Approach for Developing Water Quality Goals for United Keno Hill Mines

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EXECUTIVE SUMMARY

United Keno Hill Mines Limited and UKH Minerals Ltd. were the previous owners of the properties located on and around Galena Hill, Keno Hill and Sourdough Hill, collectively known as the Keno Hill Mining Property. Although the mine has not operated since 1989, abandoned adits (more than 44), buildings/structures, and waste dumps associated with the site represent sources of contaminants to the downstream watersheds. The most significant of these sources include the lime-treated discharge from the tailings pond system, Galkeno 900 Adit, Galkeno 300 Adit, Bellekeno 600 Adit, Silver King Adit and Valley Tailings. The influence from these sources is largely limited to the tributaries that drain the properties (Christal, Flat and Lightning creeks), although some influence on water and sediment quality can be measured further downstream in the South McQuesten River (Minnow 2008, 2009).

In June 2005, Alexco Resources Corp. was selected as the preferred purchaser of the UKHM assets. As required in the purchase agreement, Alexco formed a subsidiary company – Elsa Reclamation and Development Company Ltd. (ERDC), to own and manage the site. Another requirement of the purchase agreement is for ERDC to prepare and implement, to the satisfaction of the Governments, a Reclamation Plan to address historical mining liabilities on the UHKM claims. Funding for the development and implementation of the Closure Plan is primarily from the Government of Canada (represented by Indian and Northern Affairs Canada (INAC) with some cost sharing by ERDC.

Under the purchase agreement, ERDC is allowed to resume production at a historic mine by declaring it as a Production Unit. The terrestrial liability associated with historical mine operations within the Production Unit remains with the Government of Canada, however, ERDC becomes responsible for water related liabilities in addition to any new terrestrial liabilities associated with the redevelopment of mine operations within the Production Unit. Alexco Resources operates the Bellekeno Mine and is responsible for the BK625 treatment facility and new terrestrial liabilities associated with Bellekeno operations.

One of the mandates of ERDC is to develop a Reclamation Plan for the “Existing State of the Mine” such that historical mining liabilities may be addressed and future environmental conditions anticipated. ERDC is currently in the process of developing this reclamation plan.

As part of the development and implementation of a closure plan, EDRC, INAC, Yukon Government (YG), First Nations and other interested groups will need to establish criteria on which to evaluate closure conditions and set expectations for environmental performance within the downstream receiving environment. Based on a review of water quality data within the watersheds affected by historical UKHM operations, it is unlikely that concentrations of

key mine related contaminants (cadmium and zinc) will achieve any site specific water quality objective (SSWQO) developed through standard approaches (CCME 2003). Therefore, an alternative approach for setting water quality expectations should be considered for these historically affected areas.

EDRC retained Minnow Environmental Inc. to develop an approach to water quality goals and assessment in Christal and Flat creeks and the South McQuesten River. The approach provided herein is a conceptual level approach to water quality evaluation that needs to be considered by the various stakeholders associated with UKHM prior to proceeding with final objectives and goals for the various affected watercourses. This Framework will be reviewed by stakeholders (INAC, First Nations and YG) to arrive at final water quality objectives for the historic properties prior to the selection of closure options. Ultimately, specific details of an approved approach to water quality evaluation will need to be incorporated into future water license requirements.

Recognizing that the UKHM receiving environment has been effected over many years and decades by various mining operations, the objective of this study was to develop an approach to assessing water quality downstream of UKHM that would serve to protect existing biota within the immediate receiving environment (Flat and Christal creeks) and provide for no further degradation of the South McQuesten River relative to upstream conditions. In order to achieve this objective, water quality data was reviewed relative to the toxicological thresholds in the proposed Canadian Water Quality Guidelines (CWQG; Environment Canada 2009a, b), and upstream or regional background conditions.

South McQuesten River

In mid 2007, it was noted that concentrations of various metals including cadmium and zinc had increased upstream of UKHM on the South McQuesten River (KV-1). Further examination found that concentrations of cadmium and zinc have been above both the existing and proposed future CWQG in the South McQuesten River since mid-2006. Furthermore, cadmium and zinc concentrations showed an increasing trend both upstream of UKHM at KV-1 and downstream at KV-4 and KV-5 between 2006 and 2009. Comparison of the slopes of these increases determined that the concentrations of cadmium and zinc are increasing at the same rate downstream (KV-4 and KV-5) as upstream (KV-1) indicating that the source of the increase in water concentrations in the South McQuesten River is upstream of UKHM.

When background concentrations exceed a CWQG, a statistic describing the upper range of background concentrations (e.g. 95th percentile) can be used as a SSQWO (CCME 2003).

However, it is uncertain whether or for how long concentrations upstream of UKHM (KV-1) will continue to increase, so it is not currently possible to establish a single numerical value that represents the upper limit of upstream/background conditions. This means that an alternative approach must be considered for evaluating the influence of UKHM in downstream areas of the South McQuesten (KV-4, KV-5). Therefore, it is recommended that downstream water quality objectives for cadmium and zinc and possibly other contaminants be linked to concentrations upstream of UKHM (i.e., KV-1) such that no further degradation of water quality occurs downstream of UKHM (KV-4 and KV-5) relative to upstream conditions.

Flat Creek and Christal Creek

Over the past twenty years concentrations of cadmium and zinc have been elevated well above the CWQG (i.e., mean values more than ten times the CWQG) in Flat Creek and Christal Creek (Minnow 2008). Since 2006, concentrations of both cadmium and zinc have been decreasing in both Flat Creek (KV-9) and Christal Creek (KV-7), and concentrations are now in the same range as those observed in the South McQuesten River. The improvement in water quality within the tributaries is likely associated with remedial measures implemented by EDRC starting in 2006 (e.g. clarifies at Galkeno 300 and water management and treatment at the Galkeno 900). While it is expected that concentrations will continue to decrease, they are not expected to achieve CWQG in the near future due to continued contributions from non-point sources. Therefore, alternative water quality goals need to be developed for Flat and Christal creeks.

Mean cadmium and zinc concentrations (2009) in both Flat and Christal Creeks have been greater than proposed long-term term exposure guidelines and also, in the case of zinc, maximum concentrations are above the proposed short-term exposure guideline, suggesting potential for effects to biota within these watercourses.

It is recommended that water quality goals for Flat and Christal creeks should aim to prevent further degradation of water quality such that the diversity and abundance of the existing resident biota is protected. Routine monitoring conducted as part of the Long-Term Aquatic Monitoring Program (Minnow 2011) should be assessed annually to ensure conditions are stable or improved relative to previous conditions and background and the effects of these goals should be verified through routine biological monitoring. It is expect that as conditions improve and stabilize the magnitude and frequency will be reduced.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background

United Keno Hill Mines Limited and UKH Minerals Ltd. were the previous owners of the properties located on and around Galena Hill, Keno Hill and Sourdough Hill, collectively known as the Keno Hill Mining Property. For the purposes of this report these mining areas are referred to as the United Keno Hill Mines (UKHM). The UKHM complex is located in north-central Yukon Territory (Figure 1.1) and is comprised of approximately 827 mineral claims that cover an area of approximately 15,000 ha (about 29 km long and 8 km wide). Although the mine has not operated since 1989, there are abandoned adits (more than 44), buildings/structures, and waste dumps associated with the UKHM Complex that represent sources of contaminants to the downstream watersheds. The most significant of these sources include the lime-treated discharge from the tailings pond system, Galkeno 900 Adit, Galkeno 300 Adit, Bellekeno 600 Adit, Silver King Adit and Valley Tailings (Figure 1.2; Burns 2008). The influence from these sources is largely limited to the tributaries that drain the properties (Christal, Flat and Lightning creeks), although some influence on water and sediment quality can be measured further downstream in the South McQuesten River (Minnow 2008, 2009). In addition to the historical mining activities, the area is currently host to a number of placer mining operations which cause extensive alteration of the watercourses and impacts to habitat and water quality downstream (Dan Cornett, Access Consulting, pers. comm.; Pentz and Kostaschuk, 1999).

In June 2005, Alexco Resources Corp. was selected as the preferred purchaser of the UKHM assets. As required in the purchase agreement, Alexco formed a subsidiary company – Elsa Reclamation and Development Company Ltd. (ERDC), to own and manage the site. Another requirement of the purchase agreement was for ERDC to prepare and implement, to the satisfaction of the Governments, a Closure Plan to address historical mining liabilities on the UHKM claims. Funding for the development and implementation of the Closure Plan is primarily from the Government of Canada (represented by Indian and Northern Affairs Canada (INAC) with some shared costs by ERDC.

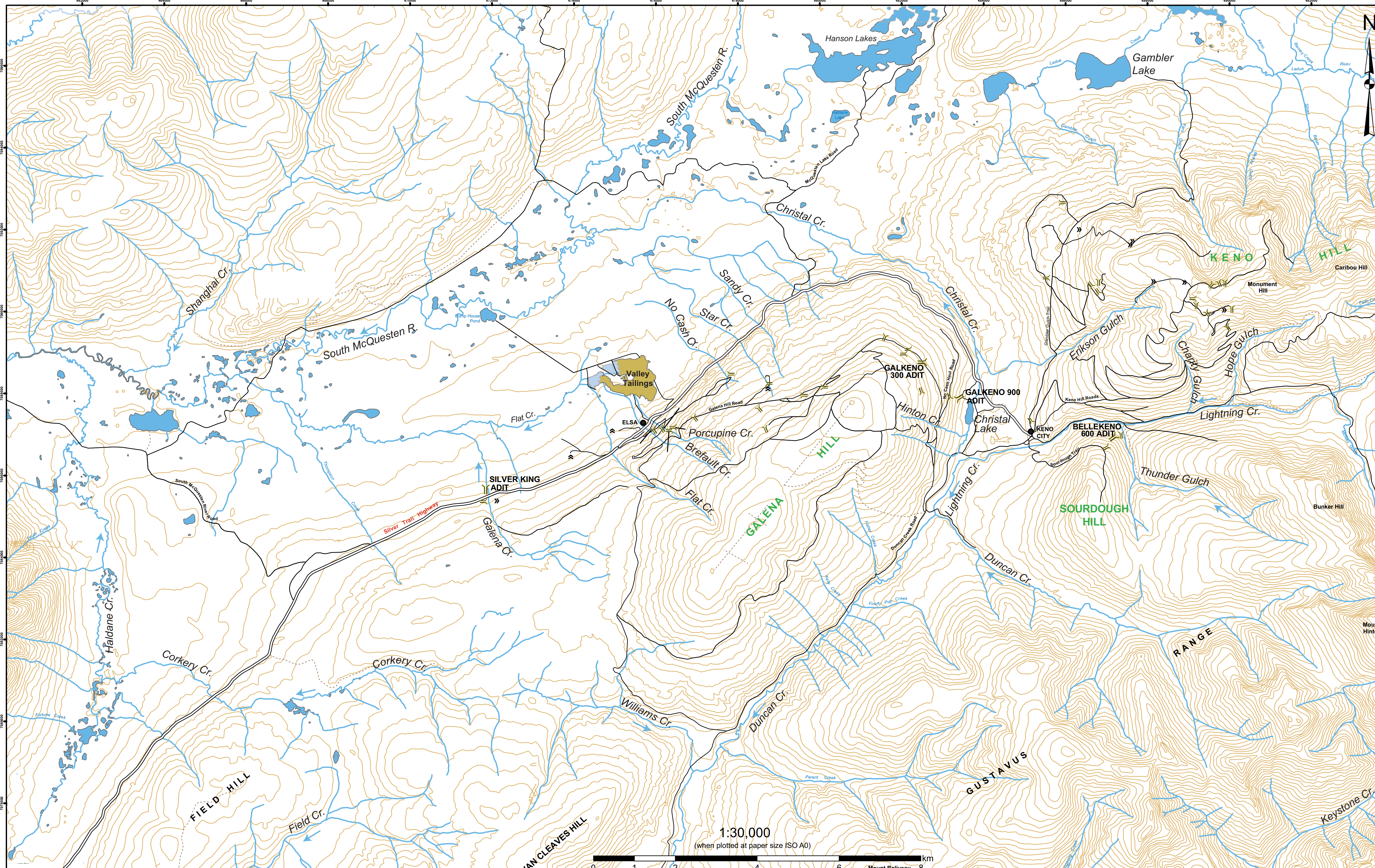
Under the purchase agreement, ERDC is allowed to resume production at a historic mine by declaring it as a Production Unit. The terrestrial liability associated with historical mine operations within the Production Unit remains with the Government of Canada, however, ERDC becomes responsible for water related liabilities in addition to any new terrestrial

Figure 1.1

Location of United Keno Hill Mines within the Yukon Territory.

Ref: 2272
Date: April 2011

Source: Access Consulting Group



Legend

Mine Working
- Adit
- Shaft (to surface - connection to underground not determined)
- Valley Tailings
- Pit

Topography
- Town
- Silver Trail
- Secondary and Limited-use roads
- Trail
- Watercourse
- Waterbody
- Flow Direction

ALEXCO ERDC

Figure 1.2

minnow environmental inc.

United Keno Hill Mines, Mine Workings and Surrounding Watercourses

Ref: 2272
Date: April 2011

Source: Access Consulting Group

liabilities associated with the redevelopment of mine operations within the Production Unit. Alexco Resources operates the Bellekeno Mine and is responsible for the BK625 treatment facility and new terrestrial liabilities associated with Bellekeno operations. Regardless of the current and potential future production units, INAC has, and will continue to have, significant involvement in the development of the Closure Plan for the UKHM property.

As part of the development and implementation of a closure plan, EDRC, INAC, YG, First Nations and other interested groups will need to establish criteria on which to evaluate closure conditions and set expectations for environmental performance within the downstream receiving environment. A review of water quality at UKHM identified cadmium and zinc as the primary contaminants of concern (Minnow 2008). The concentrations of these substances were substantially elevated in the tributaries of the South McQuesten River (Flat Creek and Christal Creek) but were generally within Canadian Water Quality Guidelines (CWQG; CCME, 1999) within the South McQuesten River downstream of UKHM. Therefore it was expected that the CWQG could be used as assessment values for the South McQuesten River. However, water quality within the tributaries (Flat and Christal creeks) is not expected to achieve the CWQG in the near future. Furthermore, it is unlikely that concentrations of these elements (cadmium and zinc) would achieve a site specific water quality objective (SSWQO) developed through standard approaches (CCME 2003). Therefore, an alternative approach for setting water quality expectations should be considered for these historically affected areas.

EDRC retained Minnow Environmental Inc. to develop an approach to water quality goals and assessment in Christal and Flat creeks and the South McQuesten River[1]. This report summarizes our assessment of water quality conditions in both the tributaries and South McQuesten River and provides a recommended approach for future water quality assessment downstream of UKHM. The approach provided herein is a conceptual level approach to water quality evaluation that needs to be considered by the various stakeholders associated with UKHM prior to proceeding with final objectives and goals for the various affected watercourses. This Framework will be reviewed by stakeholders (INAC, First Nations and YG) to arrive at final water quality objectives for the historic properties prior to the selection of closure options. Ultimately, specific details of an

[1] Lightning Creek was not considered in this assessment as the existing data base indicated that concentrations within Lightning Creek were close to the CWQG. However, the data base for the creek was limited with respect to the extent of data and appropriate method detection limits. As additional monitoring data is obtained, the status of Lightning Creek with respect to the need for water quality objectives should be reassessed.

approved approach to water quality evaluation will need to be incorporated into future water license requirements.

1.2 Project Objectives and Approach

As part of a previous water quality assessment (Minnow 2008), cadmium and zinc were identified as the primary contaminants of concern (COCs) related to the UKHM complex because they are the substances that are most elevated relative to guidelines and water quality in undisturbed areas. While a number of other substances were identified as possible COCs, these have yet to be confirmed[2]. However, management of cadmium and zinc is expected to control other mine related substances. Thus, an approach to water quality goals is only recommended for cadmium and zinc at this time. Once sufficient information is compiled on the possible COCs, the need for water quality goals or objectives for these substances should be revisited.

Recognizing that the UKHM receiving environment has been effected over many years and decades by various mining operations, the objective of this study was to develop an approach to assessing water quality downstream of the historic UKHM complex that would:

- serve to protect the resident biota (no decline relative to current species diversity) and prevent further degradation of water quality with in the immediate receiving environment (Flat and Christal creeks) and
- provide for no further degradation in the South McQuesten River relative to upstream conditions.

In order to achieve this objective, recent water quality was reviewed relative to the toxicological thresholds in the proposed CWQG (Environment Canada 2009a, b), and upstream or regional background conditions.

1.3 Document Organization

Section 2.0 presents the methods used in the evaluation of data for this project. Section 3.0 summarizes the current water quality in the South McQuesten River and its tributaries, the toxicity data for cadmium and zinc presented in the scientific literature, and compares these values to recent water quality concentrations for aquatic environments downstream

[2] EDRC has initiated a more robust water quality monitoring program in order to compile the data necessary to assess possible COCs. When two years of monitoring data at appropriate method detection limits has been compiled, the final list of mine COCs and monitoring parameters can be established.

of UKHM. Conclusions are presented in Section 4.0. References cited throughout the document are presented in Section 5.0

2.0 METHODS

2.1 Evaluation of Recent Water Quality

Aqueous cadmium and zinc concentrations were assessed for routine monitoring stations in Christal Creek (KV-7) and Flat Creek (KV-9), as well as in the South McQuesten River both upstream (KV-1) and downstream of UKHM inputs (KV-4 and KV-5) (Figure 2.1; Appendix A). The mine exposed stations selected delimit mine influence within each water course assessed. Concentrations of these substances were plotted over time (2006 to 2009) and relative to water quality guidelines. The current guidelines (CCME 1999) were initially used to evaluate past water quality data. However, new guidelines are in development for cadmium and zinc that incorporate the large number of studies published in the scientific literature since the original guidelines were developed and also involve a different method for guideline derivation (Environment Canada 2009 a, b). The proposed guidelines are therefore a better reflection of the state-of-the-science regarding aquatic effects of cadmium and zinc; however, they are still undergoing provincial agency review and then will need to be circulated for public comment prior to being adopted. Although this process may result in modification of the guideline values, any adjustments are expected to be minor, so the proposed guidelines were considered in the water quality evaluation for UKHM.

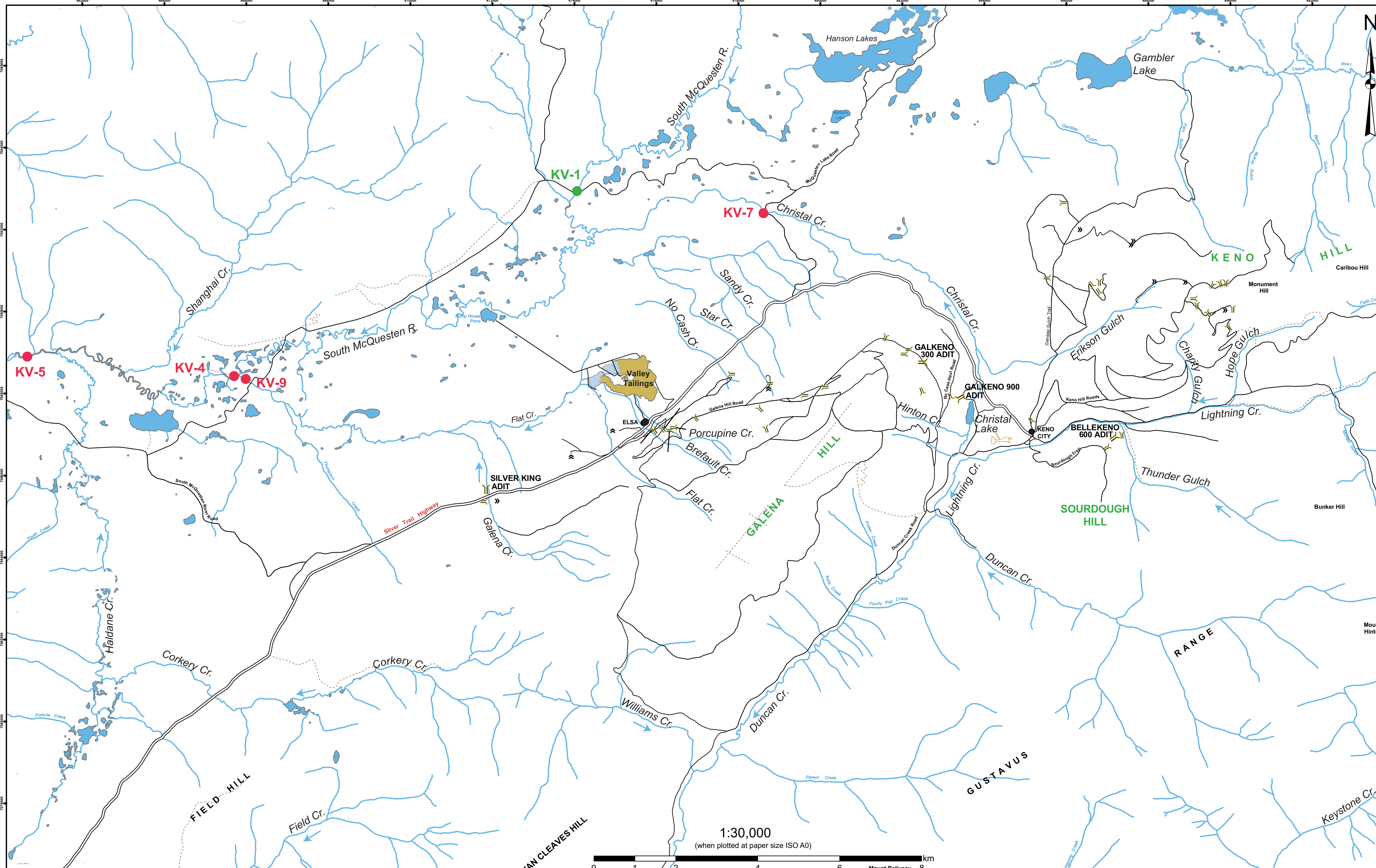
The existing CWQG for cadmium (CCME 1999) and proposed revised guidelines for both cadmium and zinc (Environment Canada 2009 a, b) depend on water hardness, because the toxicity of these substances declines as hardness increases. A hardness of 100 mg/L as $CaCO_3$ was selected as the basis for comparison in this evaluation, because water hardness downstream of the UKHM is rarely lower than this level (Appendix A) and the mean background concentration is also higher (i.e., 162 mg/L; Minnow 2008). Thus the water quality guidelines applied in this assessment were conservative in terms of flagging concentrations that might be of concern with respect to protection of aquatic biota in waters downstream of UKHM.

