Gartner Lee Limited

memorandum

to: Anvil Range Site Specific Water Quality Working Group
from: Neil Hutchinson, Leslie Gomm, Eric Denholm
date: December 1, 2005
ref: GLL 23843
re: **Recommended SSWQO for Anvil Range Receiving Waters**

This technical memorandum is written for review by and discussion with the technical working group for this project (Anvil Range project 23b). The work is based on the information described herein and may not be published or distributed beyond the technical working group for this project without the written permission of Gartner Lee Limited.

We have now finalized the approach for deriving Draft Site Specific Water Quality Objectives (SSWQOs) for the Anvil Range Receiving Waters, in response to the review of the initial draft approach (Gartner Lee Ltd., April 15, 2005) and the revised approach (Gartner Lee Ltd. August 10, 2005) by the technical working group.

This document outlines the final approach, developed after review of the August 10 revised approach, as discussed with the technical working group on August 17 2005 and summarized in the September 12, 2005 memo from Leslie Gomm to the Technical Working Group. Throughout these revisions, we have worked in close cooperation with Don MacDonald, of Macdonald Environmental Sciences Ltd. His constructive and critical insights have been extremely valuable to our work.

The final SSWQO is based on a hybrid approach. We modified the Water Effects Ratio Procedure (CCME, 2003) from a ratio to a statistical model developed using the on-site toxicity data generated as part of this project. This accounts for the varying water hardness on site. We have also incorporated elements of the CCME recalculation procedure and applied it to the database of zinc toxicity that was developed by the Province of British Columbia. In the end, these efforts resulted in one SSWQO, expressed as a mathematical function, that covers both Faro Creek and Vangorda Creek and all aquatic Valued Ecosystem Components (VECs) in the receiving waters.

All recommendations arising from the August review were incorporated into the final SSWQO. The resultant SSWQO protects the receiving waters, considers existing conditions and ecological receptors at the site and incorporates the relationship between zinc toxicity and water hardness. Our trial implementation of the SSWQO (described herein) shows that aquatic life will be protected for all current conditions on site, except during minimum hardness conditions in Rose Creek, during the peak spring freshet.

Development of the Site Specific WQO for Anvil Range Receiving Waters

1. Background

In April of 2005, Gartner Lee Ltd. submitted a draft document (Gartner Lee Ltd., 2005a) outlining a proposed SSWQO for the Anvil Range Site. The draft document presented results of toxicity testing completed in 2004 using the receiving waters from the Anvil Range site. It was focused on use of the Water Effects Ratio Procedure (WER; CCME, 2003) to develop a Site Specific WQO for zinc to protect aquatic life, the most sensitive use of the Anvil Range receiving waters. The WER method was chosen because the toxicity of zinc, the major contaminant of concern on site, is hardness dependent. The receiving waters on site show wide natural variation in hardness and hardness is also increased during periods of effluent discharge.

The WER procedure, as written, compares toxicity of zinc in the receiving waters on site to toxicity of zinc in standard "lab" water. This comparison produces a numeric "ratio", a number used to correct the generic CCME WQO for zinc to a site specific WQO. We note that the "standard lab water" is not defined by CCME, but is interpreted to mean the characteristics of the water used in the toxicity test that defined the most sensitive response used to develop the CCME WQO.

The receiving waters at the Anvil Range site show a range of hardness over the year (Figure 1), such that a single WER could not be used to derive a SSWQO. The ratio would have to vary with water hardness. As such, we attempted to use the hardness-dependent zinc guideline of the Province of British Columbia as a model to develop a hardness-dependent WQO for zinc on site.

Figure 1. Annual variation in total hardness for Anvil Range receiving waters.

