as stable strontium or strontium.

Sufficient data were available to develop an SSD for strontium as there were 9 species with chronic data (Attachment 8.IV.1, Table 8.IV.1-7). However, a logistic model could not provide a good fit to the data. The fitted curve became parallel to the x-axis at strontium concentrations below approximately 10,000 µg/L (Figure 8.IV.3-4). The apparent reason for the lack of fit was the disparity between the majority of toxicity estimates (in the range 34,000 to 465,000 µg/L), and the very low values reported by Birge et al. (1979) for rainbow trout embryos (49 and 200 µg/L). Borgmann et al. (2005) reported toxicity data for *Hyalella azteca* intermediate between the Birge et al. (1979) and other toxicity data, but these were unbounded NOECs, and therefore are lower than the true threshold for effects for this species.

Although the toxicity value from Birge et al. (1979) appear to be very low compared to other studies with strontium, there is no clear basis for concluding that the value is incorrect. Therefore, it was included in the toxicity database for strontium.

Given that an HC5 could not be derived for this dataset, the CEB was conservatively set equal to the lowest effect concentration of 49 µg/L reported by Birge et al. (1979), which is a 28-day LC10 with rainbow trout embryos. Given the disparity between this toxicity estimate and other values in the database, the CEB of 49 µg/L is likely to be a highly conservative benchmark for the evaluation of potential adverse effects to aquatic life.

Figure 8.IV.3-4 Species Sensitivity Distribution for Strontium



% = percent; µg/L = micgrograms per litre

8.IV.3.11 URANIUM

Uranium is both radiotoxic and chemotoxic; however, the specific activity of uranium radioisotopes such as ^{238}U is low with minimal uranium radiotoxicity occurring through aqueous exposure (Ribera et al. 1996). Given that uranium is generally more chemotoxic than radiotoxic to aquatic biota, only the chemical toxicity of uranium was considered for the CEB analysis. Hardness, pH and alkalinity are known to affect the toxicity and speciation of uranium in aquatic environments. Hexavalent uranium is the most stable form and the most commonly occuring form of uranium in aquatic environments, whereas tetravalent uranium forms insoluble hydroxides with fluoride and phosphates (Clark et al. 1995). Dissolved organic matter in the form of fulvic and humic acids forms stable complexes with uranium and ameliorates its toxicity to aquatic organisms (Markich et al. 1996). Uranium sorption to organic matter decreases in environments with pH above 8 due to the presence of carbonate ligands that compete with uranium for binding sites.

The National Guidelines and Standards Office of Environment Canada recently evaluated the toxicological literature for uranium and generated a long-term exposure guideline for the protection of freshwater aquatic life (Environment Canada 2010). Given that this guideline was developed using the SSD approach based on a recent review of the literature, this draft Canadian uranium guideline was carried forward as the CEB for this substance. The CEB for uranium was set to 15 µg/L.

8.IV.3.12 VANADIUM

The transport and speciation of vanadium in water is influenced by pH, redox potential and the presence of particulate matter. In fresh water, vanadium (V) generally exists in solution as the vanadyl ion (V^{4+}) under reducing conditions and the vanadate ion (V^{5+}) under oxidizing conditions, or as an integral part of, or adsorbed onto, particulate matter (Wehrli and Stumm 1989). The partitioning of vanadium between water and sediment is strongly influenced by the presence of particulates in the water. Both vanadate and vanadyl species are known to bind strongly to mineral or biogenic surfaces by adsorption or complexing (Wehrli and Stumm 1989). It has been estimated that approximately 13% of the total vanadium in river water will be present in dissolved form (WHO 1988).

Insufficient data were available to develop an SSD for vanadium (Attachment 8.IV.1, Table 8.IV.1-8). The lowest reported toxicity value of 33.8 µg/L was, therefore, selected for use as the CEB for vanadium. This value is based on a 28-day LC10 test result generated using rainbow trout embryos.

8.IV.4 SUMMARY OF SELECTED CHRONIC EFFECTS BENCHMARKS

The chronic effects benchmarks identified for each of the SOPCs listed in Section 8.IV.2 are summarized in Table 8.IV.4-1.

Table 8.IV.4-1 Summary of Chronic Effects Benchmarks Selected for Use in the Aquatic Health Assessment

Parameter	Chronic Effects Benchmark (µg/L)	Basis for Benchmark
antimony	157	Lowest reported toxicity value (28-d LC10 with rainbow trout) from Birge et al. (1979)
barium	5,800	Lowest reported toxicity value (21-d EC16 for reproduction with *Daphnia magna*) from Biesinger and Christensen (1972)
beryllium	5.3	Lowest reported toxicity value (28-d MATC for reproduction with *Daphnia magna*) from Kimball (1978)
cadmium	0.27 [(a)]	Lowest species mean chronic value (for *Hyalella azteca*) as reported by US EPA (2001)
chromium (VI)	8.3	Species sensitivity distribution using chronic toxicity data from 14 species
chromium (III)	89	Lowest reported toxicity value (30-d post-swim-up LOEC for survival with rainbow trout embryos) from Stevens and Chapman (1984)
cobalt	9.3	Lowest reported toxicity value from Kimball (1978), which was used as the basis for BC MWLAP (2004) cobalt water quality guideline
copper	2.0	CCME guideline for the protection of freshwater aquatic life in soft water
iron	300	CCME guideline for the protection of freshwater aquatic life
manganese	1,455	Species sensitivity distribution using chronic toxicity data from 5 species
strontium	49	Lowest reported toxicity value (28-d LC10 with rainbow trout) from Birge et al. (1979)
uranium	15	Draft CCME guideline for the protection of freshwater aquatic life
vanadium	33.8	Lowest reported toxicity value (28-d LC10 with rainbow trout) from Birge et al. (1979)

(a) Based on a hardness of 50 mg/L as $CaCO_3$.

µg/L = micrograms per litre; BC MWLAP = British Columbia Ministry of Water Land and Air Protection; CCME = Canadian Council of Ministers of the Environment; mg/L = milligrams per litre; $CaCO_3$ = calcium carbonate.