For stations where water quality trends were observed over time, slopes were plotted and statistically compared using analysis of covariance (ANCOVA) (SPSS 2003).

2.2 Assessment of Potential Impacts

2.2.1 Toxicity Data Sources and Organization

Recently-prepared toxicity data summaries for zinc and cadmium, along with copies of much of the source literature were obtained from Environment Canada's Guidelines and



Legend

Mine Working

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Topography

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Figure 2.1

minnow

Water Quality Monitoring Stations Assessed for Development of Water Quality Goals, United Keno Hill Mines

Ref: 2272
Date: April 2011

Source: Access Consulting Group

Standards Office in Gatineau Quebec, augmented by relevant scientific literature from Minnow's in-house files. The source literature was reviewed to verify the accuracy of the data sets provided and allow for clarification of test conditions. The reviews of source literature resulted in some minor modifications of the original data sets.

Raw data tables presented details of each toxicity test, including results of replicate exposures within studies, if available. The tabulated information included species common and scientific name, test duration, test endpoint, observed effect concentration, test conditions (e.g., hardness, pH, etc., if reported) and source (author, year). Toxicity test data were distinguished as short-term versus long-term exposures. Depending on the species and life-stage tested, short-term exposures were defined as less than one (algae), four (invertebrates and larval fish), or seven days (older fish), consistent with current Environment Canada protocols (Environment Canada 2008, 2009). Long-term exposure data were considered most relevant for assessing potential effects associated with chronic exposure to mine-related contaminants at UKHM so toxicity evaluations for cadmium and zinc focussed primarily on long-term exposure data.

2.2.2 Assessing Relative Species Sensitivities

The toxicities of cadmium and zinc are influenced by various water quality factors, of which the best characterized is hardness (Environment Canada 2009 a, b). In order to rank the relative sensitivities of different aquatic species to these contaminants, it was necessary to convert reported effect concentrations to common water hardness, thereby removing the influence of variable test conditions on relative species toxicity thresholds. A conservative hardness of 100 mg L^{-1} as $CaCO_3$ was selected as the basis for comparison, because water hardness downstream of the UKHM is rarely lower than this level. However, effects at other hardnesses were also evaluated (see below).

Hardness-toxicity relationships were first defined for individual species for which adequate data were available. This was done by examining the raw data to identify toxicity tests for which the hardness of the exposure water was reported and identifying species for which there were data for the same or similar endpoints over a range of exposure water hardness levels (>2-fold range), including at least one exposure with water hardness of at least 100 mg/L. For zinc, only tests conducted at pH ≥ 7.4 were included to minimize the variability associated with this potentially confounding factor (more data were available for a basic than neutral-acidic range of exposure pH). If there were replicate test results within a study for the same endpoint at the same or similar water hardness, geometric mean hardness and effect concentrations were computed before using the data to define the hardness-toxicity relationship for the substance.

The resulting data were then plotted for each species based on a regression of natural logarithm (Ln) of toxicant concentration as the dependent variable against Ln hardness as the independent variable. This yielded the species-specific slope for the hardness-toxicity relationship. For both substances (Cd, Zn), there were sufficient data to derive a slope for at least one plant/alga, invertebrate, and fish species.

For each contaminant, the slopes for the hardness-toxicity relationship were tested for differences among species and, if not different, the slopes were combined to generate an average slope. After consideration of the data and potential implications of applying different slopes for different species or groups of species, a decision was made to generate a combined slope (including short- and long-term exposure data). This recognized that the range of slopes for short- versus long-term exposure data overlapped, there were no differences in slope that could be confidently ascribed to particular species or group, and this approach would ensure better consistency with respect to data handling for both contaminants.

To assess relative species sensitivity, the lowest toxic effect concentration corresponding to an exposure hardness of 100 mg/L was identified for each study and species. For studies not including an exposure hardness of 100 mg/L, the toxic effect concentration for each study-species combination was adjusted to an exposure hardness of 100 mg/L based on the combined slope for the hardness-toxicity relationship. The lowest value for each species (at hardness of 100 mg/L) was then identified and used to rank all species in terms of relative sensitivity. In cases where there were both effect (e.g., EC10, IC25, maximum acceptable toxicant concentration [MATC], etc.) and no-effect (NOEC) endpoints reported, the lowest effect concentration was selected.

For species for which the original test hardness was reported, the same slope factors described above were also used to estimate toxicity at other water hardness values (than 100 mg/L). If test hardness was not reported, an adjustment could not be made and the same reported effect concentration for the species was assumed for all water hardnesses.

2.3 Assessment of Water Quality Impacts

Recent water concentrations of cadmium and zinc measured at key locations downstream from UKHM were compared to toxic threshold concentrations reported in the literature for different aquatic species (at a water hardness of 100 mg/L). This was done to identify species that may be adversely affected by current water quality and take this into account in setting future water quality goals.

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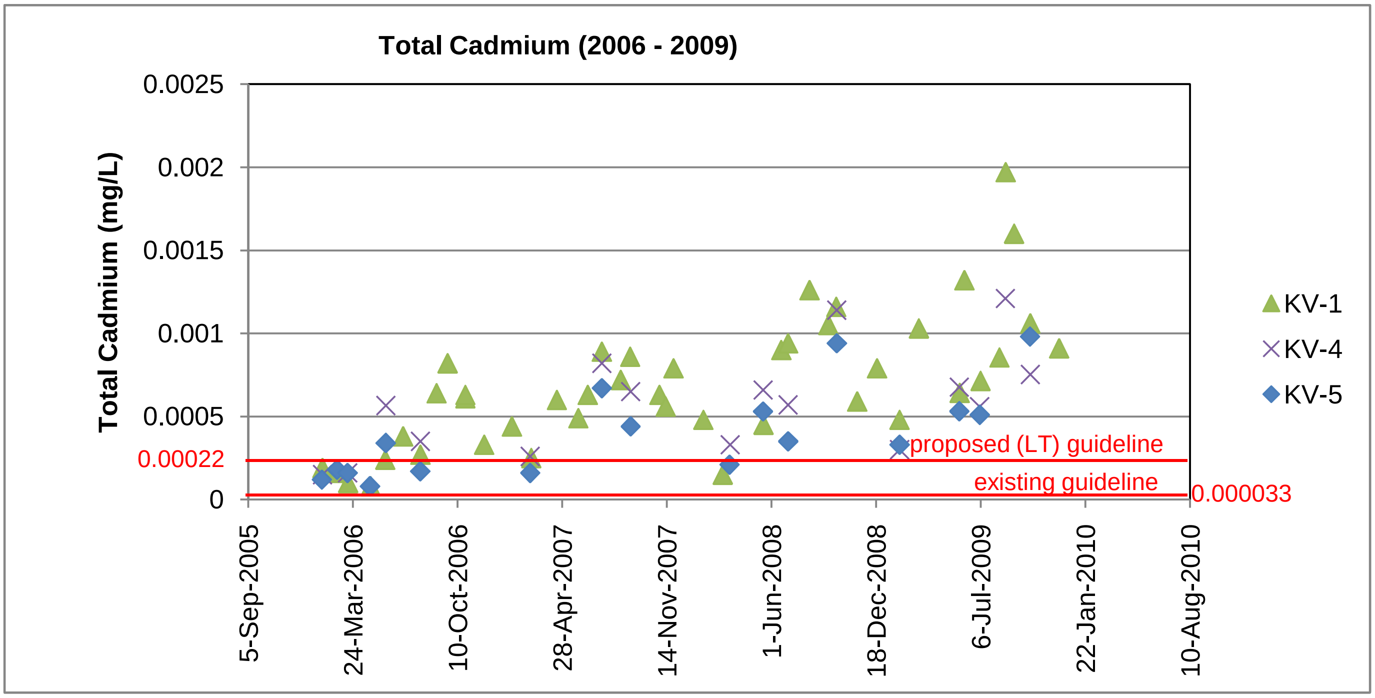
3.0 GOALS AND OBJECTIVES

3.1 South McQuesten River

3.1.1 Current Conditions

Prior to 2006, water concentrations of cadmium and zinc in the South McQuesten River downstream of UKHM were generally less than the existing CWQG (Minnow 2008). Therefore, it was expected that the CWQG could be used as benchmarks for assessment of future water quality and that site-specific water quality goals or objectives would not be required. However, in mid 2007, it was noted that concentrations of various metals including cadmium and zinc had increased upstream on the South McQuesten River at KV-1. Further examination of cadmium and zinc concentrations indicated that the concentrations have been above both the existing and proposed future CWQG both upstream and downstream of UKHM since mid-2006 (Figure 3.1). In addition, concentrations showed an increasing trend both upstream of UKHM at KV-1 and downstream at KV-4 and KV-5 between 2006 and 2009. Comparison of the slopes of these increases determined that the concentrations of cadmium and zinc are increasing at the same rate downstream (KV-4 and KV-5) as upstream (KV-1; Figure 3.2). Furthermore, mean zinc concentrations adjusted for date were significantly lower at stations downstream of the UKHM discharges (KV-4 and KV-5; $p<0.001$) than at upstream station KV-1 over the same period. Similarly, cadmium concentrations at KV-5 were significantly lower than at KV-1 ($p=0.001$), while mean cadmium concentrations at KV-4 and KV-1 were similar ($p=0.208$; Appendix Table A.2c). These results indicate that a source upstream of KV-1 was responsible for the increase in water concentrations in the South McQuesten River (KV-1, KV-4 and KV-5) and that UKHM is not causing a measurable increase in concentrations downstream of the site at KV-4 and KV-5.

When background concentrations exceed a CWQG, a statistic describing the upper range of background concentrations (e.g. 95th percentile) can be used as a site specific water quality objective (SSQWO; CCME 2003). However, it is uncertain whether or for how long concentrations upstream of UKHM (KV-1) will continue to increase, so it is not currently possible to establish a single numerical value that represents the upper limit of upstream background conditions. This means that an alternative approach must be considered for evaluating the influence of UKHM in downstream areas of the South McQuesten (KV-4, KV-5).



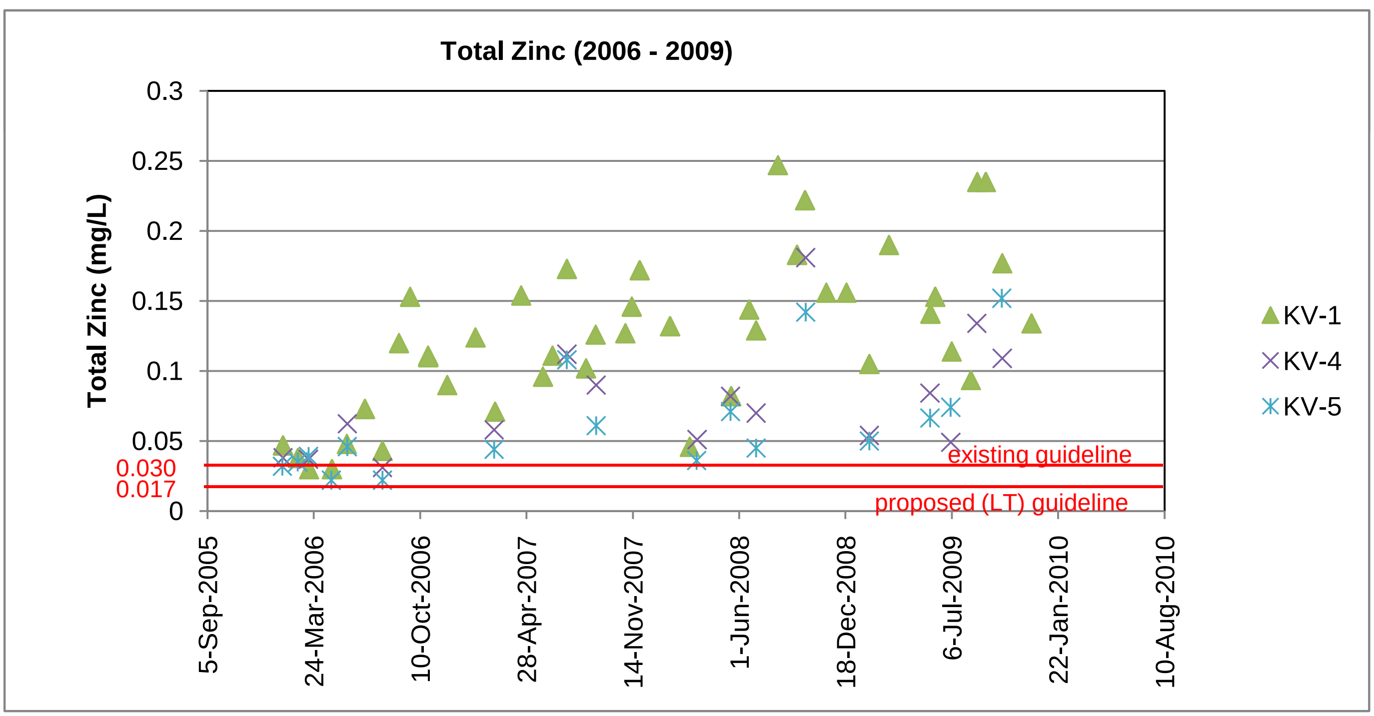
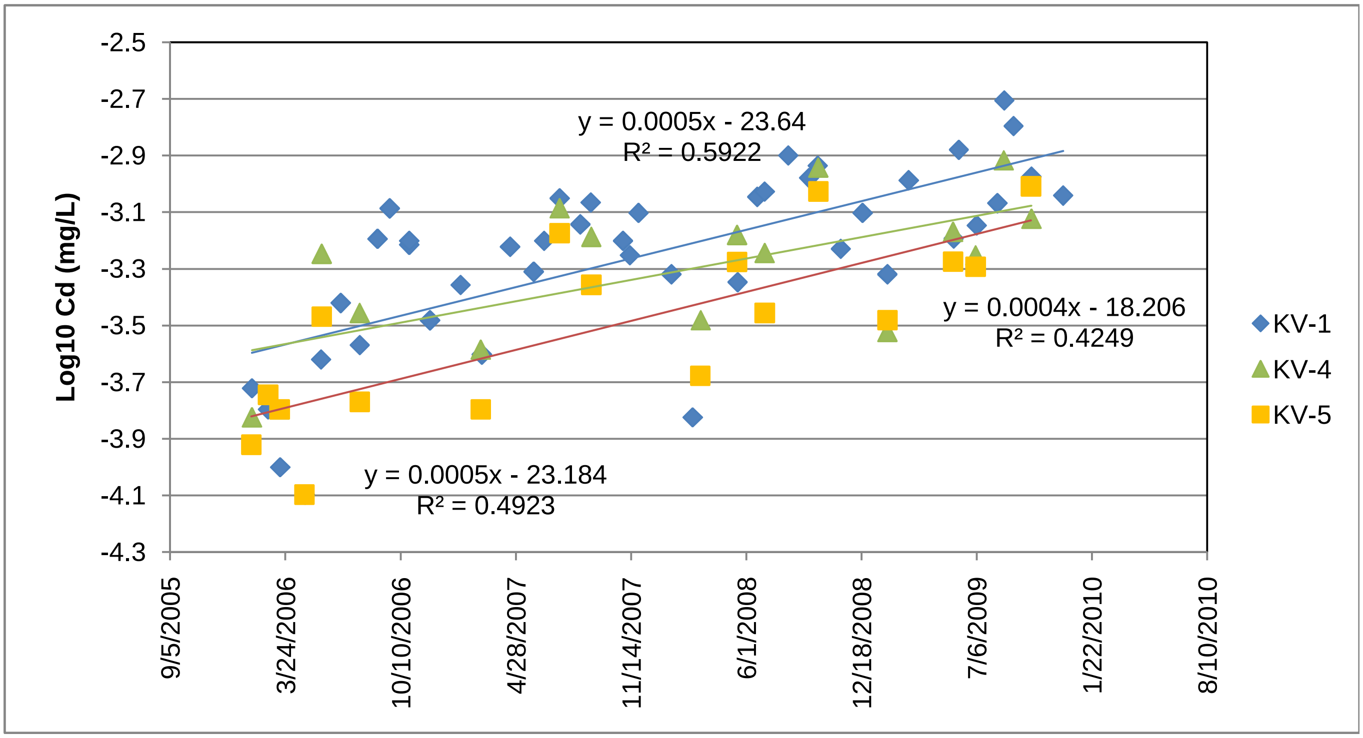


Figure 3.1: Water concentrations of total cadmium and zinc measured in the South McQuesten River at KV-1, KV-4 and KV-5 between 2006 and 2009 relative to existing (CCME 1999) and proposed long-term (LT) exposure guidelines based on a water hardness of 100 mg/L (Environment Canada 2009 a,b).



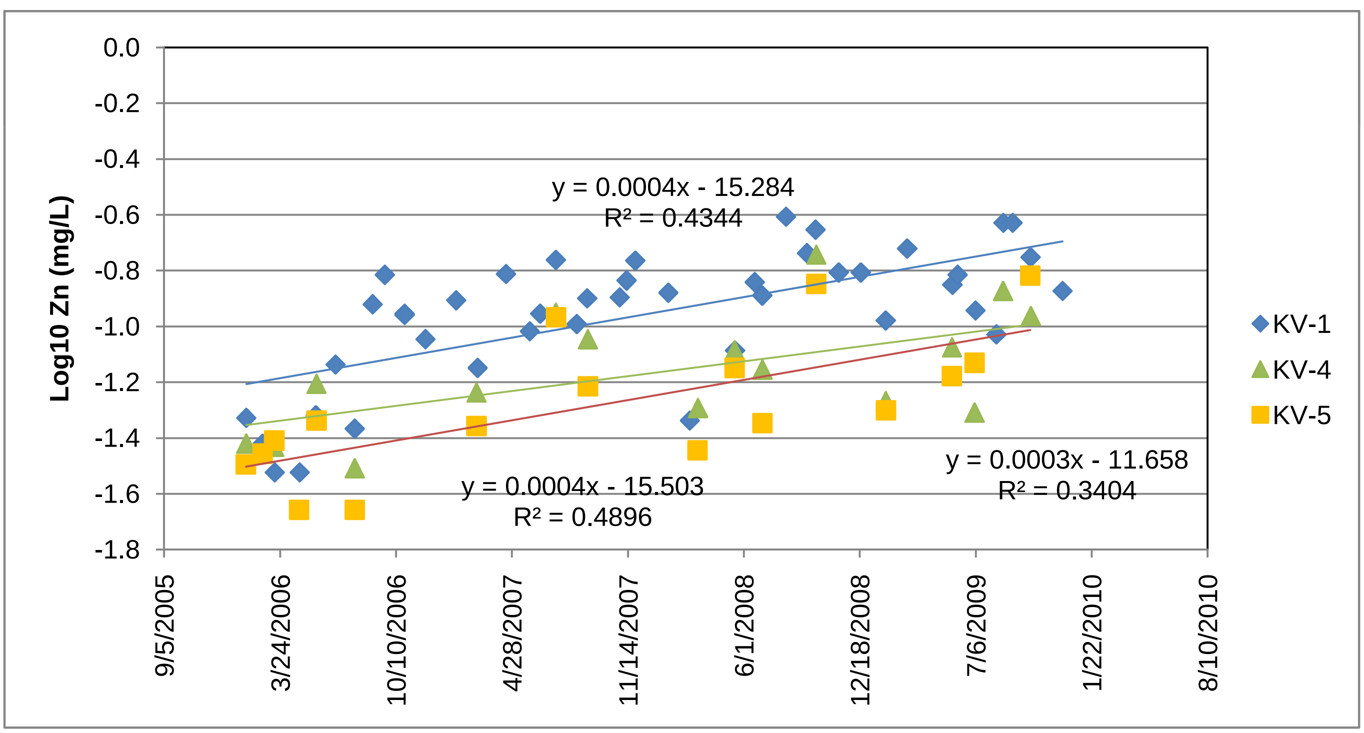


Figure 3.2: Comparison of water concentrations over time (slopes) at South McQuesten River stations KV-1, KV-4 and KV-5, 2006 to 2009. Slopes were not significantly different at p=0.05 (Appendix Table A.2).

3.1.2 Proposed Approach for Water Quality Assessment in the South McQuesten River

As noted above, concentrations of cadmium and zinc have been increasing downstream of UKHM as a result of increasing concentrations upstream. Until the concentrations upstream are reduced or stabilize, a single water quality criterion cannot reasonably be employed downstream in the South McQuesten River. Therefore, downstream water quality objectives for cadmium and zinc and possibly other contaminants should be linked to concentrations upstream of UKHM (i.e., KV-1) such that no further degradation of water quality occurs downstream of UKHM (KV-4 and KV-5) relative to upstream conditions. A possible approach to evaluating water quality within the South McQuesten River might include:

- An annual evaluation of monthly water samples collected at KV-1, KV-4 and KV-5, relative to all substances associated with UKHM, particularly cadmium and zinc.
- The mean annual concentrations of cadmium and zinc at KV-4 and KV-5 should not exceed those measured upstream at KV-1. Means should be statistically compared using ANOVA. An increase in mean cadmium and/or zinc that is not statistically significant should still be investigated to determine if it may be an early indicator of an increasing trend associated with historic UKHM inputs (e.g., perhaps examine trends in water quality monitoring data from upstream source areas based on both concentrations and loads).
- Water quality trends at all areas should be evaluated by a qualified professional at a frequency consistent with detailed watershed reporting as recommended in the Long-Term Aquatic Monitoring Program (LTAMP; Minnow 2011).
- The slope of downstream concentrations (KV-4 and KV-5) should be statistically compared to KV-1 (ANCOVA) to confirm that the rates of change downstream are equal to or less than that measured upstream.