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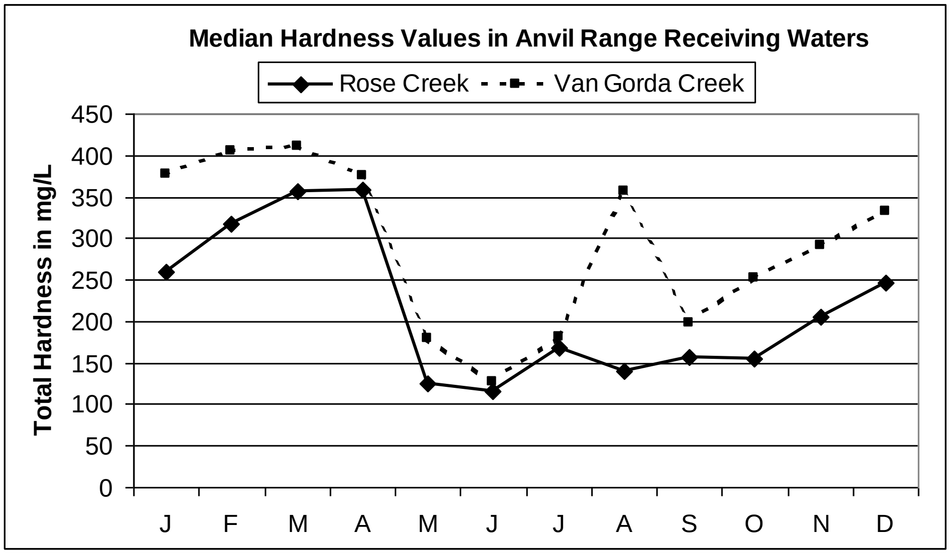


The draft SSWQO development document (Gartner Lee Ltd., April 2005a) showed that:

a) toxicity testing using Anvil Range receiving waters identified a relationship between hardness and zinc toxicity for fathead minnow early life stages but not for the more sensitive zooplankton and algae species (*Ceriodaphnia* and *Selenastrum*) that were tested.
b) the slope function used to relate hardness to zinc toxicity that was derived for the BC Zn Objective was not valid, as it used results from different species, different toxicity endpoints and different toxicity tests,
c) the intercept for the Zn-toxicity function that was used for the BC Zn Objective was derived for an assemblage of the algal and zooplankton community in Lake Michigan water and did not represent conditions in the Anvil Range streams,
d) Total zinc concentration in the receiving waters frequently exceeded the existing generic CCME objective of 0.03 mg/L but dissolved zinc concentrations were below that.

We concluded, at that time, that any objective developed from these results would not meet our intent to protect the most sensitive use of the receiving waters and to incorporate the WER into a SSWQO.

Discussion of the draft report with the Technical Committee, and among the consulting team, lead to a decision to alter our approach. This was documented in a memo to the Technical Working Group on July 7, 2005. The SSWQO development process was revised accordingly and submitted to the working group in a technical memo of August 10, 2005. The working group generally approved of the revised approach and made several recommendations to finalize it. These were documented in a memo of September 12, 2005.

This report therefore serves to finalize the SSWQO, based on the September 12 recommendations, which were as follows:

1. Use of a curvilinear, instead of a linear, function to quantify the relationship between water hardness and toxicity of zinc for the tests run on larval fathead minnows in Anvil Range waters,
2. Consideration of toxicity data for the freshwater sponge (Francis and Harrison, 1988). This was the most sensitive end point for zinc toxicity that was documented in the BC database (Nagpal, 1997) and was considered to define the intercept of the SSWQO relationship,
3. Further consideration of how to use safety factors in the derivation of the SSWQO.

2. Approach

The SSWQO for the Anvil Range waters was derived as a “hybrid” approach, using a hardness correction (a variant of the WER procedure) and the “recalculation” procedures described in CCME (2003). The recalculation procedure is generally applicable where the aquatic species present at the site under consideration are a subset of the species used to derive a generic WQO. The procedure uses the same toxicity database used to develop the generic WQO, but omits data on species that are not relevant to the site in question. The WQO is then derived using the most sensitive species that are relevant to the site in question. It therefore accounts for any real differences in the sensitivity range of the aquatic species in the complete toxicological data set and in the species that occur at the study site.