8.IV.5 REFERENCES

8.IV.5.1 LITERATURE CITED

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8.IV.5.2 PERSONAL COMMUNICATIONS

Carleton-Dodds, I. 2010. Senior Ecotoxicologist. HydroQual Laboratories Ltd., Calgary, AB, Canada. Personal Communication: E-mail to Kerrie Serben October 15, 2010.

8.IV.6 ACRONYMS AND GLOSSARY

8.IV.6.1 ABBREVIATIONS AND ACRONYMS

BC MWLAP	British Columbia Ministry of Water, Land and Air Protection
Be	beryllium
BLM	Biotic Ligand Model
Ca	calcium
CCME	Canadian Council of Ministers of the Environment
CEB	chronic effects benchmark
Cd	cadmium
Co	cobalt
$CoCl_2$	cobalt chloride
Cr	chromium
Cu	copper
DOC	dissolved organic carbon
EC	effects concentration
EIS	Environmental Impact Statement
Fe	Iron
HC5	hazardous concentration to no more than 5%
IC	inhibition concentration
LC	lethal concentration
LOEC	lowest observed effects concentration
MATC	maximum allowable toxicant concentration
Mg	magnesium
Na	sodium
NOEC	no observed effects concentration
OH	hydoxide
SOPC	substance of potential concern
SSD	species sensitivity distribution
TDS	total dissolved solids
US EPA	United States Environmental Protection Agency
U	uranium
V	vanadium

8.IV.6.2 UNITS OF MEASURE

%	percent
~	approximately
<	less than
±	plus or minus
°C	degrees Celsius
µg/L	micrograms per litre
mg/L	milligrams per litre

8.IV.6.3 GLOSSARY

Chemotoxic	Relating to the toxic effects of a chemical
Chronic	The development of adverse effects after extended exposure to a given substance. In chronic toxicity tests, the measurement of a chronic effect can be reduced growth, reduced reproduction or other non-lethal effects, in addition to lethality. Chronic should be considered a relative term depending on the life span of the organism.
Chronic Effects Benchmark (CEB)	A no-effects threshold beyond which detrimental effects to aquatic health may occur.
EC*p*	The effect concentration in water that is estimated to cause a specific effect to *p*% of the test organisms. "*p*" can represent any percentage (e.g., EC10, EC25). The EC*p* describes quantal effects (lethal or sublethal).
Endpoint	The statistic that is estimated as a result of a toxicity test with a particular test organism and chemical.
Geometric Mean	A measure of central tendency for a set of data that is calculated as the nth root of the product of all values included in the data.
HC5	The hazardous concentration at which 5% of the species may show effects due to aquatic exposure to a particular chemical.
IC*p*	The inhibitory concentration in water that is estimated to cause an impairment of a specific percentage (*p*) of the test organisms. As with EC*p*, "*p*" can represent any percentage (e.g., IC10, IC25). The IC*p* describes effects that require comparison to the control response to interpret (e.g., reduction in growth or reproduction).
Lowest Observable Effects Concentration (LOEC)	The lowest concentration in water that causes an effect that is statistically significant different in magnitude compared to controls.
Maximum Allowable Toxicant Concentration (MATC)	The geometric mean value of the NOEC and LOEC reported for a given test.
No Observed Effect Concentration (NOEC)	The highest concentration in water that causes an effect that is not statistically significant different in magnitude compared to controls.
Quantal Effect	An effect that is either shown by the test organism or is not shown, and is not dependent upon the response of the control organisms to be interpreted. Two examples of quantal effects include survival (exposed test organism either lived or died) and presence of abnormalities (exposed test organism either developed normally or abnormally).
Radiotoxic	Relating to the toxic effects of radiation or radioactive substances.

Species Sensitivity Distribution (SSD)	A probability distribution of measures of toxicity that describe the relative toxicity of a particular chemical among a population of species.
Sublethal Effect	An effect that is detrimental to the test organism, but which does not directly cause a reduction in survival.
Substance of Potential Concern (SOPC)	A particular chemical that was selected for further assessment.
Toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.