3.2 Tributaries

3.2.1 Current Water Quality

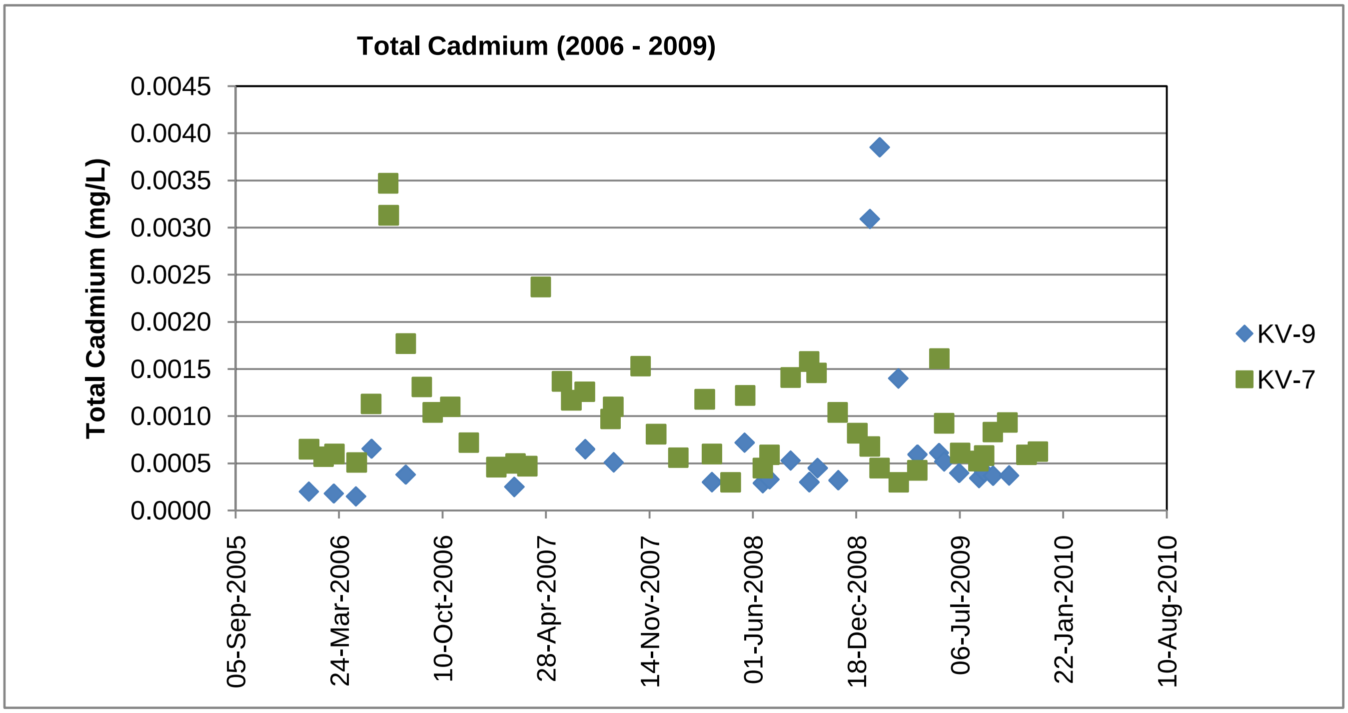
Lightning Creek was not considered in this assessment as the existing data base indicated that concentrations within Lightning Creek were close to the CWQG (CCME 1999). However, the data base for the creek was limited with respect to the extent of data and appropriate method detection limits. The status of Lightning Creek with respect to the need for water quality objectives should be reassessed when additional monitoring data is obtained and in light of proposed changes to the CCME cadmium and zinc guidelines (Environment Canada 2009a,b). In addition, there is extensive placer mining within the Lightning Creek and Duncan Creek watersheds and this will need to be taken into consideration as a potential contributor when an approach to water quality assessment is developed for Lightning Creek.

In Flat Creek and Christal Creek, concentrations of cadmium and zinc have historically been elevated well above the CWQG (i.e., mean values more than ten times the CWQG; Minnow 2008). Although closure and associated remediation measures are planned and/or underway, it is not possible to accurately predict future concentrations due to the number of sources and uncertainty of future loads from surface contamination within these catchments (i.e., remedial measures are aimed at addressing specific known sources but it is unclear to what extent total loadings can be expected to decrease).

Since 2006, concentrations of both cadmium and zinc have been decreasing in both Flat Creek (KV-9) and Christal Creek (KV-7; Figure 3.3), and concentrations are now in the same range of those observed in the South McQuesten River (Figure 3.4). The improvement in water quality within the tributaries is likely associated with remedial measures implemented by EDRC starting in 2006 (e.g. clarifies at Galkeno 300 and water management and treatment at the Galkeno 900). While it is expected that concentrations will continue to decrease, they are not expected to achieve CWQG in the near future due to continued contributions from non-point sources (e.g. disbursed tailings dust on surface soils). Therefore, alternative water quality goals need to be developed for these creeks. Mean cadmium and zinc concentrations (2009) in both Flat and Christal Creeks have been greater than proposed long-term term exposure guidelines and in the case of zinc, maximum concentrations are also above the proposed short-term exposure guideline, suggesting potential for effects to biota within these watercourses (Environment Canada 2009 a, b; Figure 3.5). Potential site-specific impacts are evaluated in more detail below.

3.2.2 Review of Toxicity Information

While concentrations are expected to remain above the long-term CWQG for the foreseeable future, the implications to resident and locally important biota is species-specific because effect concentrations vary widely between aquatic species and are dependent upon site specific water quality factors. Also, the CWQG presented are based on a conservative water hardness of 100 mg/L, which is lower than the hardnesses observed in Flat Creek and Christal Creek during the past three years (i.e., 80% of values > 200 mg/L and mean values ≥ 300 mg/L) (Figure 3.4; Appendix Table A.1).



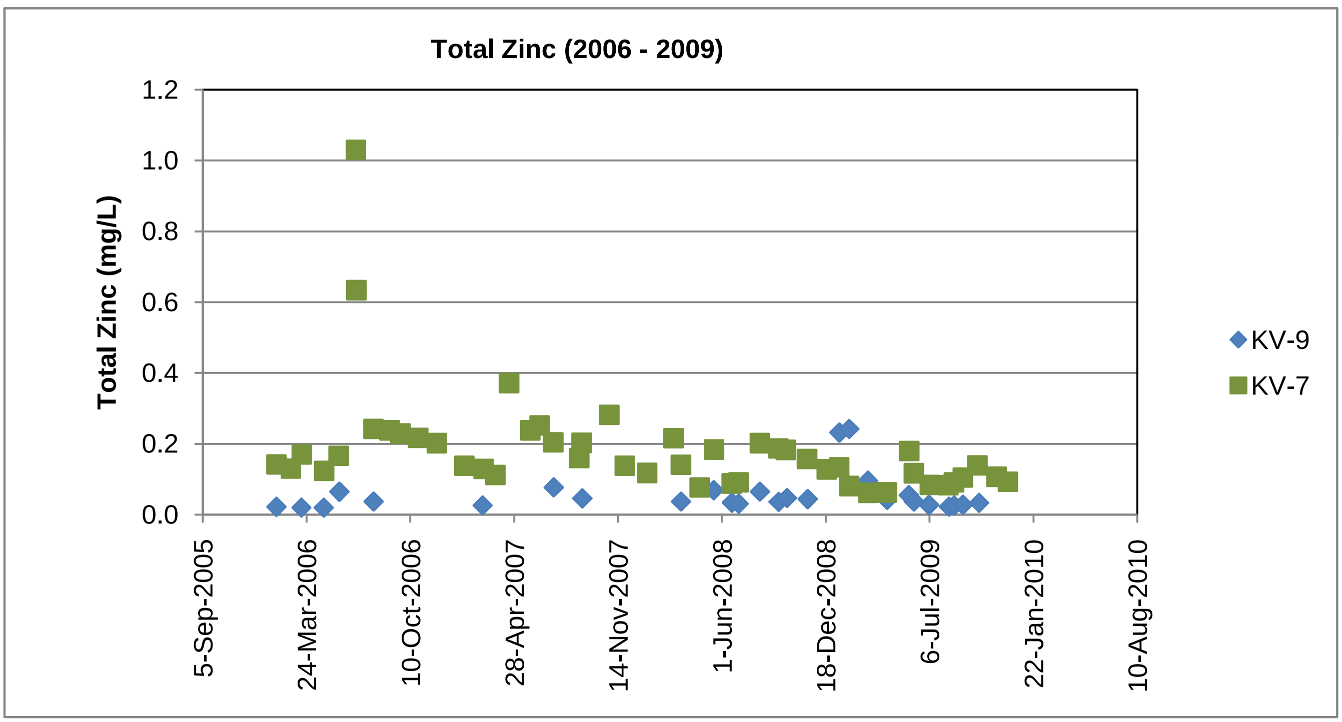
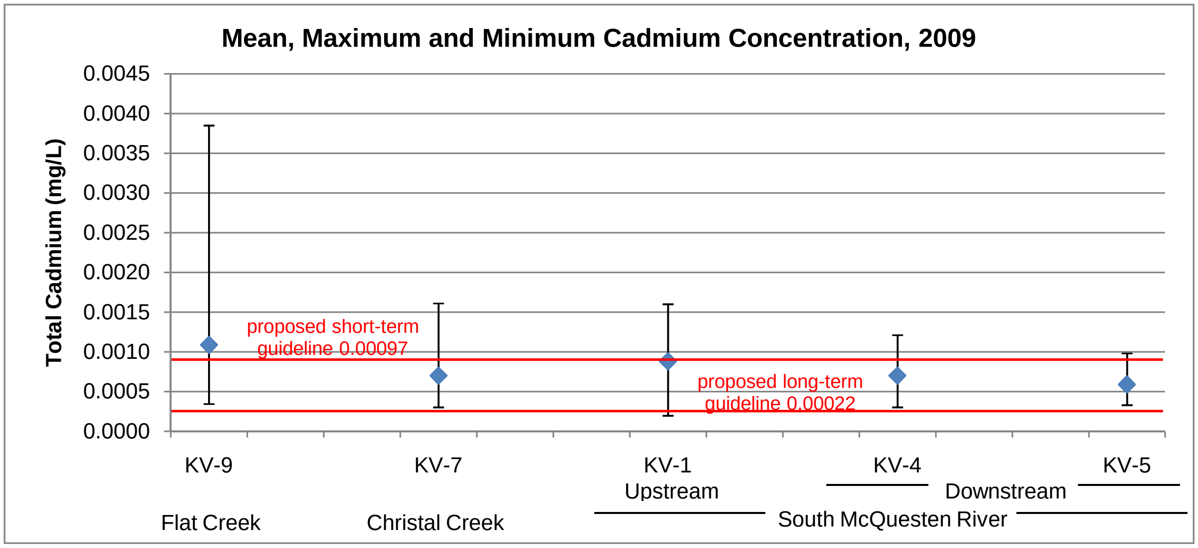
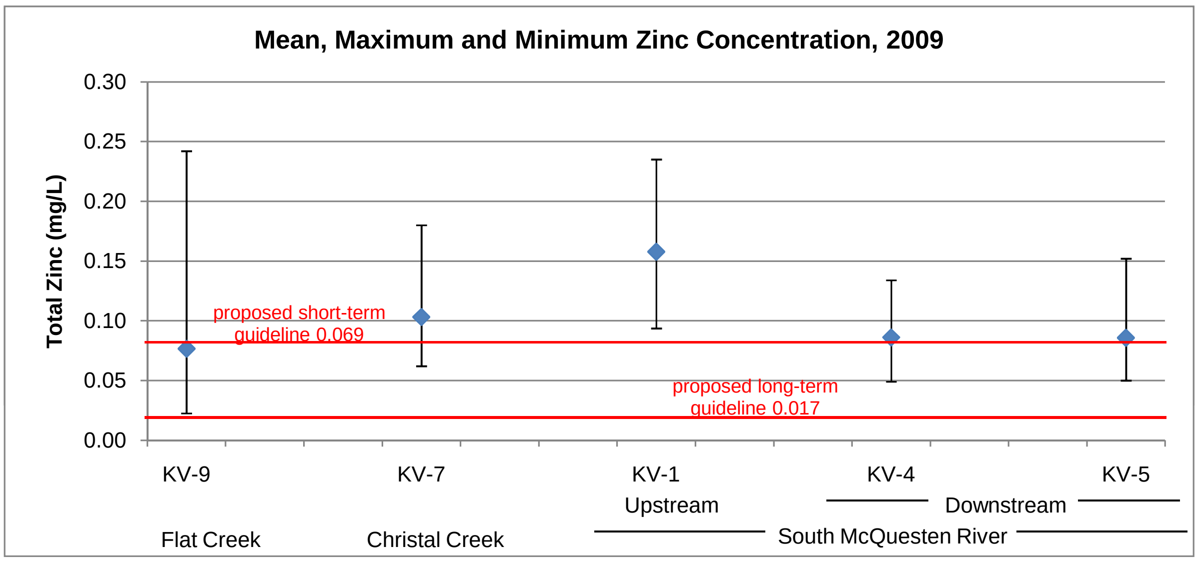


Figure 3.3: Concentrations of total cadmium and zinc measured at Flat Creek (KV-9) and Christal Creek (KV-7) between 2006 and 2009.





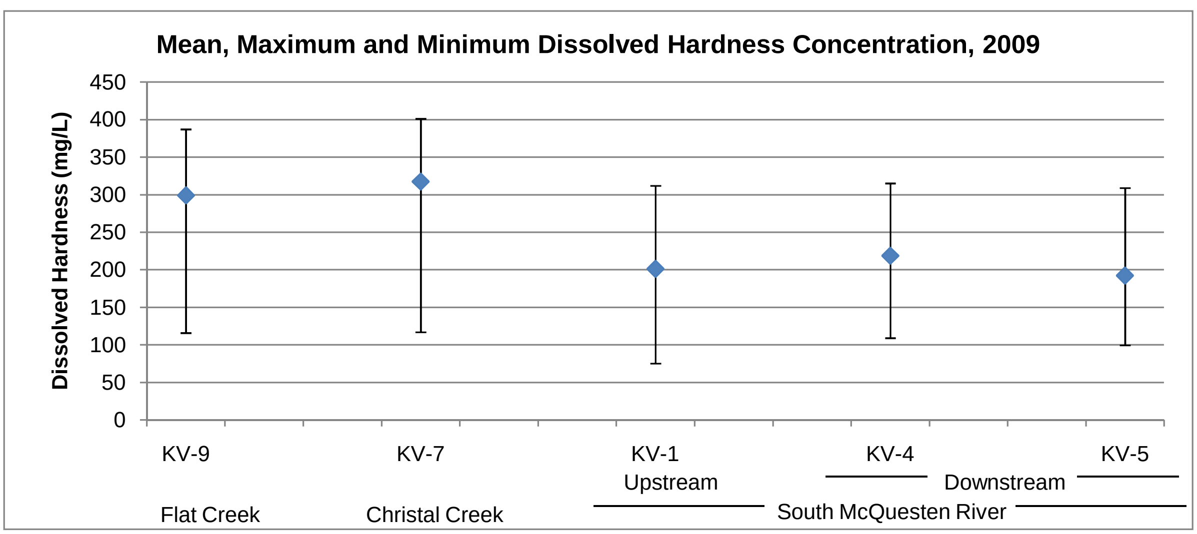
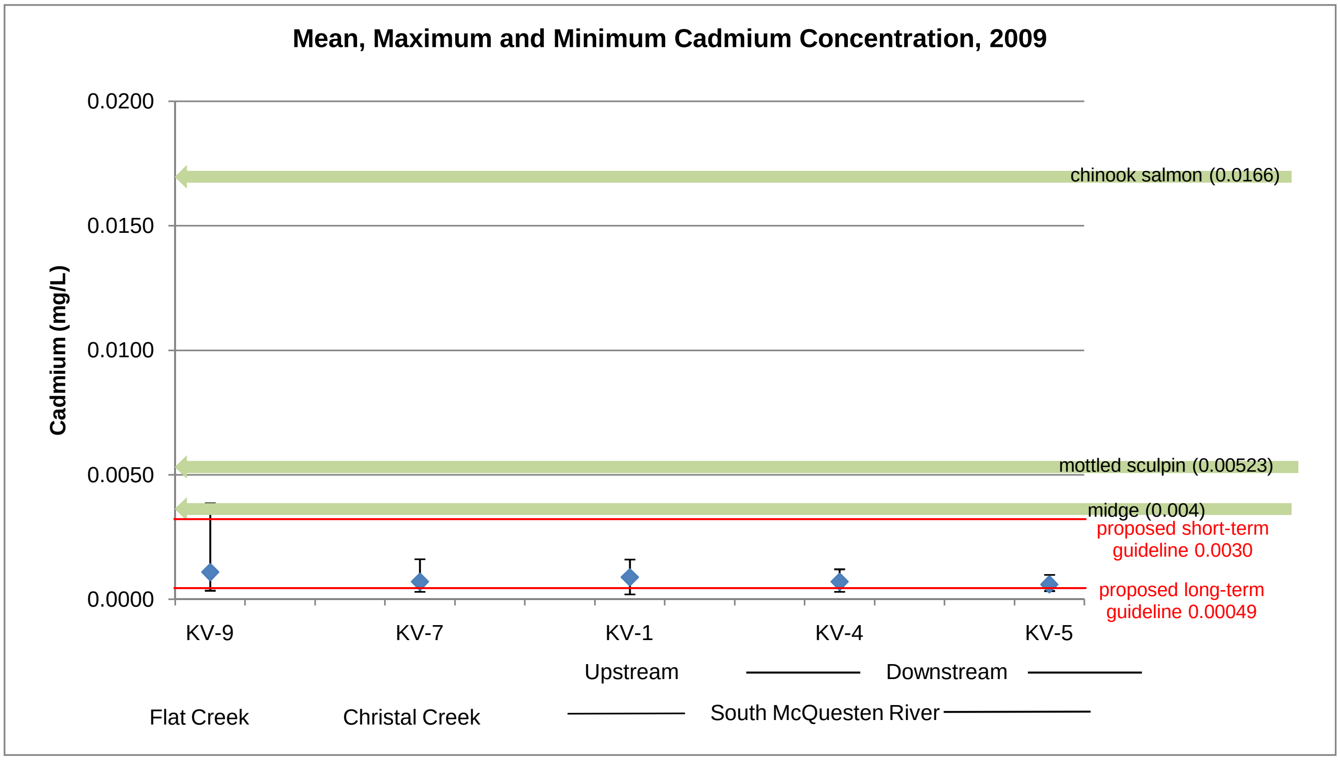


Figure 3.4: Mean water concentration (with maximum and minimum) of total cadmium, total zinc and dissolved hardness at key stations near UKHM in 2009. Guidelines are based on water hardness of 100 mg/L.



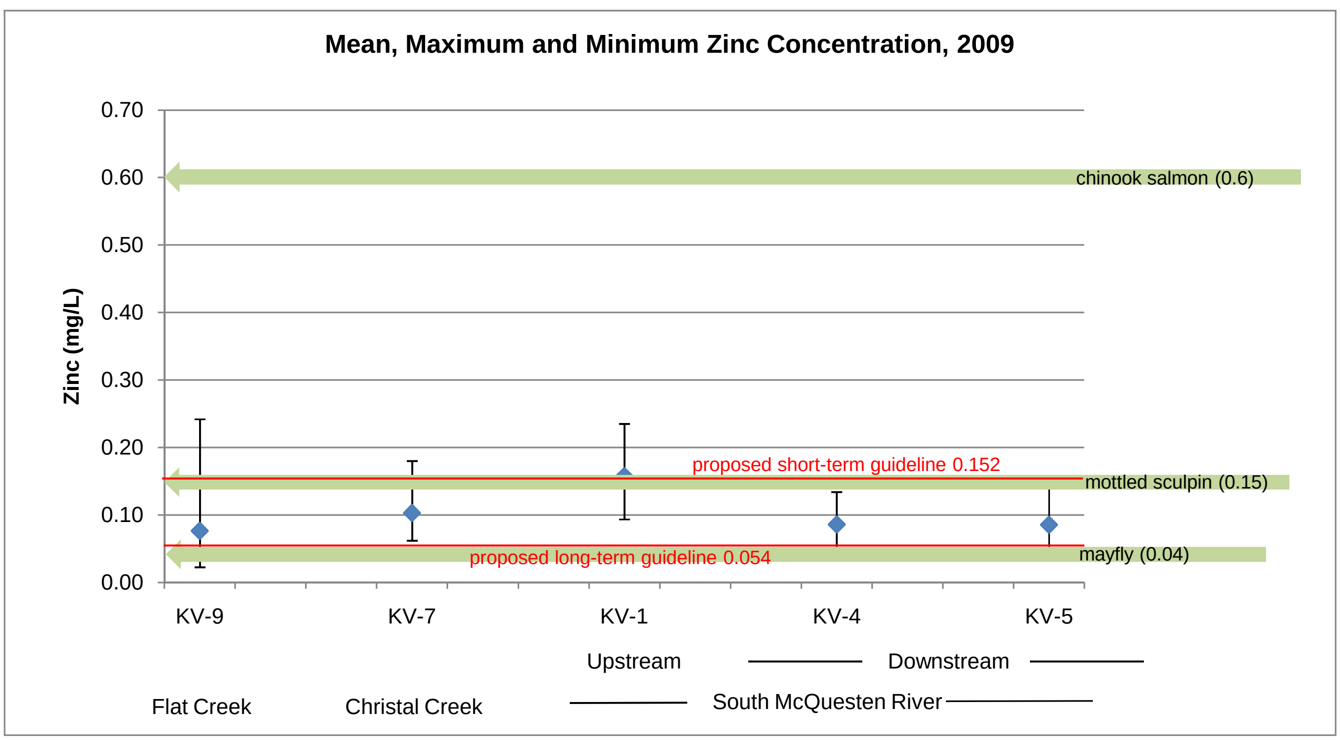


Figure 3.5: Total cadmium and zinc concentrations at selected UKHM stations relative to proposed CWQG and toxicity thresholds reported in the literature for selected species based on a water hardness of 300 mg/L.

The aquatic toxicities of zinc and cadmium are lower at higher water hardness (Appendix Figure D.1 and D.2), so effects to resident biota are likely less than would be predicted by CWQG established for a hardness of 100 mg/L. Therefore, potential impacts to aquatic biota near UKHM are discussed in more detail below relative to observed concentrations of cadmium, zinc and hardness and toxicity data presented in the literature.

In 2009, mean **cadmium** concentrations in Flat (KV-9) and Christal (KV-7) creeks were 0.0011 and 0.0007 mg/L, respectively (Figure 3.4). These concentrations were above the toxic thresholds of some aquatic biota at water hardnesses up to 300 mg/L (Table 3.1). Although this suggests that current water quality may affect some sensitive biota within these tributaries, the majority of species would not likely be affected, even during periods when water hardness is below average for each tributary (Table 3.1). In particular, fish species such as sculpin[3] and Chinook salmon would not be affected at cadmium and hardness levels typically observed in each creek (Figure 3.5). While long-term exposure data were not available for arctic grayling, a short-term (4-day) test in very low water hardness (41 mg/L) resulted in mortality to 50% of exposed organisms (LC50) at 0.004 mg/L (Buhl and Hamilton 1991), suggesting arctic grayling are also not affected by current water quality downstream of UKHM. Overall, it is expected that if cadmium concentrations remain stable or decline over time that further biological impacts will be minimal and existing biological communities will be protected.