Development of a hardness corrected SSWQO for the Anvil Range site therefore required determining:

a) the nature of the relationship between zinc toxicity and water hardness, as a variant of the WER procedure, to address seasonal changes in hardness in the Anvil Range waters, and

b) the intercept of the toxicity/hardness relationship with the zinc concentration representing the "safe" exposure concentration for protection of aquatic life at the Anvil Range site, derived using the "recalculation" procedure of CCME.

The slope function was developed using toxicity testing of zinc in on-site waters. The intercept was derived using the recalculation procedure, applied to the toxicity database for the BC WQO for Zn (Nagpal, 1997).

3. Zinc Toxicity vs Water Hardness – Linear Slope Function

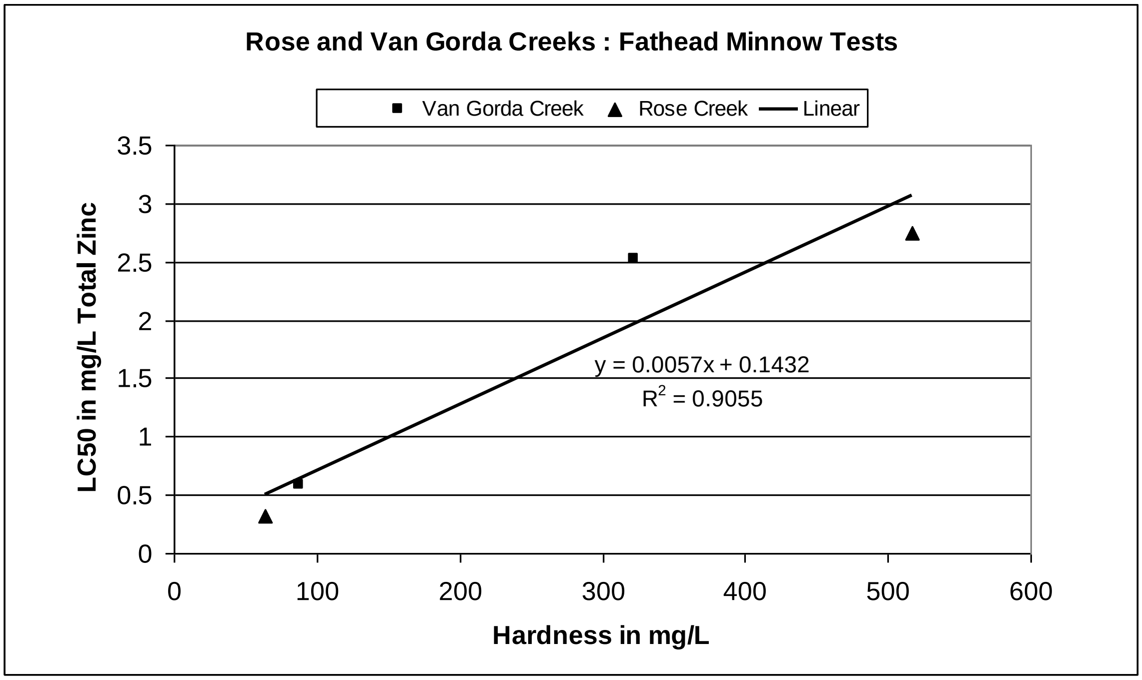
Bioassays to assess the toxicity of zinc to larval fathead minnows in Rose Creek and Van Gorda Creek waters were run in April (low flow/high hardness) and June (high flow/low hardness) of 2004. Details are provided in GLL (April, 2005). Linear responses of zinc toxicity and hardness were observed, as follows:

Rose Creek : LC50 (mg/L) = 0.0054 * (hardness) – 0.0233
Van Gorda Creek : LC50 (mg/L) = 0.0083 * (hardness) – 0.1533

Statistical testing of the significance of the relationship for each creek was not possible, as there were only two points describing the line for each creek. Because these slopes were similar, the data were combined to facilitate the development of a relationship that covered a broad range of water hardness. The resultant relationship was statistically significant at the $p<0.05$ level (Figure 2) and was described by:

Anvil Range Receiving Waters
LC50 (mg/L) = 0.0057 * hardness + 0.1432. (r^2 = 0.91)

Figure 2. Effect of hardness on toxicity of zinc to larval fathead minnows in Rose and Vangorda Creeks – linear fit.