ATTACHMENT 8.IV.1

SUMMARY OF AVAILABLE CHRONIC TOXICITY DATA FOR SUBSTANCES OF POTENTIAL CONCERN

Table 8.IV.1-1 Summary of Chronic Toxicity Data Available for Antimony

Chemical species	Test Species	Common Name	Life Stage	pH	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
antimony trioxide	*Pimephales promelas*	fathead minnow	embryos	6.2 to 7.3	30 days	survival and growth	NOEC	7.5	LeBlanc and Dean 1984	included	Note: unbounded NOEC
antimony trichloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC10	157	Birge et al. 1979	included	-
antimony trichloride	*Oncorhynchus mykiss*	rainbow trout	embryos	7.4	28 days	survival	LC50	580	Birge 1978	included	-
antimony potassium tartrate	*Daphnia magna*	water flea	<24 hours old	7.8 ± 0.2	33 days	growth	NOEC	800	Doe et al. 1987	included	-
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	7.97	28 days	length	MATC	1,620	Kimball 1978 (Test 1)	included	-
antimony potassium tartrate	*Daphnia magna*	water flea	<24 hours old	7.8 ± 0.2	30 days	reproduction	NOEC	1,700	Doe et al. 1987	included	-
antimony potassium tartrate	*Daphnia magna*	water flea	<24 hours old	7.8 ± 0.2	30 days	survival	LC50	2,700	Doe et al. 1987	included	-
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	7.97	28 days	weight	MATC	3,220	Kimball 1978 (Test 2)	included	-
antimony trichloride	*Daphnia magna*	water flea	-	8.5	28 days	survival	LC50	4,510	Kimball 1978 (Test 7)	included	-
antimony trichloride	*Daphnia magna*	water flea	-	8.5	28 days	reproduction	MATC	5,420	Kimball 1978 (Test 3)	included	-
antimony trichloride	*Daphnia magna*	water flea	2 week old adults	8.27	7 days	reproduction	MATC	5,500	Kimball 1978 (Test 4)	included	-
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	7.97	28 days	survival	MATC	6,470	Kimball 1978 (Test 5)	included	-
antimony trichloride	*Daphnia magna*	water flea	2 week old adults	8.27	7 days	survival	LC50	14,500	Kimball 1978 (Test 6)	included	-
antimony potassium tartrate	*Oncorhynchus mykiss*	rainbow trout	weight 1.2 g	6.7 to 7.3	30 days	survival	LC50	16,000	Doe et al. 1987	included	-
antimony trichloride	*Caenorhabditis elegans*	nematode	young adult (3 to 4 days old)	-	4 days	survival	LC50	>20,000	Williams and Dusenbury 1990	included	-
antimony trichloride	*Pimephales promelas*	fathead minnow	8 weeks old	8.02	192 hours	survival	LC50	20,200	Kimball 1978	included	-
antimony trichloride	*Gastrophryne carolinensis*	narrow-mouthed toad	embryos	7.4	7 days	survival	LC1	4	Birge 1978	excluded	non-resident species
antimony trichloride	*Oncorhynchus mykiss*	rainbow trout	embryos	7.4	28 days	survival	LC1	29	Birge 1978	excluded	endpoint
antimony trichloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC1	49	Birge et al. 1979	excluded	endpoint
antimony trichloride	*Carassius auratus*	goldfish	embryos	7.4	7 days	survival	LC1	111	Birge 1978	excluded	non-resident species
antimony trichloride	*Gastrophryne carolinensis*	narrow-mouthed toad	embryos	7.4	7 days	survival	LC50	300	Birge 1978	excluded	non-resident species
antimony trichloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC50	660	Birge et al. 1979	excluded	LC10 chosen over LC50
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old embryos	7.97	28 days	length	NOEC	1,130	Kimball 1978 (Test 1)	excluded	MATC used rather than NOEC
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old embryos	7.97	28 days	length	LOEC	2,310	Kimball 1978 (Test 1)	excluded	MATC used rather than LOEC
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old embryos	7.97	28 days	weight	NOEC	2,310	Kimball 1978 (Test 2)	excluded	MATC used rather than NOEC
antimony trichloride	*Daphnia magna*	water flea	2 weeks old adults	8.27	7 days	reproduction	NOEC	3,900	Kimball 1978 (Test 4)	excluded	MATC used rather than NOEC
antimony trichloride	*Daphnia magna*	water flea	-	8.5	28 days	reproduction	NOEC	4,160	Kimball 1978 (Test 3)	excluded	MATC used rather than NOEC
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old embryos	7.97	28 days	survival	NOEC	4,500	Kimball 1978 (Test 5)	excluded	MATC used rather than NOEC
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old embryos	7.97	28 days	weight	LOEC	4,500	Kimball 1978 (Test 2)	excluded	MATC used rather than LOEC
antimony trichloride	*Daphnia magna*	water flea	-	8.5	28 days	reproduction	LOEC	7,050	Kimball 1978 (Test 3)	excluded	MATC used rather than LOEC
antimony trichloride	*Daphnia magna*	water flea	2 weeks old adults	8.27	7 days	reproduction	LOEC	7,700	Kimball 1978 (Test 4)	excluded	MATC used rather than LOEC
antimony trichloride	*Pimephales promelas*	fathead minnow	16 to 40 hours old embryos	7.97	28 days	survival	LOEC	9,310	Kimball 1978 (Test 5)	excluded	MATC used rather than LOEC
antimony trichloride	*Carassius auratus*	goldfish	embryos	7.4	7 days	survival	LC50	11,300	Birge 1978	excluded	non-resident species
antimony trichloride	*Caenorhabditis elegans*	nematode	-	-	96 hours	survival	LC50	20,000	AQUIRE 1996 as cited in Sample et al. 1997	excluded	reference not found

µg/L = micrograms per litre;- = Not available; MATC = maximum allowable toxicant concentration; LC = lethal concentration; NOEC = no observed effects concentration; LOEC = lowest obsesrved effects concentration.

Table 8.IV.1-2 Summary of Chronic Toxicity Data Available for Barium

Chemical Species	Test Species	Common Name	Life Stage	pH	Duration	Biological Measurement	End Point	Concentration [µg/L]	Citation	Included/ Excluded	Reason
barium chloride	*Daphnia magna*	water flea	12 hours old	7.74	21 days	reproduction	EC16	5,800	Biesinger and Christensen 1972	included	-
barium chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC10	9,543	Birge et al. 1979	included	-
barium chloride	*Daphnia magna*	water flea	12 hours old	7.74	21 days	survival	LC50	13,500	Biesinger and Christensen 1972	included	-
barium chloride	*Daphnia magna*	water flea	12 hours old	7.74	21 days	reproduction	EC50	8,900	Biesinger and Christensen 1972	excluded	EC16 chosen over EC50
barium chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC50	42,700	Birge et al. 1979	excluded	LC10 chosen over LC50

µg/L = micrograms per litre; - = Not available; LC = lethal concentration; EC = effects concentration.

Table 8.IV.1-3 Summary of Chronic Toxicity Data Available for Beryllium

Chemical Species	Test Species	Common Name	Life Stage	pH	Hardness (mg/L as $CaCO_3$)	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
Beryllium sulphate	*Daphnia magna*	water flea	-	8.36	226	28 days	reproduction	MATC	5.3	Kimball 1978	included	-
Beryllium sulphate	*Daphnia magna*	water flea	-	8.36	226	28 days	survival	LC50	34	Kimball 1978	included	-
Beryllium chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	92 to 110	28 days	survival	LC10	42	Birge et al. 1979	included	-
Beryllium sulphate	*Caenorhabditis elegans*	nematode	3 to 4 days	-	-	4 days	survival	LC50	140	Williams and Dusenbury 1990	included	-
Beryllium	*Hyalella azteca*	amphipod	1 to 11 days	7.37 to 8.27	18	7 days	survival	LC50	2,935	Borgman et al. 2005	included	-
Beryllium sulphate	*Chlorella vulgaris*	algae	-	-	-	3 to 4 months	growth	LOEC	3,000	den Dooren de Jong 1965	included	-
Beryllium	*Hyalella azteca*	amphipod	1 to 11 days	8.21 to 8.46	124	7 days	survival	LC50	>3,150	Borgman et al. 2005	included	-

µg/L = micrograms per litre; - = Not available; > = greater than; LC = lethal concentration; LOEC = lowest observed effects concentration.