Mean **zinc** concentrations in 2009 were 0.077 and 0.103 mg/L in Flat Creek and Christal Creek respectively (Figure 3.4). The majority of species tested would not likely be affected by such concentrations, particularly at typical water hardnesses of 300 mg/L (Table 3.2). This includes locally important fish species such as sculpin and Chinook salmon. Long-term exposure data are lacking for Arctic grayling, but 96-h LC50s of 0.11 to 0.17 mg/L zinc were reported in exposures involving very low water hardness, so effect concentrations would be higher (lower toxicity) at water hardnesses typically observed in Flat and Crystal creeks. Generally, the effects associated with current zinc levels are probably low, although the upper concentrations reported in both creeks have the potential to affect locally important species if sustained. Nonetheless, as indicated for cadmium, current biological communities will be protected if future concentrations remain stable or decline relative to current levels.

The above results are consistent with continued observations of both sculpin and grayling in Flat and Christal creeks (Minnow 2009).

[3] Toxicity data are available for mottled sculpin, whereas slimy sculpin is the species present near UKHM.

Table 3.1: Lowest effect endpoint reported for each freshwater species after a long-term exposure to cadmium (adapted from Minnow 2010).

Species Common Name	Scientific Name	Duration	Endpoint	Observed Effect	Test Hardness (mg/L)	Reported Effect Concentration (mg/L)	Hardness-Adjusted Effect Concentration			
							Effect Concentration (mg/L) at 50 mg/L Hardness [a]	Effect Concentration (mg/L) at 100 mg/L Hardness [a]	Effect Concentration (mg/L) at 200 mg/L Hardness [a]	Effect Concentration (mg/L) at 300 mg/L Hardness [a]
Water flea	*Daphnia magna*	7 d	EC10	Reproduction - Brood size	179	0.00014	0.00004	0.00008	0.00016	0.00024
Water flea	*Ceriodaphnia reticulata*	7 d	MATC	Reproduction - Number of young per adult	240	0.00043	0.00009	0.00018	0.00036	0.00054
Amphipod - scud	*Hyalella azteca*	28 d	IC25	Biomass, decrease in	280	0.00051	0.00009	0.00018	0.00036	0.00055
Rainbow trout	*Oncorhynchus mykiss*	65 wks	MATC	Reproduction - delay in oogenesis	250	0.00091	0.00018	0.00036	0.00072	0.00110
Midge	*Chironomus tentans*	60 d	IC25	Hatching success	280	0.004	0.001	0.001	0.003	0.004
Mottled sculpin	*Cottus bairdi*	21 d	EC50	Biomass, decrease in	104	0.00177	0.00084	0.00170	0.00346	0.00523
Atlantic salmon	*Salmo salar*	496 d	LOEC/L	Weight and Length	28	0.00047	0.00085	0.00173	0.00351	0.00532
Bull trout	*Salvelinus confluentus*	55 d	MATC	Growth	30.6	0.00055	0.00091	0.00184	0.00375	0.00567
Green hydra	*Hydra viridissima*	7 d	NOEC/L	Population growth inhibition	19.5	0.0004	0.0010	0.0021	0.0043	0.0066
Amphipod - gammarid	*Echinogammarus meridionalis*	6 d	LOEC/L	Feeding inhibition	263.4	0.0064	0.0012	0.0024	0.0048	0.0073
Amphipod - gammarid	*Gammarus pulex*	5 d	LOEC/L	Mortality	269.2	0.0075	0.0013	0.0027	0.0055	0.0084
Brown trout	*Salmo trutta*	30 d	IC20	Biomass, decrease in	29.2	0.0009	0.0015	0.0031	0.0062	0.0094
Brook Trout	*Salvelinus fontinalis*	126 d	MATC	Biomass, decrease in	45	0.002	0.002	0.005	0.009	0.014
Coho salmon	*Oncorhynchus kisutch*	27 d	MATC	Biomass, decrease in	45	0.0021	0.0023	0.0048	0.0097	0.0146
Chinook salmon	*Oncorhynchus tshawytscha*	8 d	LC10	Mortality	23	0.0012	0.0027	0.0054	0.0110	0.0166
Water flea	*Daphnia pulex*	14 d	MATC	Reproduction - Number of young per adult	240	0.0137	0.0028	0.0056	0.0114	0.0172
Green algae	*Ankistrodesmus falcatus*	96 h	NOEC/L	Growth	118.0	0.01	0.00	0.01	0.02	0.03
Water flea	*Ceriodaphnia dubia*	14 d	MATC	Reproduction	17.0	0.002	0.006	0.012	0.025	0.038
White Sucker	*Catostomus commersoni*	40 h	MATC	Biomass, decrease in	45	0.0071	0.0079	0.0161	0.0327	0.0494
Northern pike	*Esox lucius*	35 d	MATC	Biomass, decrease in	45	0.0074	0.0082	0.0167	0.0340	0.0515
Lake Trout	*Salvelinus namaycush*	41 d	MATC	Biomass, decrease in	45	0.0074	0.0082	0.0167	0.0340	0.0515
Marsh snail	*Lymnaea palustris*	4 weeks	EC50	Growth	284	0.0582	0.0098	0.0200	0.0407	0.0616
Great pond snail	*Lymnaea stagnalis*	4 weeks	NOEC/L	Growth	284	0.08	0.01	0.03	0.06	0.08
Midge	*Chironomus riparius*	17 d	MATC	Mortality	98.0	0.0474	0.0238	0.0484	0.0983	0.1489
Duckweed	*Lemna minor*	7 d	EC50	Growth rate	166.0	0.214	0.063	0.127	0.259	0.392
Northwestern salamander	*Ambystoma gracile*	24 d	MATC	Weight	45	0.0972	0.1083	0.2200	0.4471	0.6769

[a] If reported toxicity applied to a different water hardness than that shown, a hardness adjusted toxicity value was calculated using the following equation: EXP(LN(effect conc)-(1.023)*(LN(measured water hardness)-LN(desired water hardness)))

Table 3.2: Lowest effect endpoint reported for each freshwater species after a long-term exposure to zinc (adapted from Minnow 2010).

					Test Reported		Hardness-Adjusted Effect Concentration			
Species Common Name	**Scientific Name**	**Duration**	**Endpoint**	**Observed Effect**	**Hardness (mg/L)**	**Effect Concentration (mg/L)**	**Effect Concentration (mg/L) at 50 mg/L Hardness [a]**	**Effect Concentration (mg/L) at 100 mg/L Hardness [a]**	**Effect Concentration (mg/L) at 200 mg/L Hardness a**	**Effect Concentration (mg/L) at 300 mg/L Hardness [a]**
Green algae	*Pseudokirchneriella subcapitata*	7 d	EC10	Growth	NR	0.0011	0.0011	0.0011	0.0011	0.0011
Mayfly	*Epeorus latifolium*	4 weeks	IC10	emergence	83	0.0144	0.0094	0.0169	0.0303	0.0427
Water flea	*Ceriodaphnia dubia*	4 weeks	LOEC	Reproduction - Number of young per adult	97.6	0.025	0.014	0.026	0.046	0.065
Green alga	*Chlorella vulgaris*	72 h	EC50	biomass	NR	0.034	0.034	0.034	0.034	0.034
Water flea	*Daphnia magna*	50 d	MATC	Reproduction - Brood size	51.9	0.0217	0.0210	0.0378	0.0679	0.0957
Snail	*Potamopyrgus jenkinsi*	12 weeks	MATC	Growth	159	0.091	0.034	0.061	0.110	0.156
Chironomids	*Tanytarsus dissimilis*	10 d	LC50	Mortality	46.8	0.0368	0.0389	0.0700	0.1257	0.1772
Rotifer	*Brachionus havanaensis*	18 d	EC10	Population growth inhibition	NR	0.0782	0.0782	0.0782	0.0782	0.0782
Green alga	*Chlorella pyrenoidosa*	24 h	MATC	Cell density	25.51	0.0283	0.0500	0.0898	0.1615	0.2275
Rainbow trout	*Oncorhynchus mykiss*	30 d	LC10	Mortality	31.72	0.0345	0.0507	0.0911	0.1638	0.2309
Green algae	*Scenedesmus quadricauda*	15 d	IC10	Growth	NR	0.0961	0.0961	0.0961	0.0961	0.0961
Chironomids	*Chironomus riparius*	11 weeks	LOEC	Development	NR	0.100	0.100	0.100	0.100	0.100
Mottled sculpin	*Cottus bairdi*	30 d	LC50	Mortality	48.6	0.032	0.033	0.059	0.106	0.149
Green hydra	*Hydra viridissima*	7 d	EC10	Population growth inhibition	20	0.0522	0.1134	0.2038	0.3664	0.5163
Chinook salmon	*Oncorhynchus tshawytscha*	200 h	LC10	Mortality	23	0.068	0.131	0.236	0.424	0.597
Amphipod	*Hyalella azteca*	7 d	LC50	Mortality	18	0.056	0.133	0.239	0.429	0.605
Duckweed	*Lemna minor*	7 d	IC10	Growth	NR	0.318	0.318	0.318	0.318	0.318
Brook Trout	*Salvelinus fontinalis*	24 w	MATC	egg fragility	45.9	0.174	0.187	0.336	0.604	0.852
Pink hydra	*Hydra vulgaris*	7 d	EC10	Population growth inhibition	20	0.1779	0.3863	0.6943	1.2481	1.7588
Common duckmeat	*Spirodela polyrrhiza*	4 d	IC50	Growth	NR	0.935	0.935	0.935	0.935	0.935
Cutthroat trout	*Oncorhynchus clarkii*	14 d	LC10	Mortality	40	0.453	0.547	0.983	1.768	2.491
Bryozoan	*Pectinatella magnifica*	96 h	LC10	Mortality	205	2.286	0.693	1.245	2.239	3.155
Star duckweed	*Lemna trisulca*	14 d	EC50	final yield (oven dry weight)	20.37	0.327	0.699	1.256	2.258	3.183
Atlantic salmon	*Salmo salar*	14 d	LC50	Mortality	351	3.640	0.700	1.258	2.262	3.187
Snail	*Physa gyrina*	30 d	LC50	Mortality	36	0.771	1.018	1.830	3.289	4.635
Bryozoan	*Plumatella emarginata*	96 h	LC10	Mortality	205	3.474	1.053	1.893	3.402	4.794
Bryozoan	*Lophopodella carteri*	96 h	LC50	Mortality	205	4.093	1.241	2.230	4.008	5.649
Diatom	*Cyclotella meneghiniana*	5 d	LC10	Growth rate	121	2.803	1.327	2.386	4.288	6.043
Mayfly	*Rhithrogena hageni*	10 d	EC10	Mortality	44.4	2.069	2.288	4.113	7.392	10.417
Green alga	*Chlamydomonas sp.*	10 d	LC10	Growth rate	121	8.381	3.968	7.133	12.821	18.068
Crayfish	*Orconectes virilis*	14 d	LC10	Mortality	26	9.920	17.249	31.006	55.733	78.540

[a] If reported toxicity applied to a different water hardness than that shown, a hardness-adjusted toxicity value was calculated using the following equation: EXP(LN(effect conc)-(0.846)*(LN(measured water hardness)-LN(desired water hardness)))

NR - not reported

3.2.3 Proposed Approach to Water Quality Goals

Based on the previous sections, water quality goals for Flat and Christal creeks should aim to prevent further degradation of water quality to protect the diversity and abundance of the existing resident biota. In order to accomplish this, a number of water quality goals are proposed:

- Monthly water samples should be collected in Flat Creek at KV-9 and in Christal Creek at KV-7 and concentrations of all substances associated with UKHM, particular cadmium and zinc, should be evaluated annually.
- Mean concentrations of cadmium and zinc should be equal to or less than the previous year based on statistical comparison of means by analysis of variance (ANOVA). An increase in mean concentrations, even if not statistically significant, should be investigated to determine if may be an early indicator of an increasing trend related to historic or possibly other sources within the watershed (e.g., possibly through examining trends in loads or concentrations from specific upstream source areas). Changes in background concentrations should also be considered in this assessment such that if an increase is observed in the background concentration of cadmium and/or zinc, the concentrations within the tributaries are normalized for this increase.
- Trends in the concentrations of cadmium and zinc at KV-9 and KV-7 should be evaluated by a qualified professional at a frequency consistent with detailed watershed reporting as recommended in the Long-Term Aquatic Monitoring Program (LTAMP; Minnow 2011).
- An increasing trend should trigger investigation and, if appropriate, remediation of the cause.

The effects of these goals should be verified through routine biological monitoring (i.e., LTAMP) the scope of which should include:

- The number of benthic invertebrate taxa (i.e., diversity) measured through routine environmental monitoring programs should not be less than previously observed at each area (KV-9 and KV-7) using appropriate statistical methods and assuming the use of standardized timing and methods of collection. Similar to water quality, this assessment will need to consider changes in reference locations such that changes associated with natural temporal variability are not attributed to historic UKHM influence.

- One of the most sensitive organisms to zinc is a mayfly (*Epeorus latifolium*) which a member of the family Heptageniidae. This family of mayflies is present in the South McQuesten River watershed and several local streams (Minnow 2011, in preparation; Figure 3.6). The abundance of organisms within this family should be monitored over time as a potential indicator of zinc toxicity at KV-7. The objective would be to see an increase in Hepageniidae over time. It is not recommended that this indicator be used at KV-9 as the habitat at this station is generally not suitable to this family (slower flow and soft-bottom substrate).

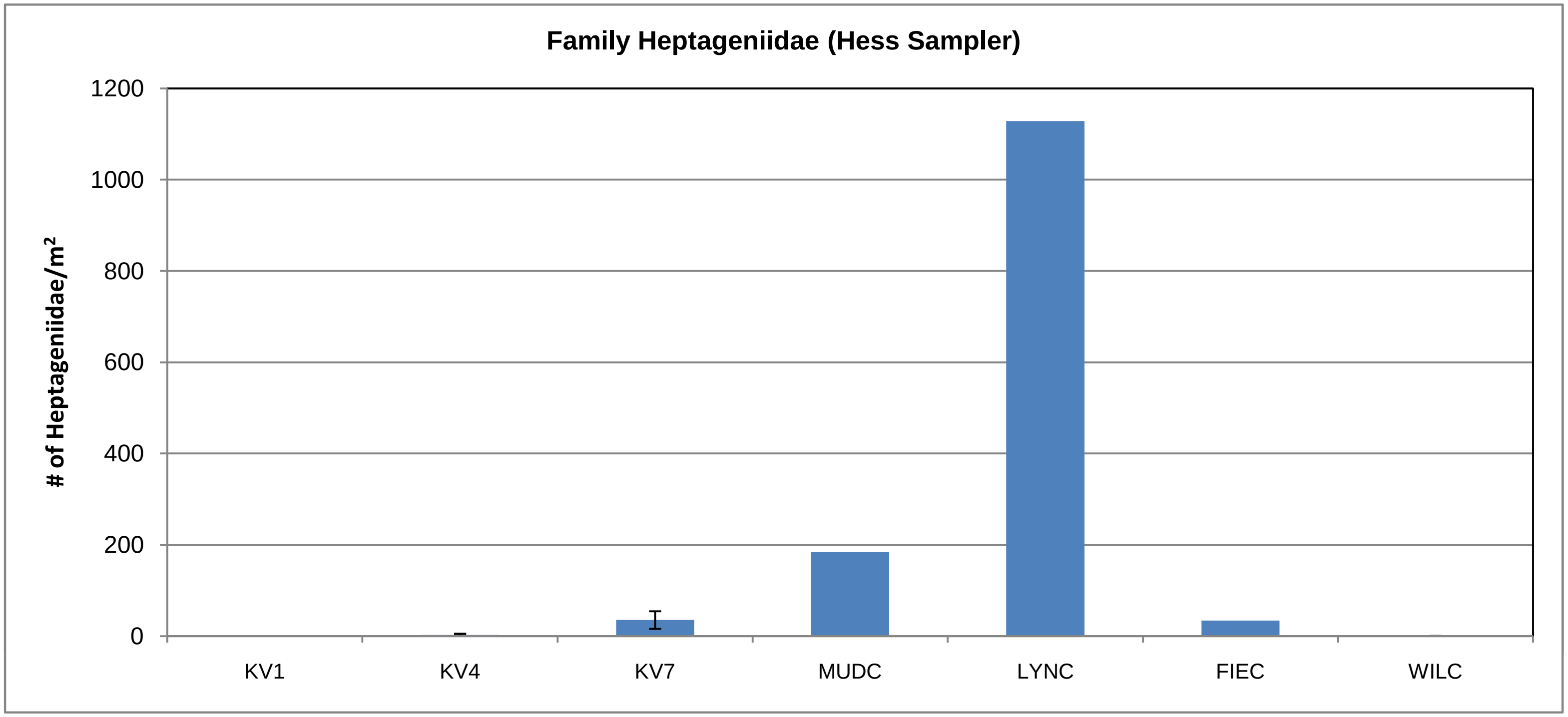


Figure 3.6: Number of heptageniidae identified in samples collected (by Hess) in August 2009 in the vicinity of United Keno Hill Mines

4.0 CONCLUSIONS

Based on the assessment of water quality presented in this report, the following conclusions are provided:

- Concentrations of cadmium and zinc have been increasing in the South McQuesten River downstream of UKHM (KV-4, KV-5) as a result of increasing concentrations upstream at KV-1. The concentrations and the rate of increase (slope) at downstream stations are equal to or lower than those upstream, indicating that the mine complex is not causing measurable increases in cadmium and zinc concentrations.

- Due to increasing concentrations upstream, a single water quality criterion can not reasonably be established for the South McQuesten River downstream of UKHM and an alternative approach is required.

- Water quality goals for cadmium and zinc should be linked to upstream concentrations and allow for no further degradation of water quality. The mean concentrations of cadmium and zinc should not exceed those measured upstream at KV-1 and the slope of concentrations relative to time at downstream stations should be equal to or less than that measured upstream at KV-1.

- Lightning Creek was not considered in this assessment as the existing data base indicated that concentrations within Lightning Creek were close to the CWQG. However, the data base for the creek was limited with respect to the extent of data and appropriate method detection limits. As additional monitoring data is obtained, the status of Lightning Creek should be reassessed with respect to the need for water quality objectives.

- Over the past twenty years concentrations of cadmium and zinc have been elevated well above the current CWQG (i.e., mean values more than ten times the CWQG) in Flat Creek and Christal Creek (Minnow 2008). It is expected that concentrations will decrease over time, but they are not expected to achieve the CWQG in the near future. Therefore, an alternative water quality goal is needed.

- Protection of current biological diversity and abundance in Flat and Christal creeks is predicated on prevention of further degradation of water quality. Therefore, annual mean concentrations of cadmium and zinc associated with the historic UKHM complex should not increase relative to the previous year and background conditions and trends over time should be stable or declining.

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APPENDIX A

Raw Water Quality Data
From Selected UKHM Stations
2006 to 2009

Table A.1: Total Cadmium, Zinc and Dissolved Hardness, 2006 - 2009

KV-9			
Sample Date	Total Cadmium (mg/L)	Total Zinc (mg/L)	Dissolved Hardness (mg/L)
25-Jan-2006	0.0002	0.022	300
14-Mar-2006	0.00018	0.02	285
26-Apr-2006	0.00015	0.02	332
26-May-2006	0.000655	0.0648	129
31-Jul-2006	0.00038	0.037	
26-Feb-2007	0.00025	0.026	
13-Jul-2007	0.00065	0.077	
06-Sep-2007	0.00051	0.046	
8-Sep-2007			
14-Mar-2008	0.0003	0.037	340
16-May-2008	0.00072	0.069	146
20-Jun-2008	0.00029	0.034	298
03-Jul-2008	0.00033	0.031	331
13-Aug-2008	0.00053	0.065	195
18-Sep-2008	0.0003	0.036	267
04-Oct-2008	0.00045	0.047	248
13-Nov-2008	0.00032	0.044	340
13-Jan-2009	0.00309	0.232	344
01-Feb-2009	0.00385	0.242	351
09-Mar-2009	0.0014	0.096	301
15-Apr-2009	0.000593	0.0419	324
26-May-2009	0.00061	0.0548	116
05-Jun-2009	0.000519	0.0374	199
04-Jul-2009	0.000397	0.0276	278
12-Aug-2009	0.000343	0.0226	376
22-Aug-2009	0.000409	0.0259	
08-Sep-2009	0.000369	0.0281	313
09-Oct-2009	0.000371	0.0333	302

KV-7			
Sample Date	Total Cadmium (mg/L)	Total Zinc (mg/L)	Dissolved Hardness (mg/L)
25-Jan-2006	0.00065	0.142	408
22-Feb-2006	0.00057	0.13	400
15-Mar-2006	0.0006	0.17	372
27-Apr-2006	0.00051	0.124	397
25-May-2006	0.00113	0.166	120
27-Jun-2006	0.00347	1.03	
28-Jun-2006	0.00313	0.634	
31-Jul-2006	0.00177	0.242	
31-Aug-2006	0.00131	0.238	
21-Sep-2006	0.00104	0.229	
25-Oct-2006	0.0011	0.217	
30-Nov-2006	0.00072	0.202	
22-Jan-2007	0.00046	0.138	
28-Feb-2007	0.0005	0.129	
23-Mar-2007	0.00047	0.112	
18-Apr-2007	0.00237	0.372	
29-May-2007	0.00137	0.238	
16-Jun-2007	0.00117	0.252	
12-Jul-2007	0.00126	0.204	
31-Aug-2007	0.00097	0.16	
5-Sep-2007	0.0011	0.203	
28-Oct-2007	0.00153	0.282	
27-Nov-2007	0.00081	0.138	355
9-Jan-2008	0.00056	0.118	384
29-Feb-2008	0.00118	0.216	437
14-Mar-2008	0.0006	0.141	383
19-Apr-2008	0.0003	0.077	414
17-May-2008	0.00122	0.184	171
20-Jun-2008	0.00045	0.088	345
3-Jul-2008	0.00059	0.091	286
13-Aug-2008	0.00141	0.202	227
18-Sep-2008	0.00158	0.187	233
2-Oct-2008	0.00146	0.183	254
12-Nov-2008	0.00104	0.157	304
20-Dec-2008	0.00082	0.128	348
13-Jan-2009	0.00068	0.134	326
1-Feb-2009	0.00045	0.081	401
10-Mar-2009	0.0003	0.062	369
15-Apr-2009	0.000426	0.0628	384
27-May-09	0.00161	0.18	117
5-Jun-09	0.000925	0.117	160
6-Jul-09	0.00061	0.084	330
11-Aug-2009	0.000525	0.0832	378
22-Aug-2009	0.000582	0.091	
8-Sep-2009	0.000833	0.105	281
6-Oct-2009	0.000933	0.139	323
12-Nov-2009	0.000591	0.107	357
4-Dec-2009	0.000624	0.0932	366