There was no relationship between hardness and zinc toxicity observed for the tests using *Selenastrum* and *Ceriodaphnia.* These organisms were very sensitive to zinc, as shown by toxicity thresholds (LC_{50} or IC_{25}) that occurred at approximately 10% of the toxicity thresholds for zinc to fathead minnows (GLL, April, 2005). As a result, derivation of the site-specific hardness function for the Anvil Range waters was based on the fathead minnow tests.

The data set of Nagpal (1997) was used to compare the slope functions derived for the Anvil Range tests with those found by other investigators. The data set was edited to obtain data for zinc toxicity and hardness derived for tests using identical species, life stages and toxicity

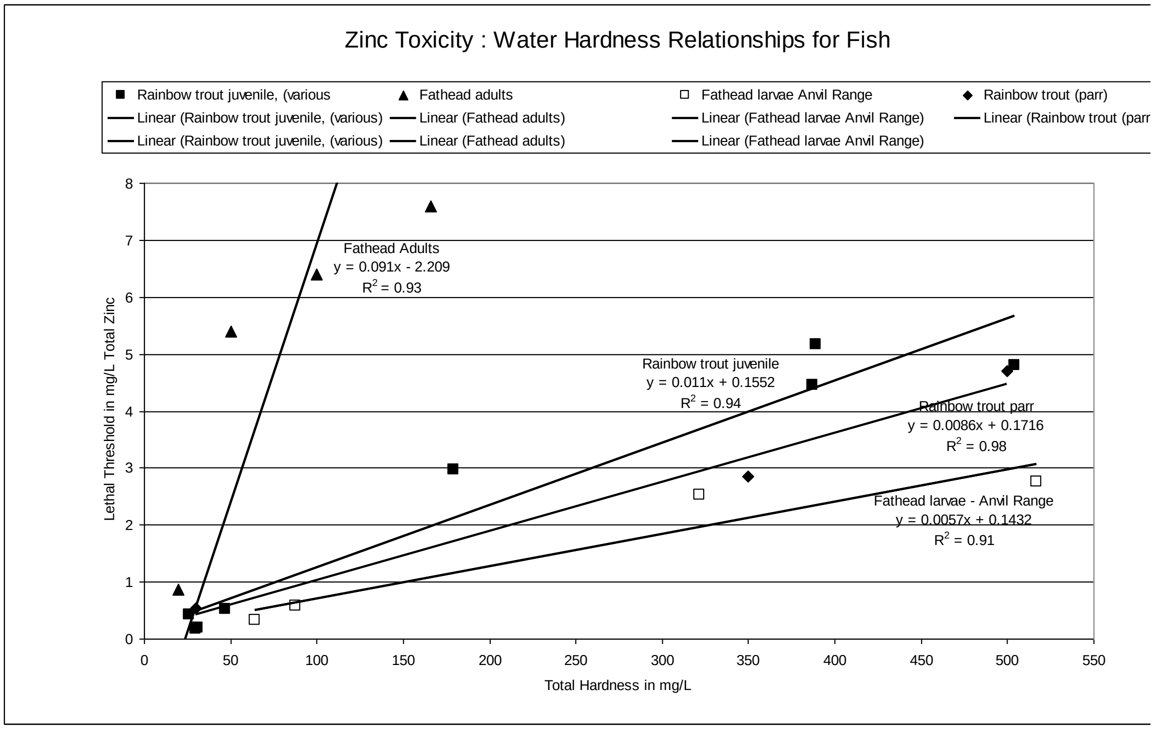
thresholds (Table 1), so that the slopes reflected the influence of hardness on zinc toxicity after standardizing for important biotic factors modifying toxicity (Sprague, 1986).

Table 1. Literature review of data on zinc toxicity/hardness relationship for fish.