Table 8.IV.1-4 Summary of Chronic Toxicity Data Available for Chromium

Speciation	Chemical species	Test Species	Common Name	Life Stage	pH	Hardness (mg/L as $CaCO_3$)	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
CrVI	potassium dichromate	*Ceriodaphnia dubia*	Water flea	24 hours	7.9	250	14 days	reproduction	LOEC	10	Hickey 1989	included	-
CrVI	sodium chromate	*Hyalella azteca*	amphipod	0-1 week	8.2	not reported	28 days	survival	LC25	12.6	Norwood et al. 2007	included	-
CrVI	potassium dichromate	*Pimephales promelas*	fathead minnow	4 weeks old (juvenile)	7.7	209	9 weeks	growth	LOEC	18	Pickering 1980	included	-
CrVI	chromium trioxide	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	reproduction	IC25	20	Baral et al. 2006	included	-
CrVI	potassium dichromate	*Daphnia magna*	Water flea	24 hours	7.9	250	14 days	reproduction	MATC	50	Hickey 1989	included	-
CrVI	not reported	*Oncorhynchus tshawytscha*	Chinook salmon	Parr stage	7.6 to 8	76 to 89	105 days	survival	NOEC	54	Farag et al. 2006	included	-
CrVI	not reported	*Oncorhynchus tshawytscha*	Chinook salmon	Parr stage	7.6 to 8	76 to 89	105 days	growth	NOEC	54	Farag et al. 2006	included	-
CrVI	potassium dichromate	*Caenorhabditis elegans*	Nematode	3 - 4 days	not reported	not reported	96 hours	survival	LC50	60	Williams and Dusenbury 1990	included	-

Table 8.IV.1-4 Summary of Chronic Toxicity Data Available for Chromium (continued)

Speciation	Chemical species	Test Species	Common Name	Life Stage	pH	Hardness (mg/L as $CaCO_3$)	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
CrVI	potassium dichromate	*Daphnia carinata*	Water flea	24 hours	7.9	250	14 days	reproduction	MATC	71	Hickey 1989	included	-
CrVI	chromium trioxide	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	survival	LC25	124	Baral et al. 2006	included	-
CrVI	chromate	*Nitella graciliformis*	freshwater macrophyte	apical tips (2-3 internodes, 2-3 cm long)	7	very low (distilled water)	35 days	growth	LOEC	150	Hawa Bibi et al. 2010	included	-
CrVI	chromium trioxide	*Culex quinquefasciatus*	mosquito	larvae - adult	not reported	not reported	10 days	growth	LOEC	160	Sorensen et al. 2006	included	-
CrVI	sodium dichromate	*Salvelinus fontinalis*	brook trout	embryo	7 to 8	45	8 months	growth	IC20	200	Benoit 1975	included	-
CrVI	sodium dichromate	*Onchorhynchus mykiss*	rainbow trout	alevin (1 week old)	7 to 8	45	8 months	growth	IC30	200	Benoit 1975	included	-
CrVI	not reported	*Pseudokirchneriella subcapitata*	green algae	log-growth phase cells	7.7	not reported	21 days	biomass	EC50	238	Turbak et al. 1986	included	-
CrVI	sodium dichromate	*Onchorhynchus mykiss*	rainbow trout	alevin (1 week old)	7 to 8	45	8 months	survival	MATC	261	Benoit 1975	included	-
CrVI	sodium dichromate	*Salvelinus fontinalis*	brook trout	alevin (1 week old)	7 to 8	45	22 months	survival	LOEC	350	Benoit 1975	included	-
CrVI	sodium dichromate	*Salvelinus fontinalis*	brook trout	alevin (1 week old)	7 to 8	45	22 months	reproduction	NOEC	350	Benoit 1975	included	-
CrVI	chromium trioxide	*Culex quinquefasciatus*	mosquito	larvae - adult	not reported	not reported	10 days	survival	LC50	410	Sorensen et al. 2006	included	-
CrVI	chromate $(Cr_20_7)^{-2}$	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (root weight)	IC50	1,900	Stanley 1974	included	-
CrVI	potassium dichromate	*Pimephales promelas*	fathead minnow	4 weeks old (juvenile)	7.7	209	9 weeks	survival	MATC	1987	Pickering 1980	included	-
CrVI	chromate $(Cr_20_7)\text{-}^{2}$	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (shoot weight)	IC50	2,600	Stanley 1974	included	-
CrVI	not reported	*Pimephales promelas*	fathead minnow	<24 hours old	8.2 to 8.5	202	7 days	growth	MATC	4,243	Pickering 1988	included	-
CrVI	chromate $(Cr_20_7)^{-2}$	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (root length)	IC50	8,000	Stanley 1974	included	-
CrVI	potassium dichromate	*Lemna minor*	duckweed	plant	6	not reported	7 days	growth	EC50	8500	Ince et al. 1999	included	-
CrVI	chromate $(Cr_20_7)^{-2}$	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (shoot length)	IC50	9,500	Stanley 1974	included	-
CrVI	not reported	*Pimephales promelas*	fathead minnow	<24 hours old	8.2 to 8.5	202	7 days	survival	MATC	16,971	Pickering 1988	included	-
CrVI	chromium trioxide	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	reproduction	NOEC	15	Baral et al. 2006	excluded	IC25 chosen over NOEC
CrVI	potassium dichromate	*Daphnia magna*	Water flea	24 hours	7.9	250	14 days	reproduction	NOEC	25	Hickey 1989	excluded	MATC chosen over NOEC
CrVI	chromium trioxide	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	reproduction	IC50	37	Baral et al. 2006	excluded	IC25 chosen over IC50
CrVI	sodium chromate	*Hyalella azteca*	amphipod	0-1 week	8.2	not reported	28 days	survival	LC50	38	Norwood et al. 2007	excluded	LC25 chosen over LC50
CrVI	potassium dichromate	*Daphnia carinata*	Water flea	24 hours	7.9	250	14 days	reproduction	NOEC	50	Hickey 1989	excluded	MATC chosen over NOEC

Table 8.IV.1-4 Summary of Chronic Toxicity Data Available for Chromium (continued)