KV-1			
Sample Date	Total Cadmium (mg/L)	Total Zinc (mg/L)	Dissolved Hardness (mg/L)
25-Jan-2006	0.00019	0.047	233
22-Feb-2006	0.00016	0.038	240
15-Mar-2006	0.0001	0.03	243
27-Apr-2006	0.00008	0.03	220
25-May-2006	0.00024	0.048	72
28-Jun-2006	0.00038	0.073	
31-Jul-2006	0.00027	0.043	
31-Aug-2006	0.00064	0.12	
21-Sep-2006	0.00082	0.153	
25-Oct-2006	0.00061	0.111	
25-Oct-2006	0.00063	0.11	
30-Nov-2006	0.00033	0.09	
22-Jan-2007	0.00044	0.124	
28-Feb-2007	0.00025	0.071	
18-Apr-2007	0.0006	0.154	
29-May-2007	0.00049	0.096	
16-Jun-2007	0.00063	0.111	
13-Jul-2007	0.00089	0.173	
18-Aug-2007	0.00072	0.102	
5-Sep-2007	0.00086	0.126	
31-Oct-2007	0.00063	0.127	
12-Nov-2007	0.00056	0.146	200
27-Nov-2007	0.00079	0.172	226
23-Jan-2008	0.00048	0.132	254
29-Feb-2008	0.00015	0.046	314
17-May-2008	0.00045	0.082	165
20-Jun-2008	0.0009	0.144	172
3-Jul-2008	0.00094	0.129	179
13-Aug-2008	0.00126	0.247	162
18-Sep-2008	0.00105	0.183	186
3-Oct-2008	0.00116	0.222	186
12-Nov-2008	0.00059	0.156	203
20-Dec-2008	0.00079	0.156	229
1-Feb-2009	0.00048	0.105	312
10-Mar-2009	0.00103	0.19	306
27-May-2009	0.000642	0.141	75.3
5-Jun-2009	0.00132	0.153	129
6-Jul-2009	0.000714	0.114	163
11-Aug-2009	0.000855	0.0936	194
23-Aug-2009	0.00197	0.235	
8-Sep-2009	0.0016	0.235	176
9-Oct-2009	0.00106	0.177	181
3-Dec-2009	0.00091	0.134	298

KV-4			
Sample Date	Total Cadmium (mg/L)	Total Zinc (mg/L)	Dissolved Hardness (mg/L)
25-Jan-2006	0.00015	0.038	244
14-Mar-2006	0.00016	0.037	273
26-May-2006	0.000566	0.0623	122
31-Jul-2006	0.00035	0.031	
26-Feb-2007	0.00026	0.058	
13-Jul-2007	0.00082	0.112	
6-Sep-2007	0.00065	0.09	
14-Mar-2008	0.00033	0.051	321
16-May-2008	0.00066	0.082	142
3-Jul-2008	0.00057	0.07	219
4-Oct-2008	0.00114	0.181	193
1-Feb-2009	0.0003	0.054	315
26-May-2009	0.000677	0.0842	109
4-Jul-2009	0.000559	0.0491	249
22-Aug-2009	0.00121	0.134	
9-Oct-2009	0.000753	0.109	205

KV-5			
Sample Date	Total Cadmium (mg/L)	Total Zinc (mg/L)	Dissolved Hardness (mg/L)
24-Jan-2006	0.00012	0.032	235
22-Feb-2006	0.00018	0.035	263
14-Mar-2006	0.00016	0.039	268
26-Apr-2006	0.00008	0.022	237
26-May-2006	0.00034	0.046	86
31-Jul-2006	0.00017	0.022	
26-Feb-2007	0.00016	0.044	
13-Jul-2007	0.00067	0.108	
6-Sep-2007	0.00044	0.061	
13-Mar-2008	0.00021	0.036	283
16-May-2008	0.00053	0.071	134
3-Jul-2008	0.00035	0.045	186
4-Oct-2008	0.00094	0.142	177
1-Feb-2009	0.00033	0.05	309
26-May-2009	0.000531	0.0664	99.5
4-Jul-2009	0.00051	0.0741	172
8-Oct-2009	0.00098	0.152	189

Table A.2: Statistical comparison of cadmium and zinc concentrations over time between KV-1, KV-4 and KV-5.

a) Linear regression of concentration versus time

Substance	Station	P value	r^2
Cadmium	KV-1	0.000	0.492
	KV-4	0.006	0.425
	KV-5	0.000	0.592
Zinc	KV-1	0.000	0.434
	KV-4	0.018	0.340
	KV-5	0.002	0.490

b) Comparison of slopes of cadmium and zinc concentrations over time

Substance	Comparison	Significantly Different	P value
Cadmium	KV-1 vs KV-4	N	0.381
	KV-1 vs KV-5	N	0.966
Zinc	KV-1 vs KV-4	N	0.415
	KV-1 vs KV-5	N	0.986

c) ANCOVA comparisons of means adjusted for date

Substance	Comparison	Log Adjusted Mean	Significantly Different	Difference Relative to KV-1	P value
Cadmium	KV-1 vs KV-4	KV-1 -3.244	N	-	0.208
		KV-4 -3.327			
	KV-1 vs KV-5	KV-1 -3.260	Y	⬇	0.001
		KV-5 -3.480			
Zinc	KV-1 vs KV-4	KV-1 -0.954	Y	⬇	0.000
		KV-4 -1.170			
	KV-1 vs KV-5	KV-1 -0.965	Y	⬇	0.000
		KV-5 -1.261			

APPENDIX B

Cadmium Toxicity Data

Table B.1: Summary of long-term effects of cadmium on a variety of aquatic organisms

Species Common Name	Scientific Name	Life stage	Duration	Endpoint	Observed Effect	Test Hardness (mg/L)	Effect Concentration (ug/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Amphipod - gammarid	Echinogammarus meridionalis	Adult	6 d	LOEC/L	Feeding inhibition	263.4	6.35	2.4	7.92 (+-0.02)	Pestana et al.	2007
Amphipod - gammarid	Echinogammarus meridionalis	Adult	6 d	NOEC/L	Feeding inhibition	263.4	4.2	1.6	7.92 (+-0.02)	Pestana et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	5 d	LOEC/L	Behaviour - Inhibition of swimming ability	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	LOEC/L	Behaviour - Inhibition of swimming ability	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	LOEC/L	Feeding inhibition	269.2	15	5.4	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	5 d	LOEC/L	Mortality	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	LOEC/L	Mortality	269.2	15	5.4	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	5 d	LOEC/L	Respiration	269.2	15	5.4	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	LOEC/L	Respiration	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	MATC	Feeding inhibition	269.2	10.6	3.8	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	MATC	Mortality	269.2	10.6	3.8	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	5 d	MATC	Respiration	269.2	10.6	3.8	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	NOEC/L	Feeding inhibition	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	7 d	NOEC/L	Mortality	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - gammarid	Gammarus pulex	Adult	5 d	NOEC/L	Respiration	269.2	7.5	2.7	7.19 +- 0.02	Felten et al.	2007
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	IC25	Biomass, decrease in	280	0.51	0.2	7.80	Ingersoll and Kemble	2001
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	IC25	Length	280	2.6	0.9	7.80	Ingersoll and Kemble	2001
Amphipod - scud	Hyalella azteca	7-8 d old	42 d	IC25	Mortality	280	1.9	0.7	7.80	Ingersoll and Kemble	2001
Amphipod - scud	Hyalella azteca	7-8 d old	42 d	IC25	Reproduction	280	1.4	0.5	7.80	Ingersoll and Kemble	2001
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	IC25	Weight	280	0.74	0.3	7.80	Ingersoll and Kemble	2001
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	LOEC/L	Mortality	139.6	22.97	16.3	7.0 (0.3)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	42 d	LOEC/L	Mortality	139.6	22.97	16.3	7.0 (0.3)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	LOEC/L	Mortality	162.7	5.09	3.1	7.9 (0.1)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	MATC	Mortality	139.6	12.52	8.9	7.0 (0.3)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	42 d	MATC	Mortality	139.6	12.52	8.9	7.0 (0.3)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	MATC	Mortality	162.7	3.56	2.2	7.9 (0.1)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	NOEC/L	Mortality	139.6	6.82	4.8	7.0 (0.3)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	42 d	NOEC/L	Mortality	139.6	6.82	4.8	7.0 (0.3)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	7-8 d old	28 d	NOEC/L	Mortality	162.7	2.49	1.5	7.9 (0.1)	Stanley et al.	2005
Amphipod - scud	Hyalella azteca	Juvenile	14 d	MATC	Mortality	17.0	0.16	1.0	5.5-7.7	Suedel et al	1997
Amphipod - scud	Hyalella azteca	Juvenile	7 d	MATC	Mortality	17.0	1.4	8.6	5.5-7.7	Suedel et al	1997
Amphipod - scud	Hyalella azteca	Juvenile	10 d	MATC	Mortality	17.0	1.4	8.6	5.5-7.7	Suedel et al	1997
Amphipod - scud	Hyalella azteca	Juvenile	14 d	NOEC/L	Growth	17.0	2	12.3	5.5-7.7	Suedel et al	1997
Atlantic salmon	Salmo salar	Egg	470 d	LOEC/L	Biomass, decrease in	28	2.5	9.2	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	470 d	LOEC/L	Weight	28	2.5	9.2	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	496 d	LOEC/L	Weight and Length	28	0.47	1.7	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	402 d	MATC	Biomass, decrease in	19	5.5	30.1	6.5 (6.3-6.8)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	496 d	MATC	Biomass, decrease in	28	0.61	2.2	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Early gastrulation	78 d	MATC	Hatching success	19	88	481	6.5 (6.3-6.8)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Eyed egg stage	45 d	MATC	Hatching success	19	156	853	6.5 (6.3-6.8)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	96 d	MATC	Hatching success	19	156	853	6.5 (6.3-6.8)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	45 d	MATC	Hatching success	28	490	1802	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	48 d	MATC	Hatching success	28	490	1802	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	158 d	MATC	Mortality after hatch	19	156	853	6.5 (6.3-6.8)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	92 d	MATC	Mortality after hatch	28	4.5	16.5	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	92 d	MATC	Mortality after hatch	28	490	1802	7.3 (6.8-7.5)	Rombough and Garside	1982
Atlantic salmon	Salmo salar	Egg	402 d	MATC	Weight	19	5.5	30.1	6.5 (6.3-6.8)	Rombough and Garside	1982

Table B.1: Summary of long-term effects of cadmium on a variety of aquatic organisms

Species Common Name	Scientific Name	Life stage	Duration	Endpoint	Observed Effect	Test Hardness (mg/L)	Effect Concentration (ug/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Brook Trout	Salvelinus fontinalis	Larva	126 d	LOEC/L	Biomass, decrease in	45	3.8	8.6	7.6 (7.2-7.8)	Eaton et al.	1978
Brook Trout	Salvelinus fontinalis	Larva	126 d	MATC	Biomass, decrease in	45	2	4.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brook Trout	Salvelinus fontinalis	Larva	126 d	NOEC/L	Biomass, decrease in	45	1.1	2.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Swim-up fry	30 d	IC20	Biomass, decrease in	29.2	0.87	3.1	7.54 (0.13)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	IC20	Biomass, decrease in	30.6	2.22	7.5	7.72 (0.12)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	IC20	Biomass, decrease in	67.6	2.18	3.3	7.60 (0.10)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	IC20	Biomass, decrease in	71.3	4.71	6.7	7.75 (0.14)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	IC20	Biomass, decrease in	151.0	6.62	4.3	7.51 (0.12)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	IC20	Mortality	149.0	13.6	9.0	7.83 (0.14)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	LOEC/L	Mortality	29.2	1.4	4.9	7.54 (0.13)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	LOEC/L	Mortality	30.6	4.87	16.4	7.72 (0.12)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	LOEC/L	Mortality	67.6	2.58	3.9	7.60 (0.10)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	LOEC/L	Mortality	71.3	8.64	12.2	7.75 (0.14)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	LOEC/L	Mortality	149.0	19.1	12.7	7.83 (0.14)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	LOEC/L	Mortality	151.0	8.88	5.8	7.51 (0.12)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	LOEC/L	Weight	29.2	2.72	9.6	7.54 (0.13)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	LOEC/L	Weight	67.6	4.49	6.7	7.60 (0.10)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	NOEC/L	Mortality	29.2	0.74	2.6	7.54 (0.13)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	NOEC/L	Mortality	30.6	2.54	8.5	7.72 (0.12)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	NOEC/L	Mortality	67.6	1.3	1.9	7.60 (0.10)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	NOEC/L	Mortality	71.3	4.68	6.6	7.75 (0.14)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Egg	55 d	NOEC/L	Mortality	149.0	9.62	6.4	7.83 (0.14)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	NOEC/L	Mortality	151.0	4.81	3.2	7.51 (0.12)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	NOEC/L	Weight	29.2	1.4	4.9	7.54 (0.13)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Swim-up fry	30 d	NOEC/L	Weight	67.6	2.58	3.9	7.60 (0.10)	Brinkman and Hansen	2007
Brown trout	Salmo trutta	Embryo	83 d	LOEC/L	Biomass, decrease in	45	11.7	26.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Embryo	31 d	LOEC/L	Biomass, decrease in	45	11.2	25.4	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Larva	60 d	LOEC/L	Biomass, decrease in	45	11.7	26.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Larva	61 d	LOEC/L	Biomass, decrease in	45	3.7	8.4	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Larva	61 d	MATC	Biomass, decrease in	45	2	4.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Embryo	31 d	MATC	Biomass, decrease in	45	6.4	14.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Larva	60 d	MATC	Biomass, decrease in	45	6.7	15.2	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Embryo	83 d	MATC	Biomass, decrease in	45	6.7	15.2	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Larva	61 d	NOEC/L	Biomass, decrease in	45	1.1	2.5	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Embryo	31 d	NOEC/L	Biomass, decrease in	45	3.7	8.4	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Larva	60 d	NOEC/L	Biomass, decrease in	45	3.8	8.6	7.6 (7.2-7.8)	Eaton et al.	1978
Brown trout	Salmo trutta	Embryo	83 d	NOEC/L	Biomass, decrease in	45	3.8	8.6	7.6 (7.2-7.8)	Eaton et al.	1978
Bull trout	Salvelinus confluentus	Juvenile	55 d	LOEC/L	Growth	30.6	0.786	2.6	7.55 (SD = 0.12)	Hansen et al.	2002
Bull trout	Salvelinus confluentus	Juvenile	55 d	LOEC/L	Mortality	30.6	0.786	2.6	7.55 (SD = 0.12)	Hansen et al.	2002
Bull trout	Salvelinus confluentus	Juvenile	55 d	MATC	Growth	30.6	0.549	1.8	7.55 (SD = 0.12)	Hansen et al.	2002
Bull trout	Salvelinus confluentus	Juvenile	55 d	MATC	Mortality	30.6	0.549	1.8	7.55 (SD = 0.12)	Hansen et al.	2002
Bull trout	Salvelinus confluentus	Juvenile	55 d	NOEC/L	Growth	30.6	0.383	1.3	7.55 (SD = 0.12)	Hansen et al.	2002
Bull trout	Salvelinus confluentus	Juvenile	55 d	NOEC/L	Mortality	30.6	0.383	1.3	7.55 (SD = 0.12)	Hansen et al.	2002
Chinook salmon	Oncorhynchus tshawytscha	Swim-up fry	8 d	LC10	Mortality	23	1.2	5.4	7.1-7.5	Chapman	1978
Chinook salmon	Oncorhynchus tshawytscha	Alevin	8 d	LC10	Mortality	23	>6	>27	7.1-7.5	Chapman	1978

Table B.1: Summary of long-term effects of cadmium on a variety of aquatic organisms

Species Common Name	Scientific Name	Life stage	Duration	Endpoint	Observed Effect	Test Hardness (mg/L)	Effect Concentration (ug/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	7 d	MATC	Reproduction - Number of young per adult	240	0.43	0.2	8.0 +- 0.3	Elnabarawy et al	1986
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	9 d	LOEC/L	Mortality	67.0	15.2	22.9	7.2-7.8	Spehar and Carlson	1984
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	9 d	LOEC/L	Reproduction	67.0	7.2	10.8	7.2-7.8	Spehar and Carlson	1984
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	9 d	MATC	Mortality	67.0	10.5	15.8	7.2-7.8	Spehar and Carlson	1984
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	9 d	MATC	Reproduction	67.0	4.9	7.4	7.2-7.8	Spehar and Carlson	1984
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	9 d	NOEC/L	Mortality	67.0	7.2	10.8	7.2-7.8	Spehar and Carlson	1984
Cladocerans	Ceriodaphnia reticulata	Less than 24hrs	9 d	NOEC/L	Reproduction	67.0	3.4	5.1	7.2-7.8	Spehar and Carlson	1984
Coho salmon	Oncorhynchus kisutch	Embryo	27 d	LOEC/L	Biomass, decrease in	45	3.4	8	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Embryo	47 d	LOEC/L	Biomass, decrease in	45	12.5	28	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Larva	62 d	LOEC/L	Biomass, decrease in	45	12.5	28	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Embryo	27 d	MATC	Biomass, decrease in	45	2.1	5	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Embryo	47 d	MATC	Biomass, decrease in	45	7.2	16	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Larva	62 d	MATC	Biomass, decrease in	45	7.2	16	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Embryo	27 d	NOEC/L	Biomass, decrease in	45	1.3	3	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Embryo	47 d	NOEC/L	Biomass, decrease in	45	4.1	9	7.6 (7.2-7.8)	Eaton et al.	1978
Coho salmon	Oncorhynchus kisutch	Larva	62 d	NOEC/L	Biomass, decrease in	45	4.1	9	7.6 (7.2-7.8)	Eaton et al.	1978
Duckweed	Lemna minor	Not reported	7 d	EC50	Growth rate	166.0	214	127	5.5 +- 0.2	Drost et al.	2007
Duckweed	Lemna minor	Not reported	6 d	EC50	Growth rate	166.0	214	127	5.5 +- 0.2	Drost et al.	2007
Duckweed	Lemna minor	Not reported	5 d	EC50	Growth rate	166.0	315	188	5.5 +- 0.2	Drost et al.	2007
Duckweed	Lemna minor	Not reported	3 d	EC50	Growth rate	166.0	393	234	5.5 +- 0.2	Drost et al.	2007
Duckweed	Lemna minor	Not reported	4 d	EC50	Growth rate	166.0	337	201	5.5 +- 0.2	Drost et al.	2007
European shrimp	Atyaephyra desmarestii	Adult	6 d	LOEC/L	Feeding inhibition	263.4	6.53	2.4	7.92 (+-0.02)	Pestana et al.	2007
European shrimp	Atyaephyra desmarestii	Adult	6 d	NOEC/L	Feeding inhibition	263.4	4.2	1.6	7.92 (+-0.02)	Pestana et al.	2007
Fathead minnow	Pimephales promelas	Juvenile	32 d	LOEC/L	Mortality	67.0	26.7	40.2	7.2-7.8	Spehar and Carlson	1984
Fathead minnow	Pimephales promelas	Juvenile	32 d	MATC	Mortality	67.0	18.9	28.5	7.2-7.8	Spehar and Carlson	1984
Fathead minnow	Pimephales promelas	Juvenile	32 d	NOEC/L	Mortality	67.0	13.4	20.2	7.2-7.8	Spehar and Carlson	1984
Fathead minnow	Pimephales promelas	Larva	10 d	MATC	Mortality	17.0	1.4	8.6	5.5-7.7	Suedel et al	1997
Fathead minnow	Pimephales promelas	Larva	7 d	MATC	Mortality	17.0	4.9	30.0	5.5-7.7	Suedel et al	1997
Fathead minnow	Pimephales promelas	Larva	14 d	MATC	Mortality	17.0	2.4	14.7	5.5-7.7	Suedel et al	1997
Fathead minnow	Pimephales promelas	Larva	10 d	NOEC/L	Growth	17.0	2	12.3	5.5-7.7	Suedel et al	1997
Fathead minnow	Pimephales promelas	Larva	14 d	NOEC/L	Growth	17.0	3	18.4	5.5-7.7	Suedel et al	1997
Great pond snail	Lymnaea stagnalis	Adult	4 weeks	EC50	Growth	284	142.2	48.9	6.65-8.14	Coeurdassier et al.	2003
Great pond snail	Lymnaea stagnalis	Adult	4 weeks	NOEC/L	Growth	284	80	27.5	6.65-8.14	Coeurdassier et al.	2003
Green alga	Ankistrodesmus falcatus	Population	96 h	NOEC/L	Growth	118.0	10	8	7.7 (7.2-8.2)	Baer et al.	1999
Green alga	Pseudokirchneriella subcapitata	Population	96 h	NOEC/L	Growth	118.0	5	4	7.7 (7.2-8.2)	Baer et al.	1999
Green alga	Pseudokirchneriella subcapitata	Population	72 h	EC50	Growth	250	43.5	17	8.1	Benhra et al.	1997
Green alga	Pseudokirchneriella subcapitata	Population	72 h	EC10	Growth rate	3.42	2.8	88	6.71	Kallqvist	2007
Green alga	Pseudokirchneriella subcapitata	Population	72 h	EC10	Growth rate	6.21	7.5	129	6.85	Kallqvist	2007
Green alga	Pseudokirchneriella subcapitata	Population	72 h	EC10	Growth rate	16.21	8.5	55	6.74	Kallqvist	2007
Green alga	Pseudokirchneriella subcapitata	Population	72 h	EC10	Growth rate	46.21	6	13	6.65	Kallqvist	2007
Green alga	Pseudokirchneriella subcapitata	Population	72 h	Mean EC10	Growth rate		5.7	53.6		Mean	
Green hydra	Hydra viridissima		7 d	NOEC/L	Population growth inhibition	19.5	0.4	2.1	7.25-7.53	Holdway et al.	2001
Lake Trout	Salvelinus namaycush	Embryo	41 d	LOEC/L	Biomass, decrease in	45	12.3	27.8	7.6 (7.2-7.8)	Eaton et al.	1978
Lake Trout	Salvelinus namaycush	Larva	64 d	LOEC/L	Biomass, decrease in	45	12.3	27.8	7.6 (7.2-7.8)	Eaton et al.	1978
Lake Trout	Salvelinus namaycush	Embryo	41 d	MATC	Biomass, decrease in	45	7.4	16.7	7.6 (7.2-7.8)	Eaton et al.	1978
Lake Trout	Salvelinus namaycush	Larva	64 d	MATC	Biomass, decrease in	45	7.4	16.7	7.6 (7.2-7.8)	Eaton et al.	1978
Lake Trout	Salvelinus namaycush	Embryo	41 d	NOEC/L	Biomass, decrease in	45	4.4	10.0	7.6 (7.2-7.8)	Eaton et al.	1978
Lake Trout	Salvelinus namaycush	Larva	64 d	NOEC/L	Biomass, decrease in	45	4.4	10.0	7.6 (7.2-7.8)	Eaton et al.	1978

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Species Common Name	Scientific Name	Life stage	Duration	Endpoint	Observed Effect	Test Hardness (mg/L)	Effect Concentration (ug/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Marsh snail	Lymnaea palustris	Adult	4 weeks	EC50	Growth	284	58.2	20.0	6.65-8.14	Coeurdassier et al.	2003
Marsh snail	Lymnaea palustris	Adult	4 weeks	EC50	Repro - No. egg masses per individual	284	60.9	20.9	6.65-8.14	Coeurdassier et al.	2003
Marsh snail	Lymnaea palustris	Adult	4 weeks	EC50	Repro - No. eggs per egg mass	284	124	42.6	6.65-8.14	Coeurdassier et al.	2003
Marsh snail	Lymnaea palustris	Adult	4 weeks	EC50	Repro - No. eggs per individual	284	64.7	22.2	6.65-8.14	Coeurdassier et al.	2003
Marsh snail	Lymnaea palustris	Adult	4 weeks	NOEC/L	Growth	284	40	13.8	6.65-8.14	Coeurdassier et al.	2003
Marsh snail	Lymnaea palustris	Adult	4 weeks	NOEC/L	Repro - No. egg masses per individual	284	40	13.8	6.65-8.14	Coeurdassier et al.	2003
Marsh snail	Lymnaea palustris	Adult	4 weeks	NOEC/L	Repro - No. eggs per individual	284	40	13.8	6.65-8.14	Coeurdassier et al.	2003
Midge	Chironomus riparius	1st instar	17 d	LOEC/L	Mortality	98.0	150	153.1	7.6	Pascoe et al.	1989
Midge	Chironomus riparius	1st instar	17 d	MATC	Mortality	98.0	47.4	48.4	7.6	Pascoe et al.	1989
Midge	Chironomus riparius	1st instar	17 d	NOEC/L	Mortality	98.0	15	15.3	7.6	Pascoe et al.	1989
Midge	Chironomus tentans	Less than 24hrs	20 d	IC25	Biomass, decrease in	280	10.3	3.6	7.80	Ingersoll and Kemble	2001
Midge	Chironomus tentans	Less than 24hrs	60 d	IC25	Hatching success	280	4	1.4	7.80	Ingersoll and Kemble	2001
Midge	Chironomus tentans	Less than 24hrs	20 d	IC25	Mortality	280	16.4	>5.7	7.80	Ingersoll and Kemble	2001
Midge	Chironomus tentans	Less than 24hrs	60 d	IC25	Percent emergence	280	8.1	2.8	7.80	Ingersoll and Kemble	2001
Midge	Chironomus tentans	Less than 24hrs	60 d	IC25	Repro - No. eggs per individual	280	>16.4	>5.7	7.80	Ingersoll and Kemble	2001
Midge	Chironomus tentans	Less than 24hrs	20 d	IC25	Weight	280	9.9	3.5	7.80	Ingersoll and Kemble	2001
Midge	Chironomus tentans	2nd instar	7 d	LOEC/L	Growth	17.0	500	3063.5	5.5-7.7	Suedel et al	1997
Midge	Chironomus tentans	2nd instar	10 d	LOEC/L	Growth	17.0	500	3063.5	5.5-7.7	Suedel et al	1997
Midge	Chironomus tentans	2nd instar	14 d	LOEC/L	Growth	17.0	100	612.7	5.5-7.7	Suedel et al	1997
Midge	Chironomus tentans	2nd instar	7 d	MATC	Mortality	17.0	707	4331.8	5.5-7.7	Suedel et al	1997
Midge	Chironomus tentans	2nd instar	10 d	MATC	Mortality	17.0	707	4331.8	5.5-7.7	Suedel et al	1997
Midge	Chironomus tentans	2nd instar	14 d	MATC	Mortality	17.0	707	4331.8	5.5-7.7	Suedel et al	1997
Mottled sculpin	Cottus bairdi	Swim-up fry	28 d	EC50	Biomass, decrease in	102	2.4	2	8.21	Besser et al.	2007
Mottled sculpin	Cottus bairdi	Swim-up fry	21 d	EC50	Biomass, decrease in	104	1.77	2	8.23	Besser et al.	2007
Northern pike	Esox lucius	Embryo	35 d	LOEC/L	Biomass, decrease in	45	12.9	29	7.6 (7.2-7.8)	Eaton et al.	1978
Northern pike	Esox lucius	Embryo	35 d	MATC	Biomass, decrease in	45	7.4	17	7.6 (7.2-7.8)	Eaton et al.	1978
Northern pike	Esox lucius	Embryo	35 d	NOEC/L	Biomass, decrease in	45	4.2	10	7.6 (7.2-7.8)	Eaton et al.	1978
Northwestern salamander	Ambystoma gracile	Larva	24 d	LOEC/L	Weight	45	193.1	437	6.8	Nebeker et al	1995
Northwestern salamander	Ambystoma gracile	Larva	10 d	LOEC/L	Weight	45	227.3	514	6.8	Nebeker et al	1995
Northwestern salamander	Ambystoma gracile	Larva	24 d	MATC	Weight	45	97.2	220	6.8	Nebeker et al	1995
Northwestern salamander	Ambystoma gracile	Larva	10 d	MATC	Weight	45	155.4	352	6.8	Nebeker et al	1995
Northwestern salamander	Ambystoma gracile	Larva	24 d	NOEC/L	Weight	45	48.9	111	6.8	Nebeker et al	1995
Northwestern salamander	Ambystoma gracile	Larva	10 d	NOEC/L	Weight	45	106.3	241	6.8	Nebeker et al	1995
Rainbow trout	Oncorhynchus mykiss	Adult	65 wks	LOEC/L	Reproduction - delay in oogenesis	250	1.77	0.7	7.4-8.0	Brown et al	1994
Rainbow trout	Oncorhynchus mykiss	Adult	65 wks	MATC	Reproduction - delay in oogenesis	250	0.91	0.4	7.4-8.0	Brown et al	1994
Rainbow trout	Oncorhynchus mykiss	Adult	65 wks	NOEC/L	Reproduction - delay in oogenesis	250	0.47	0.2	7.4-8.0	Brown et al	1994
Rainbow trout	Oncorhynchus mykiss	Alevin	8 d	LC10	Mortality	23	>6	>27	7.1-7.5	Chapman	1978
Rainbow trout	Oncorhynchus mykiss	Swim-up fry	8 d	LC10	Mortality	23	1	4.5	7.1-7.5	Chapman	1978
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	EC10	Length	29.4	>2.5	>8.7	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	53 d	EC10	Mortality	19.7	0.82	4.3	6.75 (5.0-7.7)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	EC10	Mortality	29.4	1.6	5.6	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	EC10	Weight	29.4	0.15	0.5	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	LOEC/L	Length	29.4	0.16	0.6	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	53 d	LOEC/L	Mortality	19.7	1.3	6.9	6.75 (5.0-7.7)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	LOEC/L	Mortality	29.4	2.5	8.7	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	LOEC/L	Weight	29.4	0.16	0.6	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	53 d	MATC	Mortality	19.7	0.88	4.6	6.75 (5.0-7.7)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	MATC	Mortality	29.4	1.6	5.6	7.19 (SD = 0.30)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	53 d	NOEC/L	Mortality	19.7	0.6	3.2	6.75 (5.0-7.7)	Mebane et al.	2007
Rainbow trout	Oncorhynchus mykiss	Early life stage	62 d	NOEC/L	Mortality	29.4	1	3.5	7.19 (SD = 0.30)	Mebane et al.	2007

Table B.1: Summary of long-term effects of cadmium on a variety of aquatic organisms

Species Common Name	Scientific Name	Life stage	Duration	Endpoint	Observed Effect	Test Hardness (mg/L)	Effect Concentration (ug/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Water flea	Ceriodaphnia dubia	Not reported	14 d	MATC	Mortality	17.0	11.4	69.8	5.5-7.7	Suedel et al	1997
Water flea	Ceriodaphnia dubia	Not reported	10 d	MATC	Mortality	17.0	11.4	69.8	5.5-7.7	Suedel et al	1997
Water flea	Ceriodaphnia dubia	Not reported	7 d	MATC	Mortality	17.0	11.4	69.8	5.5-7.7	Suedel et al	1997
Water flea	Ceriodaphnia dubia	Not reported	14 d	MATC	Reproduction	17.0	2	12.3	5.5-7.7	Suedel et al	1997
Water flea	Ceriodaphnia dubia	Not reported	10 d	MATC	Reproduction	17.0	2	12.3	5.5-7.7	Suedel et al	1997
Water flea	Ceriodaphnia dubia	Not reported	7 d	MATC	Reproduction	17.0	2	12.3	5.5-7.7	Suedel et al	1997
Water flea	Daphnia magna	Adult	7 d	EC10	Feeding inhibition	179	0.13	0.1	8.07 +- 0.07	Barata and Baird	2000
Water flea	Daphnia magna	Adult	7 d	EC10	Repro - brood mass	179	0.13	0.1	8.07 +- 0.07	Barata and Baird	2000
Water flea	Daphnia magna	Adult	7 d	EC10	Reproduction - Brood size	179	0.14	0.1	8.07 +- 0.07	Barata and Baird	2000
Water flea	Daphnia magna	Adult	7 d	EC10	Weight	179	1.65	0.9	8.07 +- 0.07	Barata and Baird	2000
Water flea	Daphnia magna	Adult	7 d	LC10	Mortality	179	1.15	0.6	8.07 +- 0.07	Barata and Baird	2000
Water flea	Daphnia magna	Less than 24hrs	21 d	EC16	Reproduction	45.3	0.17	0.4	7.74 (7.4-8.2)	Biesinger and Christensen	1972
Water flea	Daphnia magna	Not reported	21 d	LOEC/L	Reproduction - Number of young per adult	130	1.86	1.4		Borgmann et al	1989
Water flea	Daphnia magna	Not reported	21 d	MATC	Reproduction - Number of young per adult	130	0.64	0.5		Borgmann et al	1989
Water flea	Daphnia magna	Not reported	21 d	NOEC/L	Reproduction - Number of young per adult	130	0.22	0.2		Borgmann et al	1989
Water flea	Daphnia magna	Less than 24hrs	21 d	MATC	Repro - Number of young per survivor	53	1.52	2.9	7.5 +- 0.2	Chapman et al	1980
Water flea	Daphnia magna	Less than 24hrs	21 d	MATC	Repro - Number of young per survivor	103	0.21	0.2	7.9 +- 0.3	Chapman et al	1980
Water flea	Daphnia magna	Less than 24hrs	21 d	MATC	Reproduction - Number of young per adult	53	0.15	0.3	7.5 +- 0.2	Chapman et al	1980
Water flea	Daphnia magna	Less than 24hrs	21 d	MATC	Reproduction - Number of young per adult	103	0.38	0.4	7.9 +- 0.3	Chapman et al	1980
Water flea	Daphnia magna	Less than 24hrs	14 d	MATC	Reproduction - Number of young per adult	240	4.3	1.8	8.0 +- 0.3	Elnabarawy et al	1986
Water flea	Daphnia magna	24h	21 d	LOEC/L	Reproduction	249.8	1.94	0.8	8.0 +- 0.2	Kuhn et al	1989
Water flea	Daphnia magna	24h	21 d	MATC	Reproduction	249.8	1.09	0.4	8.0 +- 0.2	Kuhn et al	1989
Water flea	Daphnia magna	24h	21 d	NOEC/L	Reproduction	249.8	0.6	0.2	8.0 +- 0.2	Kuhn et al	1989
Water flea	Daphnia magna	Not reported	7 d	MATC	Mortality	78.0	7.1	9.2	6.9-8.3	Suedel et al	1997
Water flea	Daphnia magna	Not reported	10 d	MATC	Mortality	78.0	7.1	9.2	6.9-8.3	Suedel et al	1997
Water flea	Daphnia magna	Not reported	14 d	MATC	Mortality	78.0	7.1	9.2	6.9-8.3	Suedel et al	1997
Water flea	Daphnia magna	Neonate	7 d	MATC	Growth	90	1.2	1.3		Winner	1988
Water flea	Daphnia pulex	Less than 24hrs	14 d	MATC	Reproduction - Number of young per adult	240	13.7	5.6	8.0 +- 0.3	Elnabarawy et al	1986
White Sucker	Catostomus commersoni	Embryo	40 h	LOEC/L	Biomass, decrease in	45	12	27	7.6 (7.2-7.8)	Eaton et al.	1978
White Sucker	Catostomus commersoni	Embryo	40 h	MATC	Biomass, decrease in	45	7.1	16	7.6 (7.2-7.8)	Eaton et al.	1978
White Sucker	Catostomus commersoni	Embryo	40 h	NOEC/L	Biomass, decrease in	45	4.2	10	7.6 (7.2-7.8)	Eaton et al.	1978

[1] If adjusted from another hardness, value was calculated using the following equation: EXP(LN(EFFECT conc)-(1.023)*(LN(measured water hardness)-LN(desired water hardness)))

(grey shading) most sensitive effect end-point for species

APPENDIX C

Zinc Toxicity Data

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Amphipod	*Hyalella azteca*	1 week	10 weeks	LOEC	Mortality	180	130	144	7.9-8.6	Borgmann et al	1993
Amphipod	*Hyalella azteca*	1 week	10 weeks	MATC	Mortality	134.16	130	107	7.9-8.6	Borgmann et al	1993
Amphipod	*Hyalella azteca*	1 week	10 weeks	NOEC	Mortality	100	130	80	7.9-8.6	Borgmann et al	1993
Amphipod	*Hyalella azteca*	1- 11 days	7 d	LC50	Mortality	56	18	239	6.44-8.68	Borgmann et al	2005
Amphipod	*Hyalella azteca*	1- 11 days	7 d	LC50	Mortality	70	18	299	6.44-8.68	Borgmann et al	2005
Amphipod	*Hyalella azteca*	1- 11 days	7 d	LC50	Mortality	222	124	185	7.23-8.98	Borgmann et al	2005
Atlantic salmon	*Salmo salar*	parr	14 d	LC50	Mortality	3640	351	1258	7.6	Hodson and Sprague	1975
Atlantic salmon	*Salmo salar*	parr	14 d	LC50	Mortality	5046	351	1744	7.6	Hodson and Sprague	1975
Atlantic salmon	*Salmo salar*	parr	14 d	LC50	Mortality	5198	351	1797	7.6	Hodson and Sprague	1975
Bluegill	*Lepomis macrochirus*	Not reported	20 d	TLM	Mortality	11300	370	3736	7.8 (7.7-8.0)	Pickering	1968
Brook Trout	*Salvelinus fontinalis*	Egg	100 weeks	EC10	Hatching success	418	45.9	808	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	24 w	IC10	egg fragility	200	45.9	386	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	8 weeks	LC10	Embryo (6 hours old) survival to hatch	1114	45.9	2153	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	12 weeks	LC10	Mortality	1215	45.9	2348	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	24 w	LOEC	egg fragility	266	45.9	514	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	100 weeks	LOEC	Hatching success	534	45.9	1032	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	12 weeks	LOEC	Mortality	1382	45.9	2671	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	12 weeks	LOEC	Mortality	2099	45.9	4056	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	8 weeks	LOEC	Mortality	1382	45.9	2671	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	24 w	MATC	egg fragility	174	45.9	336	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	8 weeks	MATC	Embryo (6 hours old) survival to hatch	990	45.9	1913	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	100 weeks	MATC	Hatching success	377	45.9	729	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	12 weeks	MATC	Mortality	990	45.9	1913	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	8 weeks	MATC	Mortality	1000	45.9	1932	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	8 weeks	MATC	Mortality	1685	45.9	3256	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	24 w	NOEC	egg fragility	114	45.9	220	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Egg	100 weeks	NOEC	Hatching success	266	45.9	514	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	12 weeks	NOEC	Mortality	709	45.9	1370	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	12 weeks	NOEC	Mortality	1353	45.9	2615	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	Embryo	8 weeks	NOEC	Mortality	724	45.9	1399	7.2-7.9	Holcombe et al.	1979
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	IC25	Growth	486.61		487		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	LC50	survival	798.91		799		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	LOEC	Growth	500		500		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	LOEC	survival	594.6		595		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	MATC	survival	443		443		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	NOEC	Growth	287.17		287		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	30-45-d old fry	7 d	NOEC	survival	329.87		330		Lazorchak and Smith	2007
Brook Trout	*Salvelinus fontinalis*	Juvenile	14 d	LC10	Mortality	445		445	7.3	Nehring and Goettl	1974
Brook Trout	*Salvelinus fontinalis*	Juvenile	14 d	LC50	Mortality	960		960	7.3	Nehring and Goettl	1974
Bryozoan	*Lophopodella carteri*	2-3 days	96 h	LC50	Mortality	4093	205	2230	6.7-7.0	Pardue and Wood	1980
Bryozoan	*Lophopodella carteri*	2-3 days	96 h	LC50	Mortality	5630	205	3067	6.7-7.0	Pardue and Wood	1980
Bryozoan	*Pectinatella magnifica*	2-3 days	96 h	LC10	Mortality	2286	205	1245	6.7-7.0	Pardue and Wood	1980
Bryozoan	*Pectinatella magnifica*	2-3 days	96 h	LC50	Mortality	4310	205	2348	6.7-7.0	Pardue and Wood	1980
Bryozoan	*Plumatella emarginata*	2-3 days	96 h	LC10	Mortality	3474	205	1893	6.7-7.0	Pardue and Wood	1980
Bryozoan	*Plumatella emarginata*	2-3 days	96 h	LC50	Mortality	5300	205	2888	6.7-7.0	Pardue and Wood	1980
Chinook salmon	*Oncorhynchus tshawytscha*	Alevin	200 h	LC10	Mortality	364-661	23	1262-2292	7.1	Chapman	1978
Chinook salmon	*Oncorhynchus tshawytscha*	Fry	200 h	LC10	Mortality	68	23	236	7.1	Chapman	1978
Chinook salmon	*Oncorhynchus tshawytscha*	Fry	200 h	LC50	Mortality	97	23	336	7.1	Chapman	1978
Chironomid	*Chironomus riparius*	1st instar	11 weeks	LOEC	Development	100		100	7.3-7.7	Timmermans et al.	1992
Chironomid	*Tanytarsus dissimilis*	Larva	10 d	LC50	Mortality	36.8	46.8	70	7.3- 7.7	Anderson et al	1980
Common duckmeat	*Spirodela polyrrhiza*	Adult	4 d	IC50	Growth	935	ND	935		Gaur et al.	1994
crayfish	*Orconectes virilis*	Adult	14 d	LC10	Mortality	9920	26	31006	7.1	Mirenda	1986

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
crayfish	*Orconectes virilis*	Adult	14 d	LC50	Mortality	84000	26	262550	7.1	Mirenda	1986
Cutthroat trout	*Oncorhynchus clarkii*	Juvenile	14 d	LC10	Mortality	453	40	983	7.2	Nehring and Goettl	1974
Cutthroat trout	*Oncorhynchus clarkii*	Juvenile	14 d	LC50	Mortality	670	40	1455	7.2	Nehring and Goettl	1974
Diatom	*Cyclotella meneghiniana*	Population	5 d	LC10	Growth rate	10689	121	9097	6.8	Cairns et al.	1978
Diatom	*Cyclotella meneghiniana*	Population	5 d	LC10	Growth rate	2803	121	2386	6.8	Cairns et al.	1978
Diatom	*Cyclotella meneghiniana*	Population	5 d	LC10	Growth rate	5716	121	4865	6.8	Cairns et al.	1978
Duckweed	*Lemna minor*	Adult	7 d	IC10	Growth	318		318	6.30-6.40	Dirilgen and Inel	1994
Duckweed	*Lemna minor*	Not reported	7 d	EC50	Growth	3014.48		3014	5.5 +/- 0.2	Drost et al	2007
Duckweed	*Lemna minor*	Not reported	7 d	EC10	Growth	1379.05		1379	6	Ince et al	1999
Duckweed	*Lemna minor*	Not reported	7 d	EC50	Growth	9600		9600	6	Ince et al	1999
Eurasian minnow	*Phoxinus phoxinus*	Yearling	150 d	LC10	Mortality	102	71	136	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Adult	30 d	LOEC	Growth	200	71	267	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Adult	150 d	LOEC	Growth	200	71	267	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Yearling	30 d	LOEC	Growth	130	71	174	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Yearling	150 d	LOEC	Growth	50	71	67	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Adult	30 d	MATC	Growth	161	71	215	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Adult	150 d	MATC	Growth	161	71	215	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Yearling	30 d	MATC	Growth	81	71	108	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Yearling	150 d	MATC	Growth	32	71	43	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Adult	30 d	NOEC	Growth	130	71	174	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Adult	150 d	NOEC	Growth	130	71	174	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Yearling	30 d	NOEC	Growth	50	71	67	7.1-8.2	Bengtsson	1974
Eurasian minnow	*Phoxinus phoxinus*	Yearling	150 d	NOEC	Growth	20	71	27	7.1-8.2	Bengtsson	1974
Fathead minnow	*Pimephales promelas*	Egg	NR	EC10	Eggs adhesiveness	46.9	46	90	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	LOEC/L	Eggs adhesiveness	145	46	280	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	LOEC/L	Hatching success	295	46	569	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	LOEC/L	Mortality	295	46	569	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	MATC	Eggs adhesiveness	106	46	204	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	MATC	Hatching success	207	46	399	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	MATC	Mortality	207	46	399	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	NOEC/L	Eggs adhesiveness	78	46	150	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	NOEC/L	Hatching success	145	46	280	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Egg	NR	NOEC/L	Mortality	145	46	280	7-8	Benoit and Holcombe	1978
Fathead minnow	*Pimephales promelas*	Larva	7 d	ChV	Growth	430	190	250	8.3-8.7	Magliette et al.	1995
Fathead minnow	*Pimephales promelas*	Larva	7 d	LC50	Mortality	780	190	453	8.3-8.7	Magliette et al.	1995
Fathead minnow	*Pimephales promelas*	Larva	7 d	LOEC/L	Growth	630	190	366	8.3-8.7	Magliette et al.	1995
Fathead minnow	*Pimephales promelas*	Larva	7 d	IC10	Growth	83.9	48	156		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	LOEC	Growth	374	48	696		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	LOEC	Mortality	184	48	342		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	MATC	Growth	262	48	487		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	MATC	Mortality	125	48	233		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	NOEC	Growth	184	48	342		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	NOEC	Mortality	84.6	48	157		Norberg and Mount	1985
Fathead minnow	*Pimephales promelas*	Larva	7 d	ChV	Growth	184	47	349	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	7 d	ChV	Growth	315	47	597	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	32 d	ChV	Mortality	188	47	356	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	7 d	LC50	Mortality	250	47	474	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	7 d	LC50	Mortality	283	47	536	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	7 d	LOEC	Growth	278	47	527	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	7 d	LOEC	Growth	454	47	860	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	32 d	LOEC	Mortality	275	47	521	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	7 d	NOEC	Growth	122	47	231	7.4-8.2	Norberg-King	1989