Speciation	Chemical species	Test Species	Common Name	Life Stage	pH	Hardness (mg/L as $CaCO_3$)	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
CrVI	potassium dichromate	*Daphnia magna*	Water flea	24 hours	7.9	250	14 days	reproduction	LOEC	100	Hickey 1989	excluded	MATC chosen over LOEC
CrVI	chromium trioxide	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	survival	NOEC	111	Baral et al. 2006	excluded	LC25 chosen over NOEC
CrVI	not reported	*Oncorhynchus tshawytscha*	Chinook salmon	Parr stage	7.6 to 8	76 to 89	134 days	survival	NOEC	120	Farag et al. 2006	excluded	Test organisms exposed to two different concentrations over the 134 day exposure period
CrVI	not reported	*Oncorhynchus tshawytscha*	Chinook salmon	Parr stage	7.6 to 8	76 to 89	134 days	growth	LOEC	120	Farag et al. 2006	excluded	Test organisms exposed to two different concentrations over the 134 day exposure period
CrVI	chromium trioxide	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	survival	LC50	145	Baral et al. 2006	excluded	LC25 chosen over LC50
CrVI	not reported	*Oncorhynchus tshawytscha*	Chinook salmon	Parr stage	7.6 to 8	76 to 89	134 days	survival	LOEC	266	Farag et al. 2006	excluded	Test organisms exposed to two different concentrations over the 134 day exposure period
CrVI	sodium dichromate	*Onchorhynchus mykiss*	rainbow trout	alevin (1 week old)	7 to 8	45	8 months	survival	LOEC	340	Benoit 1975	excluded	MATC chosen over LOEC
CrVI	potassium dichromate	*Pimephales promelas*	fathead minnow	4 weeks old (juvenile)	7.7	209	9 weeks	survival	NOEC	1000	Pickering 1980	excluded	MATC chosen over NOEC
CrVI	not reported	*Pimephales promelas*	fathead minnow	<24 hours old	8.2 to 8.5	202	7 days	growth	NOEC	3,000	Pickering 1988	excluded	MATC chosen over NOEC
CrVI	potassium dichromate	*Pimephales promelas*	fathead minnow	4 weeks old (juvenile)	7.7	209	9 weeks	survival	LOEC	3,950	Pickering 1980	excluded	MATC chosen over LOEC
CrVI	potassium dichromate	*Hypsiboas pulchellus*	Montevideo treefrog	gosner stage 25-46 (tadpoles)	not reported	not reported	53 days	survival	LOEC	6,000	Natale et al. 2006	excluded	non-resident species
CrVI	potassium dichromate	*Hypsiboas pulchellus*	Montevideo treefrog	gosner stage 25-46 (tadpoles)	not reported	not reported	53 days	growth	LOEC	6,000	Natale et al. 2006	excluded	non-resident species
CrVI	not reported	*Pimephales promelas*	fathead minnow	<24 hours old	8.2 to 8.5	202	7 days	growth	LOEC	6,000	Pickering 1988	excluded	MATC chosen over LOEC
CrVI	not reported	*Pimephales promelas*	fathead minnow	<24 hours old	8.2 to 8.5	202	7 days	survival	NOEC	12,000	Pickering 1988	excluded	MATC chosen over NOEC
CrVI	not reported	*Pimephales promelas*	fathead minnow	<24 hours old	8.2 to 8.5	202	7 days	survival	LOEC	24,000	Pickering 1988	excluded	MATC chosen over LOEC
CrIII	chromium nitrate	*Oncorhynchus mykiss*	rainbow trout	newly fertilized eggs	~7.3	25	30 days post-swim-up	survival	LOEC	89	Stevens and Chapman 1984	included	-
CrIII	not reported	*Pseudokirchneriella subcapitata*	green algae	log-growth phase cells	7.7	not reported	21 days	biomass	EC50	566	Turbak et al. 1986	included	-
CrIII	chromium chloride	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	reproduction	IC25	1,886	Baral et al. 2006	included	-
CrIII	chromium chloride	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	survival	LC25	2,649	Baral et al. 2006	included	-
CrIII	Cr+3	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (root weight)	IC50	9,900	Stanley 1974	included	-
CrIII	Cr+3	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (shoot weight)	IC50	14,600	Stanley 1974	included	-
CrIII	Cr+3	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (root length)	IC50	24,400	Stanley 1974	included	-
CrIII	Cr+3	*Myriophyllum spicatum*	watermilfoil	4 cm plant	8.2	340	32 days	growth (shoot length)	IC50	26,000	Stanley 1974	included	-
CrIII	chromium chloride	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	reproduction	NOEC	1,253	Baral et al. 2006	excluded	IC25 chosen over NOEC

Table 8.IV.1-4 Summary of Chronic Toxicity Data Available for Chromium (continued)

Speciation	Chemical species	Test Species	Common Name	Life Stage	pH	Hardness (mg/L as $CaCO_3$)	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
CrIII	chromium chloride	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	survival	NOEC	2,272	Baral et al. 2006	excluded	LC25 chosen over NOEC
CrIII	chromium chloride	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	reproduction	IC50	3,428	Baral et al. 2006	excluded	IC25 chosen over IC50
CrIII	chromium chloride	*Ceriodaphnia dubia*	Water flea	neonate	7.8 to 8.1	90 to 100	7 days	survival	LC50	3,711	Baral et al. 2006	excluded	LC25 chosen over LC50
not reported	Cr salt (chromate)	*Hyalella azteca*	amphipod	1 to 11 days	7.4 to 8.3	18	7 days	survival	LC50	3.1	Borgmann et al. 2005	excluded	Speciation not reported
not reported	Cr salt (chromate)	*Hyalella azteca*	amphipod	1 to 11 days	8.2 to 8.5	124	7 days	survival	LC50	137	Borgmann et al. 2005	excluded	Speciation not reported
not reported	atomic absoption standards	*Hyalella azteca*	amphipod	1 to 11 days	7.4 to 8.3	18	7 days	survival	NOEC	315	Borgmann et al. 2005	excluded	Speciation not reported
not reported	atomic absoption standards	*Hyalella azteca*	amphipod	1 to 11 days	8.2 to 8.5	124	7 days	survival	NOEC	1000	Borgmann et al. 2005	excluded	Speciation not reported
not reported	atomic absoption standards	*Hyalella azteca*	amphipod	1 to 11 days	7.4 to 8.3	18	7 days	survival	LC50	>1000	Borgmann et al. 2005	excluded	Speciation not reported
not reported	atomic absoption standards	*Hyalella azteca*	amphipod	1 to 11 days	8.2 to 8.5	124	7 days	survival	LC50	>3,150	Borgmann et al. 2005	excluded	Speciation not reported
not reported	not reported	*Lemna minor*	duckweed	not reported	not reported	not reported	10 days	growth (frond number)	EC50	3900	Smith and Kwan 1989	excluded	insufficient information presented to judge experimental design; speciation not reported