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Fathead minnow	*Pimephales promelas*	Larva	7 d	NOEC	Growth	218	47	413	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Larva	32 d	NOEC	Mortality	129	47	244	7.4-8.2	Norberg-King	1989
Fathead minnow	*Pimephales promelas*	Egg	12 d	NOEC	Mortality	1050	186	621	7.5-7.6	Pickering and Vigor	1965
Fathead minnow	*Pimephales promelas*	Fry	7 d	NOEC	Mortality	560	186	331	7.5-7.6	Pickering and Vigor	1965
Fathead minnow	*Pimephales promelas*	Egg	7 d	TLM	Mortality	1690	186	1000	7.5-7.6	Pickering and Vigor	1965
Fathead minnow	*Pimephales promelas*	Egg	12 d	TLM	Mortality	1630	186	964	7.5-7.6	Pickering and Vigor	1965
Fathead minnow	*Pimephales promelas*	Fry	7 d	TLM	Mortality	870	186	515	7.5-7.6	Pickering and Vigor	1965
Green alga	*Chlamydomonas sp.*	Population	10 d	LC10	Growth rate	8381	121	7133	6.8	Cairns et al.	1978
Green alga	*Chlamydomonas sp.*	Population	10 d	LC10	Growth rate	9398	121	7998	6.8	Cairns et al.	1978
Green alga	*Chlorella pyrenoidosa*	Not reported	24 h	EC50	Growth	57	25.51	181		Lin et al	2007
Green alga	*Chlorella pyrenoidosa*	Not reported	24 h	LOEC	Cell density	40	25.51	127		Lin et al	2007
Green alga	*Chlorella pyrenoidosa*	Not reported	24 h	MATC	Cell density	28.28	25.51	90		Lin et al	2007
Green alga	*Chlorella pyrenoidosa*	Not reported	24 h	NOEC	Cell density	20	25.51	64		Lin et al	2007
Green alga	*Chlorella vulgaris*	exponential growth phase	72 h	EC50	biomass	34		34		Muyssen and Janssen	2001
Green alga	*Chlorella vulgaris*	exponential growth phase	72 h	EC50	Growth	153		153		Muyssen and Janssen	2001
Green alga	*Pseudokirchneriella subcapitata*	Not reported	24 h	EC50	Growth	15		15		Chen et al	1997
Green alga	*Pseudokirchneriella subcapitata*	Not reported	96 h	EC50	Growth	178		178		Chen et al	1997
Green alga	*Pseudokirchneriella subcapitata*	Not reported	7 d	EC10	Growth	1.05		1.1	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	96 h	EC10	Growth	1.32		1.3	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	96 h	EC10	Growth	11.74		12	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	7 d	EC10	Growth	13.48		13	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	7 d	EC50	Growth	4.1		4.1	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	96 h	EC50	Growth	4.4		4.4	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	96 h	EC50	Growth	27		27	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Not reported	7 d	EC50	Growth	32		32	6.0-6.3	Chiaaudani and Vighi	1978
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	58.1	19.6	231	8	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	62.3	19.6	247	8	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	71.2	19.6	283	8	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	85	19.6	337	7	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	131	19.6	520	7	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	142	19.6	564	6	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	142	19.6	564	7	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	191	19.6	758	6	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	215	19.6	853	6	De Schamphelaere et al.	2004
Green alga	*Pseudokirchneriella subcapitata*	less than 72h	72 h	IC50	biomass	4.12	40	8.9	7.3	Errécalde et al.	1998
Green alga	*Pseudokirchneriella subcapitata*	less than 72h	72 h	IC50	biomass	32.7	40	71	7.3	Errécalde et al.	1998
Green alga	*Pseudokirchneriella subcapitata*	less than 72h	72 h	IC50	biomass	39.24	40	85	7.3	Errécalde et al.	1998
Green alga	*Pseudokirchneriella subcapitata*	less than 72h	72 h	IC50	Growth rate	11.12	40	24	7.3	Errécalde et al.	1998
Green alga	*Pseudokirchneriella subcapitata*	less than 72h	72 h	IC50	Growth rate	45.13	40	98	7.3	Errécalde et al.	1998
Green alga	*Pseudokirchneriella subcapitata*	less than 72h	72 h	IC50	Growth rate	68.68	40	149	7.3	Errécalde et al.	1998
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	10.5	24.4	35	7.8	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	15.8	24.4	52	7.7	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	21.1	24.4	70	7.65	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	26.4	24.4	87	7.3	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	26.4	24.4	87	7.4	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	29	24.4	96	7.6	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	47.5	24.4	157	7.1	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	94.8	24.4	313	6.8	Heijerick et al.	2002

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Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	119	24.4	392	6.2	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	224	24.4	739	5.6	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	8.44	37.2	19	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	10.5	37.2	24	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	10.9	62.3	16	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	11.1	62.3	17	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	14.9	112.3	14	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	27.9	112.3	25	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	15.4	162.3	10	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	33.2	162.3	22	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	17.5	212.4	9	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	34.4	212.4	18	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	Population	72 h	EC50	biomass	54.9	262.6	24	7.5	Heijerick et al.	2002
Green alga	*Pseudokirchneriella subcapitata*	exponential growth phase	72 h	EC50	biomass	39		39		Muyssen and Janssen	2001
Green alga	*Pseudokirchneriella subcapitata*	exponential growth phase	72 h	EC50	Growth	138		138		Muyssen and Janssen	2001
Green alga	*Pseudokirchneriella subcapitata*	Not reported	48 h	EC50	Growth	96	130	77	7.8-8.8	Pardos et al	1998
Green alga	*Scenedesmus quadricauda*	Population	5 d	LC10	Growth rate	10451	121	8894	6.8	Cairns et al.	1978
Green alga	*Scenedesmus quadricauda*	Population	5 d	LC10	Growth rate	9559	121	8135	6.8	Cairns et al.	1978
Green alga	*Scenedesmus quadricauda*	Population	15 d	IC10	Growth	96.1		96	4.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	14 d	LOEC	Growth	225		225	6.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	14 d	LOEC	Growth	500		500	8.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	15 d	LOEC	Growth	100		100	4.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	14 d	MATC	Growth	150		150	6.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	14 d	MATC	Growth	335		335	8.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	14 d	NOEC	Growth	100		100	6.5	Starodub et al.	1987
Green alga	*Scenedesmus quadricauda*	Population	14 d	NOEC	Growth	225		225	8.5	Starodub et al.	1987
Green hydra	*Hydra viridissima*	Not reported	7 d	EC10	Population growth inhibition	52.23	20	204	7.25-7.53	Holdway et al	2001
Green hydra	*Hydra viridissima*	Not reported	7 d	LOEC	Population growth inhibition	75	20	293	7.25-7.53	Holdway et al	2001
Green hydra	*Hydra viridissima*	Not reported	7 d	MATC	Population growth inhibition	53.4	20	208	7.25-7.53	Holdway et al	2001
Green hydra	*Hydra viridissima*	Not reported	7 d	NOEC	Population growth inhibition	38	20	148	7.25-7.53	Holdway et al	2001
Mayfly	*Epeorus latifolium*	Larva	4 weeks	IC10	emergence	14.4	83	17	7.9-8.0	Hatakeyama	1989
Mayfly	*Epeorus latifolium*	Larva	4 weeks	LC10	Mortality	15	83	18	7.9-8.0	Hatakeyama	1989
Mayfly	*Rhithrogena hageni*	nymph	10 d	EC10	Mortality	2069.2	44.4	4113	7.77	Brinkman and Johnston	2008
Mayfly	*Rhithrogena hageni*	nymph	10 d	LOEC	Mortality	10800	44.4	21465	7.77	Brinkman and Johnston	2008
Mayfly	*Rhithrogena hageni*	nymph	10 d	MATC	Mortality	7565.71	44.4	15037	7.77	Brinkman and Johnston	2008
Mayfly	*Rhithrogena hageni*	nymph	10 d	NOEC	Mortality	5300	44.4	10534	7.77	Brinkman and Johnston	2008
Mixed invertebrates	N/A	Population	14 d	LOEC	Community similarity	17.1	135	13		Marshall et al.	1983
Mixed invertebrates	N/A	Population	14 d	LOEC	Primary productivity	17.1	135	13		Marshall et al.	1983
Mixed invertebrates	N/A	Population	14 d	LOEC	Specific zooplanton populations	17.1	135	13		Marshall et al.	1983
Mixed invertebrates	N/A	Population	14 d	LOEC	Zooplanction species diversity	17.1	135	13		Marshall et al.	1983
Mottled sculpin	*Cottus bairdi*	less than 2 months old	30 d	EC10	Mortality	155.7	154	108	7.5 (7.4-7.7)	Brinkman and Woodling	2005
Mottled sculpin	*Cottus bairdi*	less than 2 months old	30 d	LOEC	Mortality	379	154	263	7.5 (7.4-7.7)	Brinkman and Woodling	2005
Mottled sculpin	*Cottus bairdi*	less than 2 months old	30 d	MATC	Mortality	255	154	177	7.5 (7.4-7.7)	Brinkman and Woodling	2005
Mottled sculpin	*Cottus bairdi*	less than 2 months old	30 d	NOEC	Mortality	172	154	119	7.5 (7.4-7.7)	Brinkman and Woodling	2005
Mottled sculpin	*Cottus bairdi*	newly emerged	30 d	LC50	Mortality	32	48.6	59	7.38 (7.2-7.6)	Woodling et al	2002
Pink hydra	*Hydra vulgaris*	Not reported	7 d	EC10	Population growth inhibition	177.93	20	694	7.25-7.53	Holdway et al	2001
Pink hydra	*Hydra vulgaris*	Not reported	7 d	LOEC	Population growth inhibition	250	20	976	7.25-7.53	Holdway et al	2001
Rainbow trout	*Oncorhynchus mykiss*	Embryo	72 d	LC10	Mortality	458	25	1480	6.9-7.1	Cairns and Garton	1982
Rainbow trout	*Oncorhynchus mykiss*	Embryo	72 d	LOEC	Mortality	819	25	2646	6.9-7.1	Cairns and Garton	1982
Rainbow trout	*Oncorhynchus mykiss*	Embryo	72 d	MATC	Mortality	603	25	1948	6.9-7.1	Cairns and Garton	1982
Rainbow trout	*Oncorhynchus mykiss*	Embryo	72 d	NOEC	Mortality	444	25	1435	6.9-7.1	Cairns and Garton	1982
Rainbow trout	*Oncorhynchus mykiss*	Alevin	186 h	LC10	Mortality	256	23	888	7.1	Chapman	1978

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Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Rainbow trout	*Oncorhynchus mykiss*	Swim-up fry	200 h	LC10	Mortality	54	23	187	7.1	Chapman	1978
Rainbow trout	*Oncorhynchus mykiss*	Alevin	186 h	LC50	Mortality	555	23	1924	7.1	Chapman	1978
Rainbow trout	*Oncorhynchus mykiss*	Swim-up fry	200 h	LC50	Mortality	93	23	322	7.1	Chapman	1978
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	312	29.1	887	5.68	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	46.1	29.1	131	7.65	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	73.6	29.1	209	7.58	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	99.1	29.1	282	6.78	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	38.4	29.6	108	7.45	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	34.5	31.72	91	7.58-7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	171	104.99	164	7.58-7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	290	190.35	168	7.58-7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	337	398.68	105	7.58-7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	>1280	29.1	>3637	6.7	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	>1280	29.1	>3637	7.74	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	>1740	29.1	>4944	7.58	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	>800	29.1	>2273	5.68	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	345	29.1	980	7.61	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	>375	29.6	>1050	7.45	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	Growth	2310	29.6	6470	7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	survival	162	29.1	460	7.65	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	survival	166	29.1	472	7.61	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	survival	117	29.6	328	7.45	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LOEC	survival	2310	29.6	6470	7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Growth	166	29.1	472	7.61	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Growth	974	29.6	2728	7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	survival	45.4	29.1	129	7.73	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	survival	78.9	29.1	224	7.61	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	survival	31.5	29.6	88	7.45	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	survival	974	29.6	2728	7.87	De Schamphelaere and Janssen	2004
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	259	23.4	885	6.15	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	185	28.2	540	6.8	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	219	31.5	582	7.08	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	902	103.7	875	7.76	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC10	Mortality	578	176.3	358	8.13	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC50	Mortality	582	23.4	1989	6.15	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC50	Mortality	406	28.2	1185	6.8	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC50	Mortality	337	31.5	895	7.08	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC50	Mortality	1970	103.7	1910	7.76	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	LC50	Mortality	1850	176.3	1145	8.13	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Mortality	370	23.4	1264	6.15	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Mortality	324	28.2	945	6.8	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Mortality	199	31.5	529	7.08	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Mortality	771	103.7	748	7.76	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	30 d	NOEC	Mortality	696	176.3	431	8.13	De Schamphelaere et al.	2005
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	IC25	Growth	148.03		148		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	LC50	survival	195.38		195		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	LOEC	Growth	250		250		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	LOEC	survival	250		250		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	MATC	survival	177		177		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	NOEC	Growth	114.63		115		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	15-25-d old fry	7 d	NOEC	survival	125		125		Lazorchak and Smith	2007
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	EC10	Length	300	19.7	1186	6.75 +/- 0.4	Mebane et al	2008

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	EC10	Mortality	88	19.7	348	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	EC10	Weight	199	19.7	787	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	EC20	Mortality	147	19.7	581	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	EC20	Weight	387	19.7	1530	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	LOEC	Length	365	19.7	1443	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	LOEC	Mortality	117	19.7	462	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	LOEC	Weight	365	19.7	1443	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	MATC	Length	279	19.7	1103	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	MATC	Weight	279	19.7	1103	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	NOEC	Length	214	19.7	846	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Fry	69 days	NOEC	Weight	214	19.7	846	6.75 +/- 0.4	Mebane et al	2008
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	14 d	LC10	Mortality	318	37	737	7.3	Nehring and Goettl	1974
Rainbow trout	*Oncorhynchus mykiss*	Juvenile	14 d	LC50	Mortality	410	37	951	7.3	Nehring and Goettl	1974
Rainbow trout	*Oncorhynchus mykiss*	Fingerling	22 months	LOEC/L	Mortality	640	333	231	7.81	Sinley et al.	1974
Rainbow trout	*Oncorhynchus mykiss*	Fingerling	22 months	MATC	Mortality	453	333	164	7.81	Sinley et al.	1974
Rainbow trout	*Oncorhynchus mykiss*	Fingerling	22 months	NOEC/L	Mortality	320	333	116	7.81	Sinley et al.	1974
Rotifer	*Brachionus havanaensis*	adults and juveniles	18 d	EC10	Population growth inhibition	78.2		78	7.1-7.3	Juarez-Franco et al	2007
Rotifer	*Brachionus havanaensis*	adults and juveniles	18 d	LOEC	Population growth inhibition	141.94		142	7.1-7.3	Juarez-Franco et al	2007
Rotifer	*Brachionus havanaensis*	adults and juveniles	18 d	MATC	Population growth inhibition	100.36		100	7.1-7.3	Juarez-Franco et al	2007
Rotifer	*Brachionus havanaensis*	adults and juveniles	18 d	NOEC	Population growth inhibition	70.96		71	7.1-7.3	Juarez-Franco et al	2007
Sea trout	*Salmo trutta*	Juvenile	14 d	LC10	Mortality	504	39	1118	7.2	Nehring and Goettl	1974
Sea trout	*Salmo trutta*	Juvenile	14 d	LC50	Mortality	640	39	1420	7.2	Nehring and Goettl	1974
Snail	*Physa gyrina*	Adult	30 d	LC50	Mortality	771	36	1830	6.9	Nebeker et al.	1986
Snail	*Physa gyrina*	Adult	30 d	NOEC/L	Mortality	570	36	1353	6.9	Nebeker et al.	1986
Snail	*Potamopyrgus jenkinsi*	Juvenile	12 weeks	EC50	Growth	103	159	70	7.8-8.2	Dorgelo et al.	1995
Snail	*Potamopyrgus jenkinsi*	Juvenile	12 weeks	LOEC	Growth	115	159	78	7.8-8.2	Dorgelo et al.	1995
Snail	*Potamopyrgus jenkinsi*	Juvenile	12 weeks	MATC	Growth	91	159	61	7.8-8.2	Dorgelo et al.	1995
Snail	*Potamopyrgus jenkinsi*	Juvenile	12 weeks	NOEC	Growth	72	159	49	7.8-8.2	Dorgelo et al.	1995
Star duckweed	*Lemna trisulca*	Not reported	14 d	EC50	final yield (oven dry weight)	327	20.37	1256	7.8-8.3 +/- 0.3	Huebert and Shay	1992
Star duckweed	*Lemna trisulca*	Not reported	14 d	EC50	multiplication rate (number of fronds)	915.6	20.37	3518	7.8-8.3 +/- 0.3	Huebert and Shay	1992
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	LOEC	Reproduction - Number of young per adult	25	97.6	26	6	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	LOEC	Reproduction - Number of young per adult	25	97.6	26	8	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	LOEC	Reproduction - Number of young per adult	50	97.6	51	9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	LOEC	Reproduction - Number of young per adult	100	113.6	90	6, 8, 9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	LOEC	Reproduction - Number of young per adult	100	182	60	8	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	LOEC	Reproduction - Number of young per adult	50	182	30	6	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	MATC	Reproduction - Number of young per adult	35	97.6	36	9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	MATC	Reproduction - Number of young per adult	71	113.6	64	6, 8, 9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	MATC	Reproduction - Number of young per adult	71	182	43	8	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	NOEC	Reproduction - Number of young per adult	25	97.6	26	9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	NOEC	Reproduction - Number of young per adult	50	113.6	45	6, 8, 9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	NOEC	Reproduction - Number of young per adult	100	182	60	9	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	4 weeks	NOEC	Reproduction - Number of young per adult	50	182	30	8	Belanger et Cherry	1990
Water flea	*Ceriodaphnia dubia*	60-84 h	96 h	ChV	Mortality	70	169	45	7.8-8.2	Masters et al.	1991
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	7 d	ChV	Mortality	90	169	58	7.8-8.2	Masters et al.	1991
Water flea	*Ceriodaphnia dubia*	60-84 h	96 h	ChV	Reproduction - Brood size	45	169	29	7.8-8.2	Masters et al.	1991
Water flea	*Ceriodaphnia dubia*	Less than 24hrs	7 d	ChV	Reproduction - Brood size	105	169	67	7.8-8.2	Masters et al.	1991
Water flea	*Ceriodaphnia dubia*	Juvenile	9 d	EC50	Immobility	354	280	148	7.8	Muyssen and Janssen	2002
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC16	Repro - Number of young per survivor	70	49	128	7.4-8.2	Biesinger and Christensen	1972
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Repro - Number of young per survivor	102	49	187	7.4-8.2	Biesinger and Christensen	1972
Water flea	*Daphnia magna*	Less than 24hrs	21 d	LC50	Immobility	158	49	289	7.4-8.2	Biesinger and Christensen	1972
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	92.1	26.5	283	7.3	De Schamphelaere et al.	2005

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	378	122.4	319	6.8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	59.2	124.7	49	8.4	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	265	183.2	159	8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	171	189.3	100	8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	126	196.4	71	8.2	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC10	Reproduction - Number of young per adult	196	250.5	90	7.2	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	112	26.5	344	7.3	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	536	122.4	452	6.8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	171	124.7	142	8.4	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	473	183	284	8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	313	189	183	8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	242	196.4	137	8.2	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	EC50	Reproduction - Number of young per adult	299	250.5	137	7.2	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	62.6	13.8	334	6	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	94.5	26.5	291	7.3	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	491	122.4	414	6.8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	72.7	124.7	60	8.4	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	251	183	151	8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	244	189.3	142	8	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	143	196.4	81	8.2	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Less than 24hrs	21 d	NOEC	Reproduction - Number of young per adult	155	250.5	71	7.2	De Schamphelaere et al.	2005
Water flea	*Daphnia magna*	Population	21 d	EC10	Population growth inhibition	420	225	211	8.1	Enserink et al.	1991
Water flea	*Daphnia magna*	Population	21 d	EC50	Population growth inhibition	570	225	287	8.1	Enserink et al.	1991
Water flea	*Daphnia magna*	Less than 24hrs	21 d	LC50	Mortality	840	225	423	8.1	Enserink et al.	1991
Water flea	*Daphnia magna*	Less than 24hrs	21 d	LOEC	Length	120	225	60	8.1	Enserink et al.	1991
Water flea	*Daphnia magna*	Less than 24hrs	21 d	LOEC	Mortality	1000	225	504	8.1	Enserink et al.	1991
Water flea	*Daphnia magna*	Less than 24hrs	21 d	LOEC	Repro - Number of young per survivor	1000	225	504	8.1	Enserink et al.	1991
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	328	35	797	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	233	110	215	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	277	110	256	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	313	110	289	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	557	110	514	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	179	240	85	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	308	240	147	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	331	240	158	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	394	240	188	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	502	240	239	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	634	240	302	8.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	911	240	434	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	423	240	202	6	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	114	370	38	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	341	370	113	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	600	370	198	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	EC10	Reproduction	90	370	30	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	445	35	1082	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	209	110	193	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	320	110	295	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	445	110	411	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	630	110	581	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	1000	240	477	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	209	240	100	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	320	240	153	7.25	Heijerick et al.	2003

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	575	240	274	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	575	240	274	7.25	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	630	240	300	8.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	425	240	203	6	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	320	370	106	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	320	370	106	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	630	370	208	6.5	Heijerick et al.	2003
Water flea	*Daphnia magna*	Not reported	21 d	NOEC	Reproduction	630	370	208	8	Heijerick et al.	2003
Water flea	*Daphnia magna*	Adult	21 d	EC50	Reproduction	196	50	352	7	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	EC50	Reproduction	202	50	363	6.5	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	EC50	Reproduction	218	50	392	6	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	EC50	Reproduction	233	50	419	7.5	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	EC50	Reproduction	239	50	430	5.5	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	EC50	Reproduction	262	50	471	8	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	NOEC	Reproduction	117	50	210	8	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	NOEC	Reproduction	133	50	239	7.5	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	NOEC	Reproduction	154	50	277	7	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	NOEC	Reproduction	161	50	289	5.5	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	NOEC	Reproduction	162	50	291	6.5	Heijerick et al.	2005
Water flea	*Daphnia magna*	Adult	21 d	NOEC	Reproduction	168	50	302	6	Heijerick et al.	2005
Water flea	*Daphnia magna*	Less than 48h old	21 d	IC10	Reproduction - Number of young per adult	67.6	64.9	97	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 48h old	21 d	LOEC	Mortality	150	64.9	216	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 48h old	21 d	LOEC	Reproduction - Number of young per adult	150	64.9	216	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 48h old	21 d	MATC	Mortality	122	64.9	176	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 48h old	21 d	MATC	Reproduction - Number of young per adult	122	64.9	176	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 48h old	21 d	NOEC	Mortality	100	64.9	144	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 48h old	21 d	NOEC	Reproduction - Number of young per adult	100	64.9	144	7.6-7.8	Münzinger and Monicelli	1991
Water flea	*Daphnia magna*	Less than 24hrs	50 d	IC10	Reproduction - Brood size	29.8	51.9	52	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	IC10	Reproduction - Brood size	32.8	51.9	57	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	IC10	Reproduction - Brood size	55.7	51.9	97	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	IC10	Reproduction - Brood size	65.8	101.8	65	8.32	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	IC10	Reproduction - Brood size	158	197	89	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	IC10	Reproduction - Brood size	214	197	121	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Mortality	111.8	51.9	195	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Mortality	120.2	51.9	209	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Mortality	86.6	51.9	151	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Mortality	124.4	101.8	123	8.32	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Mortality	178.7	197	101	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Mortality	237.2	197	134	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Reproduction - Brood size	21.7	51.9	38	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Reproduction - Brood size	99.2	51.9	173	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Reproduction - Brood size	86.6	101.8	85	8.32	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Reproduction - Brood size	174.6	197	98	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	MATC	Reproduction - Brood size	224.7	197	127	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Mortality	112.5	51.9	196	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Mortality	120.8	51.9	210	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Mortality	87.5	51.9	152	8.39	Paulauskis and Winner	1988

Table C.1: Summary of long-term effects of zinc on a variety of aquatic organisms

Species Common Name	Scientific Name	Life Stage	Duration	Endpoint	Observed Effect	Effect Concentration (ug/L)	Test Hardness (mg/L)	Effect Concentration (ug/L) at 100 mg/L Hardness [1]	pH	Authors	Year
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Mortality	125	101.8	123	8.32	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Mortality	179.2	197	101	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Mortality	237.5	197	134	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Reproduction - Brood size	100	51.9	174	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Reproduction - Brood size	25	51.9	44	8.39	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Reproduction - Brood size	87.5	101.8	86	8.32	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Reproduction - Brood size	175	197	99	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	50 d	NEC	Reproduction - Brood size	225	197	127	8.29	Paulauskis and Winner	1988
Water flea	*Daphnia magna*	Less than 24hrs	134 d	LOEC	Growth	100	145	73	8.2-9.5	Winner	1981
Water flea	*Daphnia magna*	Less than 24hrs	134 d	LOEC	Reproduction - Brood size	300	145	219	8.2-9.5	Winner	1981
zebra mussel	*Dreissena polymorpha*	Adult	10 weeks	EC50	Filtration rate	131	268	57	7.9	Kraak et al.	1994
zebra mussel	*Dreissena polymorpha*	Adult	10 weeks	LC10	Mortality	517	268	225	7.9	Kraak et al.	1994
zebra mussel	*Dreissena polymorpha*	Adult	10 weeks	LC50	Mortality	1065	268	463	7.9	Kraak et al.	1994
zebra mussel	*Dreissena polymorpha*	Adult	10 weeks	LOEC	Filtration rate	382	268	166	7.9	Kraak et al.	1994
zebra mussel	*Dreissena polymorpha*	Adult	10 weeks	MATC	Filtration rate	196	268	85	7.9	Kraak et al.	1994
zebra mussel	*Dreissena polymorpha*	Adult	10 weeks	NOEC	Filtration rate	101	268	44	7.9	Kraak et al.	1994

[1] If adjusted from another hardness, value was calculated using the following equation: EXP(LN(EFFECT conc)-(0.846)*(LN(measured water hardness)-LN(desired water hardness)))

(shaded) most sensitive effect end-point

APPENDIX D

Hardness – Toxicity Relationships For Zinc and Cadmium

Table D.1: Data used to develop hardness-zinc toxicity relationships for long-term exposures to zinc.

Family	Species Common Name	Scientific Name	Duration	Endpoint	Life Stage	Observed Effect	Test Hardness (mg/L)	Effect Concentration (µg/L)	Mean Effect Concentration if Applicable (ug/L)	pH	Author(s)	Year
Algae	Green Algae	*Pseudokirchneriella subcapitata*	72 h	EC50	Population	biomass	212.4	17.5	←	7.5	Heijerick et al.	2002
			72 h	EC50	Population	biomass	212.4	34.4	←	7.5	Heijerick et al.	2002
				Mean EC50					24.5			
			72 h	EC50	Population	biomass	162.3	15.4	←	7.5	Heijerick et al.	2002
			72 h	EC50	Population	biomass	162.3	33.2	←	7.5	Heijerick et al.	2002
				Mean EC50					22.6			
			72 h	EC50	Population	biomass	112.3	14.9	←	7.5	Heijerick et al.	2002
			72 h	EC50	Population	biomass	112.3	27.9	←	7.5	Heijerick et al.	2002
				Mean EC50					20.4			
			72 h	EC50	Population	biomass	62.3	10.9	←	7.5	Heijerick et al.	2002
			72 h	EC50	Population	biomass	62.3	11.1	←	7.5	Heijerick et al.	2002
				Mean EC50					11.0			
			72 h	EC50	Population	biomass	37.2	8.44	←	7.5	Heijerick et al.	2002
			72 h	EC50	Population	biomass	37.2	10.5	←	7.5	Heijerick et al.	2002
				Mean EC50					9.41			
			72 h	EC50	Population	biomass	262.6	54.9		7.5	Heijerick et al.	2002
Invertebrates	Water Flea	*Daphnia magna*	21 d	EC10	< 24 hrs	Reproduction - # young / adult	196.4	126		8.2	De Schamphelaere et al.	2005
			21 d	EC10	< 24 hrs	Reproduction - # young / adult	189.3	171		8	De Schamphelaere et al.	2005
			21 d	EC10	< 24 hrs	Reproduction - # young / adult	183.2	265		8	De Schamphelaere et al.	2005
			21 d	EC10	< 24 hrs	Reproduction - # young / adult	124.7	59.2		8.4	De Schamphelaere et al.	2005
			21 d	EC10	Not reported	Reproduction (1)	110	233	←	8	Heijerick et al.	2003
			21 d	EC10	Not reported	Reproduction (1)	110	557	←	8	Heijerick et al.	2003
				Mean EC10					360			
			21 d	EC10	Not reported	Reproduction (1)	240	634		8.5	Heijerick et al.	2003
			21 d	EC10	Not reported	Reproduction (1)	370	600	←	8	Heijerick et al.	2003
			21 d	EC10	Not reported	Reproduction (1)	370	90	←	8	Heijerick et al.	2003
				Mean EC10					232			
			50 d	IC10	< 24 hrs	Reproduction - Brood size	51.9	29.8	←	8.39	Paulauskis and Winner	1988
			50 d	IC10	< 24 hrs	Reproduction - Brood size	51.9	32.8	←	8.39	Paulauskis and Winner	1988
			50 d	IC10	< 24 hrs	Reproduction - Brood size	51.9	55.7	←	8.39	Paulauskis and Winner	1988
				Mean IC10					37.9			
			50 d	IC10	< 24 hrs	Reproduction - Brood size	101.8	65.8		8.32	Paulauskis and Winner	1988
			50 d	IC10	< 24 hrs	Reproduction - Brood size	197	158	←	8.29	Paulauskis and Winner	1988
			50 d	IC10	< 24 hrs	Reproduction - Brood size	197	214	←	8.29	Paulauskis and Winner	1988
				Mean IC10					184			
			21 d	EC10	Population	Population growth inhibition	225	420		8.1	Enserink et al.	1991
			21 d	EC16	< 24 hrs	Reproduction - Number of young per survivor	49	70		7.4-8.2	Biesinger and Christensen	1972
				IC10	< 48 hrs	Reproduction - Number of young per adult	64.9	67.6		7.6-7.8	Münzinger and Monicelli	1991
		Ceriodaphnia dubia	7 d	ChV	24hrs	Reproduction - Brood size	169	105		7.8-8.2	Masters et al.	1991
			4 weeks	MATC	< 24 hrs	Reproduction - Number of young per adult	97.6	35	←	9	Belanger et Cherry	1990
			4 weeks	MATC	< 24 hrs	Reproduction - Number of young per adult	113.6	71	←	6, 8, 9	Belanger et Cherry	1990
			4 weeks	Mean MATC	24hrs	Reproduction- Number of young per adult	106		50			
			4 weeks	MATC	24hrs	Reproduction - Number of young per adult	182	71		8	Belanger et Cherry	1990
	Amphipod	*Hyalella azteca*	7 d	LC50	1- 11 days	Mortality (1)	18	56	←	6.44-8.68	Borgmann et al	2005
			7 d	LC50	1- 11 days	Mortality (1)	18	70	←	6.44-8.68	Borgmann et al	2005
			7 d	Mean LC50	1- 11 days	Mortality (1)			63			
			7 d	LC50	1- 11 days	Mortality (1)	124	222		7.23-8.98	Borgmann et al	2005
Fish	Rainbow Trout	*Oncorhynchus mykiss*	30 d	LC10	Juvenile	Mortality (1)	31.72	34.5		7.58-7.87	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	104.99	171		7.58-7.87	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	190.35	290		7.58-7.87	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	398.68	337		7.58-7.87	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	29.6	38.4	←	7.45	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	29.1	46.1	←	7.65	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	29.1	73.6	←	7.58	De Schamphelaere and Janssen	2004
				Mean LC10			29.3		50.7			
			30 d	LC10	Juvenile	Mortality (1)	29.1	99.1	←	6.78	De Schamphelaere and Janssen	2004
			30 d	LC10	Juvenile	Mortality (1)	28.2	185	←	6.8	De Schamphelaere et al.	2005
				Mean LC10					135			
			30 d	LC10	Juvenile	Mortality (1)	31.5	219		7.08	De Schamphelaere et al.	2005
			30 d	LC10	Juvenile	Mortality (1)	176.3	578		8.13	De Schamphelaere et al.	2005
			30 d	LC10	Juvenile	Mortality (1)	103.7	902		7.76	De Schamphelaere et al.	2005
	Fathead Minnow	*Pimephales promelas*	32 d	ChV	Larva	Mortality	47	188		7.4-8.2	Norberg-King	1989
			7 d	LC50	Larva	Mortality	190	780		8.3-8.7	Magliette et al.	1995
			NR	MATC	Egg	Mortality	46	207		7-8	Benoit and Holcombe	1978
			7 d	MATC	Larva	Mortality	48	125			Norberg and Mount	1985
			7 d	TLM	Fry	Mortality	186	870		7.5-7.6	Pickering and Vigor	1965

"← " values included in mean

Table D.2: Data used to develop hardness-cadmium relationships for long-term exposure to cadmium.

Family	Species Common Name	Scientific Name	Duration	Endpoint	Life stage	Observed Effect	Average Hardness	Effect Concentration (ug/L)	Mean Effect Concentration if Applicable (ug/L)	pH	Authors	Year
Algae	Green Algae	*Pseudokirchneriella subcapitata*	72 h	EC10	Population	Growth rate	3.42	2.8	←	6.71	Kallqvist	2007
			72 h	EC10	Population	Growth rate	6.21	7.5	←	6.85	Kallqvist	2007
			72 h	EC10	Population	Growth rate	16.21	8.5	←	6.74	Kallqvist	2007
			72 h	EC10	Population	Growth rate	46.21	6	←	6.65	Kallqvist	2007
							18.01		5.7			
			72 h	EC50	Population	Growth	250	43.5		8.1	Benhra et al.	1997
Invertebrates	Water Flea	*Daphnia magna*	21 d	EC16	Less than 24hrs	Reproduction	45.3	0.17		7.74 (7.4-8.2)	Biesinger and Christensen	1972
			21 d	MATC	Less than 24hrs	Reproduction - Number of young per adult	53	0.15		7.5 +- 0.2	Chapman et al	1980
			7 d	MATC	Neonate	Growth	90	1.2			Winner	1988
			21 d	MATC	Not reported	Reproduction - Number of young per adult	130	0.64			Borgmann et al	1989
			7 d	EC10	Adult	Repro - brood mass	179	0.13		8.07 +- 0.07	Barata and Baird	2000
			21 d	MATC	24h	Reproduction	249.8	1.09		8.0 +- 0.2	Kuhn et al	1989
			14 d	MATC	Less than 24hrs	Reproduction - Number of young per adult	240	4.3		8.0 +- 0.3	Elnabarawy et al	1986
Fish	Brown Trout	*Salmo trutta*	30 d	IC20	Swim-up fry	Biomass, decrease in	29.2	0.87		7.54 (0.13)	Brinkman and Hansen	2007
			61 d	MATC	Larva	Biomass, decrease in	45	2	←	7.6 (7.2-7.8)	Eaton et al.	1978
			60 d	MATC	Larva	Biomass, decrease in	45	6.7	←	7.6 (7.2-7.8)	Eaton et al.	1978
				mean MATC			**45**		3.7			
			30 d	IC20	Swim-up fry	Biomass, decrease in	67.6	2.18		7.60 (0.10)	Brinkman and Hansen	2007
			30 d	IC20	Swim-up fry	Biomass, decrease in	151.0	6.62		7.51 (0.12)	Brinkman and Hansen	2007
			50 d	ChV	Embryo-larval		250	16.49			Brown et al. (as cited by EPA 2001)	1994

"←" values included in mean

Table D.3: Hardness-Toxicity Relationships for Zinc and Cadmium

Parameter	Species	n	Slope	*p* -value	r^2
Zinc	*Pseudokirchneriella subcapitata*	6	0.785	0.007	0.869
	Daphnia magna	13	1.027	0.004	0.541
	Ceriodaphnia dubia	3	0.983	0.432	0.606
	Hyalella azteca	2	0.656	-	1.000
	Oncorhynchus mykiss	9	0.719	0.046	0.455
	Pimephales promelas	5	1.135	0.006	0.944
	Combined Slope (p = 0.909)	38	0.846	0.000	0.804
Cadmium	*Pseudokirchneriella subcapitata*	2	0.771	-	1.000
	Daphnia magna	7	1.159	0.148	0.370
	Salmo trutta	5	1.179	0.022	0.864
	Combined Slope (p = 0.830)	14	1.023	0.830	0.810

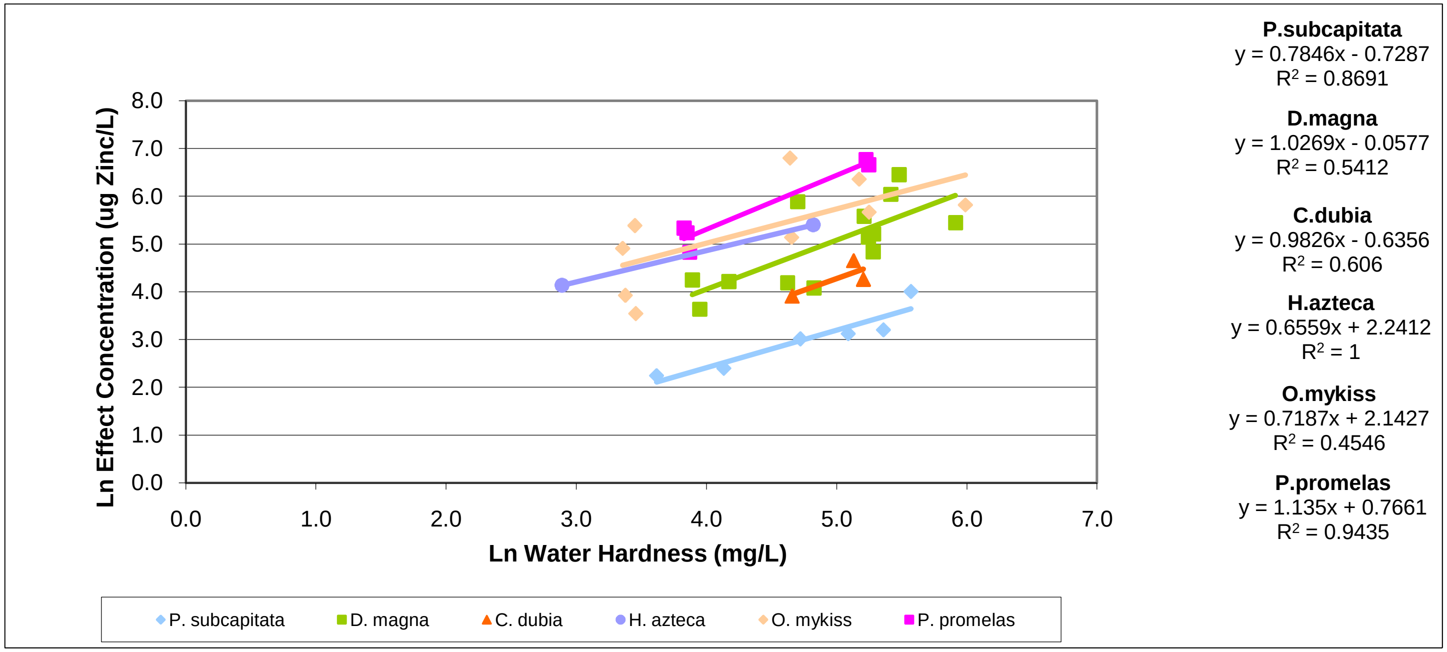

Figure D.1: Comparison of zinc hardness-toxicity relationships for various aquatic species in long-term exposures. Data in Appendix Table D.1.

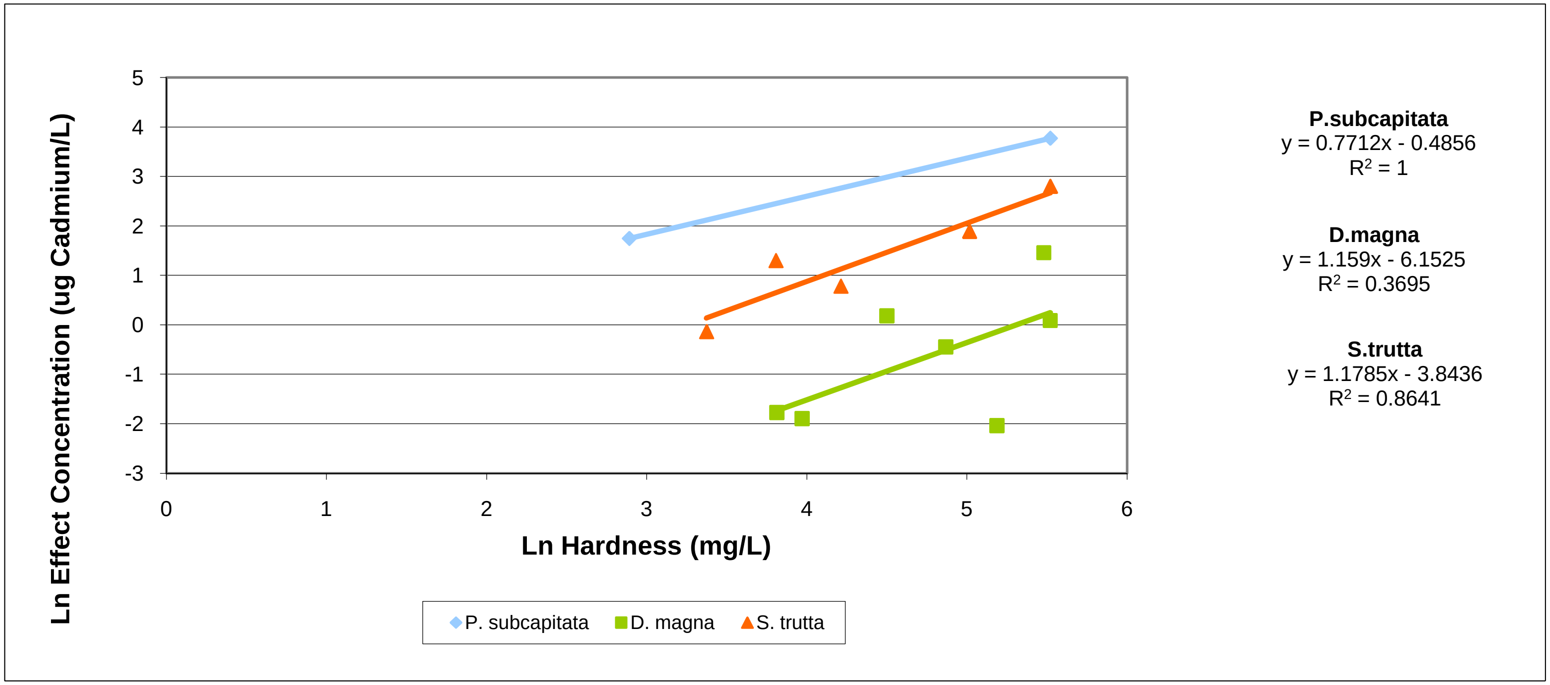

Figure D.2: Comparison of cadmium hardness-toxicity relationships for various aquatic species in long-term exposures (Data in Appendix Table D.2).