~ = approximately; < = less than; cm = centimetres; µg/L = micrograms per litre; - = Not available; < = less than; MATC = maximum allowable toxicant concentration; LC = lethal concentration; EC = effects concentration; IC = inhibition concentration; NOEC = no observed effects concentration; LOEC = lowest observed effects concentration.

Table 8.IV.1-5 Summary of Chronic Toxicity Data Available for Iron

Chemical Species	Test Species	Common Name	Life Stage	pH	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
ferric chloride	*Daphnia magna*	cladoceran	6 to 24 hours old	7.9 to 8.1	21 days	growth reproduction and survival	NOEC	128	Dave 1984	included	-
ferric chloride	*Daphnia magna*	cladoceran	6 to 24 hours old	7.9 to 8.1	21 days	reproduction	LOAEC	256	Dave 1984	included	-
ferric chloride	*Daphnia magna*	cladoceran	6 to 24 hours old	7.9 to 8.1	21 days	survival	LOAEC	512	Dave 1984	included	-
iron chloride	*Pimephales promelas*	fathead minnow	early life stage test	7.65	33 days	-	MATC	570	Birge et al. 1985	included	-
iron chloride	*Daphnia pulex*	cladoceran	-	7.57	21 days	-	MATC	960	Birge et al. 1985	included	-
ferrous sulphate	*Pimephales promelas*	fathead minnows	3 months old (average weight 0.4 g)	6.99 to 7.10	30 days post hatch	survival	LOEC	1,500	Sykora et al. 1972	included	-
iron (III)	*Lemna minor*	duckweed	-	-	7 days	growth	EC50	3,700	Wang 1986	included	-
iron chloride	*Daphnia magna*	cladoceran	12 hours old	7.74	21 days	reproduction	EC16	4,380	Biesinger and Christensen 1972	included	-
iron chloride	*Daphnia magna*	cladoceran	12 hours old	7.74	21 days	survival	LC50	5,900	Biesinger and Christensen 1972	included	-
ferrous sulphate	*Salvelinus fontinalis*	brook trout	3 months old (average length 34 mm)	7.24	35 weeks	growth	LOEC	12,000	Sykora et al. 1972	included	-
ferric chloride	*Tubifex tubifex*	worm	-	6.6	96 hours	immobilization	EC50	17,800	Rathore and Khangarot 2003	included	-
ferric chloride	*Tubifex tubifex*	worm	-	7.3	96 hours	immobilization	EC50	25,130	Rathore and Khangarot 2003	included	-
ferric chloride	*Tubifex tubifex*	worm	-	7.8	96 hours	immobilization	EC50	37,500	Rathore and Khangarot 2003	included	-
ferric chloride	*Tubifex tubifex*	worm	-	8.2	96 hours	immobilization	EC50	108,820	Rathore and Khangarot 2003	included	-
iron chloride	*Pimephales promelas*	fathead minnow	early life stage test	7.65	33 days	-	NOEC	320	Birge et al. 1985	excluded	MATC used instead
iron chloride	*Daphnia pulex*	cladoceran		7.57	21 days		LOEC	700	Birge et al. 1985	excluded	MATC used instead
iron chloride	*Pimephales promelas*	fathead minnow	early life stage test	7.65	33 days		LOEC	1,010	Birge et al. 1985	excluded	MATC used instead
iron chloride	*Daphnia pulex*	cladoceran		7.57	21 days		NOEC	1,310	Birge et al. 1985	excluded	MATC used instead
iron chloride	*Daphnia magna*	cladoceran	12 hours old	7.74	21 days	reproduction	EC50	5,200	Biesinger and Christensen 1972	excluded	EC16 chosen over EC50
ferrous sulphate	*Gammus minus*	invertebrate	-	7.2	3 weeks	survival	highest tolerable concentration	<3,000	Sykora et al. 1972	excluded	"<" value reported

µg/L = micrograms per litre;- = Not available; < = less than; MATC = maximum allowable toxicant concentration; LC = lethal concentration; EC = effects concentration; NOEC = no observed effects concentration; LOEC = lowest observed effects concentration.

Table 8.IV.1-6 Summary of Chronic Toxicity Data Available for Manganese

Chemical	Chemical Species	Test Species	Common Name	Life Stage	pH	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/ Excluded	Reason
manganese	manganese chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC10	958	Birge et al. 1979	included	-
manganese	manganese sulphate	*Daphnia magna*	water flea	-	8.37	28 day	reproduction	MATC	1,100	Kimball 1978	included	-
manganese	-	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	length	MATC	1,775	Kimball 1978 (Test 3)	included	-
manganese	-	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	weight	MATC	1,775	Kimball 1978 (Test 4)	included	-
manganese	manganese chloride	*Daphnia magna*	water flea	0 to 24 hours old	7.74	21 days	reproduction	EC16	4,100	Biesinger and Christensen 1972	included	-
manganese	manganese sulphate	*Daphnia magna*	water flea	2 weeks old adults	8.36	7 days	reproduction	MATC	5,480	Kimball 1978 (Test 1)	included	-
manganese	manganese chloride	*Daphnia magna*	water flea	0 to 24 hours old	7.74	21 days	survival	LC50	5,700	Biesinger and Christensen 1972	included	-
manganese	manganese chloride	*Oncorhynchus mykiss*	rainbow trout	eggs	7.4	28 days	survival	LC50	8,220	Birge 1978	included	-
manganese	manganese sulphate	*Daphnia magna*	water flea	-	8.37	28 days	survival	LC50	8,990	Kimball 1978	included	-
manganese	-	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	survival	MATC	14,025	Kimball 1978 (Test 2)	included	-
manganese	man ganese sulphate	*Daphnia magna*	water flea	2 weeks old adults	8.36	7 days	survival	LC50	21,000	Kimball 1978	included	-
manganese	manganese sulphate	*Tubifex tubifex*	worm	-	6.6	96 hours	immobilization	EC50	26,800	Rathore and Khangarot 2003	included	-
manganese	manganese sulphate	*Tubifex tubifex*	worm	-	7.3	96 hours	immobilization	EC50	42,700	Rathore and Khangarot 2003	included	-
manganese	manganese sulphate	*Tubifex tubifex*	worm	-	7.8	96 hours	immobilization	EC50	85,900	Rathore and Khangarot 2003	included	-
manganese	manganese chloride	*Asellus aquaticus*	isopod	-	6.75	96 hours	survival	LC50	333,000	Martin and Holdich 1986	included	Member of class Malocostra
manganese	manganese chloride	*Oncorhynchus mykiss*	rainbow trout	eggs	7.4	28 days	survival	LC1	21.5	Birge 1978	excluded	endpoint
manganese	manganese sulphate	*Daphnia magna*	water flea	-	8.37	28 days	reproduction	NOEC	<1,100	Kimball 1978 (Test 5)	excluded	MATC used instead
manganese	manganese sulphate	*Daphnia magna*	water flea	-	8.37	28 days	reproduction	LOEC	1,100	Kimball 1978 (Test 5)	excluded	MATC used instead
manganese	manganese sulphate	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	length	NOEC	1,270	Kimball 1978 (Test 3)	excluded	MATC used instead
manganese	manganese sulphate	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	weight	NOEC	1,270	Kimball 1978 (Test 4)	excluded	MATC used instead
manganese	manganese sulphate	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	length	LOEC	2,480	Kimball 1978 (Test 3)	excluded	MATC used instead
manganese	manganese sulphate	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	weight	LOEC	2,480	Kimball 1978 (Test 4)	excluded	MATC used instead
manganese	manganese sulphate	*Daphnia magna*	water flea	2 weeks old adults	8.36	7 days	reproduction	NOEC	3,900	Kimball 1978 (Test 1)	excluded	MATC used instead
manganese	manganese chloride	*Daphnia magna*	water flea	0 to 24 hours old	7.74	21 days	reproduction	EC50	5,200	Biesinger and Christensen 1972	excluded	EC16 chosen over EC50
manganese	manganese sulphate	*Daphnia magna*	water flea	2 weeks old adults	8.36	7 days	reproduction	LOEC	7,700	Kimball 1978 (Test 1)	excluded	MATC used instead
manganese	manganese sulphate	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	survival	NOEC	9,990	Kimball 1978 (Test 2)	excluded	MATC used instead
manganese	manganese sulphate	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.22	28 days	survival	LOEC	19,690	Kimball 1978 (Test 2)	excluded	MATC used instead

µg/L = micrograms per litre;- = Not available; < = less than; MATC = maximum allowable toxicant concentration; LC = lethal concentration; EC = effects concentration; NOEC = no observed effects concentration; LOEC = lowest observed effects concentration.

Table 8.IV.1-7 Summary of Chronic Toxicity Data Available for Strontium

Chemical Species	Test Species	Common Name	Life Stage	pH	Hardness (mg/L as $CaCO_3$)	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/Excluded	Reason
strontium chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	-	28 days	survival	LC10	49	Birge et al. 1979	included	-
strontium chloride	*Oncorhynchus mykiss*	rainbow trout	eggs	7.4	-	28 days	survival	LC50	200	Birge 1978	included	-
strontium	*Hyalella azteca*	amphipod	juveniles	7.4	18	7 days	survival	NOEC	315	Borgmann et al. 2005	included	-
strontium	*Hyalella azteca*	amphipod	juveniles	8.2	124	7 days	survival	NOEC	1000	Borgmann et al. 2005	included	-
strontium chloride	*Ceriodaphnia dubia*	water flea	juveniles	-	-	6 days	reproduction	IC25	34,000	Pacholski 2009	included	-
strontium chloride	*Daphnia magna*	water flea	12hours +/- 12 hours old	7.74	-	21 days	reproduction	EC16	42,000	Biesinger and Christensen 1972	included	-
strontium chloride	*Daphnia magna*	water flea	<24 hours old	-	-	21 days	reproduction	IC25	49,000	Pacholski 2009	included	-
strontium chloride	*Pseudokirchneriella subcapitata*	green algae	7 days	-	-	72 hours	growth	IC25	53,000	Pacholski 2009	included	-
strontium chloride	*Daphnia magna*	water flea	12hours +/- 12 hours old	7.74	-	21 days	survival	LC50	86,000	Biesinger and Christensen 1972	included	-
strontium chloride	*Daphnia magna*	water flea	<24 hours old	-	-	21 days	survival	LC50	122,000	Pacholski 2009	included	-
strontium chloride	*Ceriodaphnia dubia*	water flea	juveniles	-	-	6 days	survival	LC50	206,000	Pacholski 2009	included	-
strontium chloride	*Tubifex tubifex*	annelid	-	7.6	-	96 hours	immobilization	EC50	240,800	Khangarot 1991	included	-
strontium chloride	*Oncorhynchus mykiss*	rainbow trout	fry	-	-	21 days	survival	LC50	286,000	Pacholski 2009	included	-
strontium chloride	*Pimephales promelas*	fathead minnow	<24 hours old	-	-	7 days	growth	IC25	319,000	Pacholski 2009	included	-
strontium chloride	*Pimephales promelas*	fathead minnow	<24 hours old	-	-	7 days	survival	LC50	354,000	Pacholski 2009	included	-
strontium nitrate	*Caenorhabditis elegans*	nematode	young adult (3 to 4 days old)	-	-	4 days	survival	LC50	465,000	Williams and Dusenbury 1990	included	-
strontium chloride	*Gastrophryne carolinensis*	narrow-mouthed toad	eggs	7.4	-	7 days	survival	LC1	2.1	Birge 1978	excluded	non-resident species; endpoint
strontium chloride	*Salmo gairdneri*	rainbow trout	eggs	7.4	-	28 days	survival	LC1	6	Birge 1978	excluded	LC50 chosen over LC1
strontium chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	-	28 days	survival	LC1	13	Birge et al. 1979	excluded	LC10 chosen over LC1
strontium chloride	*Carassius auratus*	goldfish	eggs	7.4	-	7 days	survival	LC1	45.3	Birge 1978	excluded	non-resident species; endpoint
strontium chloride	*Gastrophryne carolinensis*	narrow-mouthed toad	eggs	7.4	-	7 days	survival	LC50	160	Birge 1978	excluded	non-resident species
strontium chloride	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	-	28 days	survival	LC50	250	Birge et al. 1979	excluded	LC10 chosen over LC50
atomic absorption standards	*Hyalella azteca*	amphipod	juveniles	8.2	124	7 days	survival	LC50	>1000	Borgmann et al. 2005	excluded	NOEC chosen over LC50
atomic absorption standards	*Hyalella azteca*	amphipod	juveniles	7.4	18	7 days	survival	LC50	>3150	Borgmann et al. 2005	excluded	NOEC chosen over LC50
strontium chloride	*Carassius auratus*	goldfish	eggs	7.4	-	7 days	survival	LC50	8,580	Birge 1978	excluded	non-resident species
strontium chloride	*Daphnia magna*	water flea	12hours +/- 12hours old	7.74	-	21 days	reproduction	EC50	60,000	Biesinger and Christensen 1972	excluded	EC16 chosen over EC50

µg/L = micrograms per litre;- = Not available; < = less than; MATC = maximum allowable toxicant concentration; LC = lethal concentration; EC = effects concentration; NOEC = no observed effects concentration; LOEC = lowest observed effects concentration.

Table 8.IV.1-8 Summary of Chronic Toxicity Data Available for Vanadium

Chemical	Chemical Species	Test Species	Common Name	Life Stage	pH	Duration	Biological Measurement	End Point	Concentration (µg/L)	Citation	Included/Excluded	Reason
vanadium	vanadium pentoxide	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC10	33.8	Birge et al. 1979	included	-
vanadium	vanadium pentoxide	*Oncorhynchus mykiss*	rainbow trout	eggs	7.4	28 days	survival	LC50	160	Birge 1978	included	-
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	length	MATC	170	Kimball 1978	included	-
vanadium	vanadium pentoxide	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC50	170	Birge et al. 1979	included	-
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	weight	MATC	339	Kimball 1978 (Test 2)	included	-
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	survival	NOEC	480	Kimball 1978	included	-
vanadium	vanadium pentoxide	*Daphnia magna*	water flea	2 weeks old adults	8.34	7 days	reproduction	MATC	707	Kimball 1978 (Test 1)	included	-
vanadium	vanadium pentoxide	*Daphnia magna*	water flea	2 weeks old adults	8.34	7 days	survival	LC50	790	Kimball 1978	included	-
vanadium	vanadium pentoxide	*Daphnia magna*	water flea	-	8.46	28 days	survival	LC50	>940	Kimball 1978	included	-
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	8 weeks old	8.07	192 hours	survival	LC50	1,060	Kimball 1978	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	7.7	7 days	survival	LC50	1,900	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	8.8	7 days	survival	LC50	2,100	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	6.6	7 days	survival	LC50	2,400	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	7.7	7 days	survival	LC50	2,500	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	6.61	7 days	survival	LC50	3,300	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	7.7	7 days	survival	LC50	3,400	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	8.78	7 days	survival	LC50	4,100	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	6.66	7 days	survival	LC50	4,300	Stendahl and Sprague 1982	included	-
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	8.75	7 days	survival	LC50	4,400	Stendahl and Sprague 1982	included	-
vanadium	vanadium pentoxide	*Oncorhynchus mykiss*	rainbow trout	eggs	7.4	28 days	survival	LC1	6.9	Birge 1978	excluded	endpoint
vanadium	vanadium pentoxide	*Oncorhynchus mykiss*	rainbow trout	embryo-larval	6.9 to 7.8	28 days	survival	LC1	9	Birge et al. 1979	excluded	endpoint
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	length	NOEC	120	Kimball 1978	excluded	MATC used instead
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	length	LOEC	240	Kimball 1978	excluded	MATC used instead
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	weight	NOEC	240	Kimball 1978 (Test 2)	excluded	MATC used instead
vanadium	vanadium pentoxide	*Pimephales promelas*	fathead minnow	16 to 40 hours old eggs	8.12	28 days	weight	LOEC	480	Kimball 1978 (Test 2)	excluded	MATC used instead
vanadium	vanadium pentoxide	*Daphnia magna*	water flea	2 weeks old adults	8.34	7 days	reproduction	NOEC	500	Kimball 1978 (Test 1)	excluded	MATC used instead
vanadium	vanadium pentoxide	*Daphnia magna*	water flea	-	8.46	28 days	reproduction	NOEC	>940	Kimball 1978	excluded	LC50 chosen over NOEC
vanadium	vanadium pentoxide	*Daphnia magna*	water flea	2 weeks old adults	8.34	7 days	reproduction	LOEC	1,000	Kimball 1978 (Test 1)	excluded	MATC used instead
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	5.51	7 days	survival	LC50	2,500	Stendahl and Sprague 1982	excluded	low pH
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	5.51	7 days	survival	LC50	5,100	Stendahl and Sprague 1982	excluded	low pH
vanadium	-	*Oncorhynchus mykiss*	rainbow trout	-	5.5	7 days	mortality	LC50	6,000	Stendahl and Sprague 1982	excluded	low pH

µg/L = micrograms per litre;- = Not available; < = less than; MATC = maximum allowable toxicant concentration; LC = lethal concentration; EC = effects concentration; NOEC = no observed effects concentration; LOEC = lowest observed effects concentration.

Dissolved and Total Metals (Kennady Lake - Area 8) (continued)