Species	Life Stage	Data type	pH	Hardness (mg/L as CaCO3)	Conc. (mg/L)	Effect	Reference
Oncorhyncus mykiss (rainbow trout)	parr	-	-	30	0.24-0.83	LC50-96 hr	EPA 1980
	parr	-	-	500	4.7	LC50-96 hr	EPA 1980
	parr	-	-	350	1.19-4.52	LC50-96 hr	EPA 1980
	juvenile	F,M,1	7.6	47	0.52	LC50-96 hr	Holcombe and Andrew, 1978
	juvenile	F,M,1	7.2	179	2.96	LC50-96 hr	Holcombe and Andrew, 1978
	juvenile	F,M,1	7.8	504	4.8	LC50-96 hr	Solbe, 1974
	juv. 4.5-7.5 g	F,M,1	6.97-7.05	31.3	0.11	LC50- 96 h to120 h	Bradley and Sprague, 1986
	juv. 4.5-7.5 g	F,M,1	6.97-7.05	30.2	0.17	LC50- 96-120 hr	Bradley and Sprague, 1986
	juv. 4.5-7.5 g	F,M,1	6.97-7.05	31.2	0.19	LC50- 96-120 hr	Bradley and Sprague, 1986
	juv. 4.5-7.5 g	F,M,1	6.97-7.05	387	4.46	LC50- 96-120 hr	Bradley and Sprague, 1986
	juv. 4.5-7.5 g	F,M,1	6.97-7.05	389	5.16	LC50- 96-120 hr	Bradley and Sprague, 1986
Pimephales promelas (fathead minnow)	adult	F,M,1	7.5	20	0.87	LC50-96 hr	Pickering and Henderson, 1966
	adult	F,M,1	7.5	360	33.4	LC50-96 hr	Pickering and Henderson, 1966
	adult	F,M,1	8	50	4.7-6.1	LC50-96 hr	Mount, 1966
	adult	F,M,1	8.6	100	6.4	LC50-96 hr	Mount, 1966
	adult	F,M,1	8	200	8.2-21.0	LC50-96 hr	Mount, 1966
	adult	F,M,1	6.2	166	7.6	LC50-96 hr	Rachlin & Perlmutter, 1968

The Anvil Range tests produced a slope of 0.0057 (Figure 3) for fathead minnow larvae. The literature review provided data to describe a slope of 0.0086 for rainbow trout parr, a slope of 0.011 for rainbow trout juveniles and a slope of 0.091 for adult fathead minnows. These results showed that the hardness effect on toxicity decreased as overall sensitivity to zinc increased and that sensitivity to zinc increased from adults to juveniles to parr to larvae. These data also show that the Anvil Range tests on fathead minnow would also be protective of salmonids. The intercept of the hardness/toxicity relationship was 0.17 mg/L for rainbow trout parr (literature values) and 0.14 mg/L for fathead minnow larvae (Anvil Range tests, Figure 3.) showing that the fathead minnow larvae were more sensitive than the rainbow trout parr.

Figure 3. Effect of water hardness on toxicity of zinc to fish.



The similarity between slopes and intercepts for rainbow trout parr (literature) and fathead minnow larvae (Anvil Range) supports a conclusion that the relationship between hardness and zinc toxicity observed in Anvil Range waters is robust and can be used as the basis for a site specific water quality objective that will protect salmonid fish in Anvil Range waters.

The observation that the slope of the hardness/toxicity relationship decreased with increasing sensitivity to zinc also suggests that the absence of a hardness response for *Ceriodaphnia* and *Selenastrum* in the Anvil Range tests may have related to their overall high sensitivity to zinc exposure.

3.1 Zinc Toxicity vs Water Hardness –Curvilinear Function

We investigated use of a curvilinear function as the basis of the SSWQO, in response to recommendations made by the technical working group. The data points from the Anvil Range tests on fathead minnow larvae produced a sigmoidal curvilinear function relating toxicity of zinc to water hardness (Figure 4).

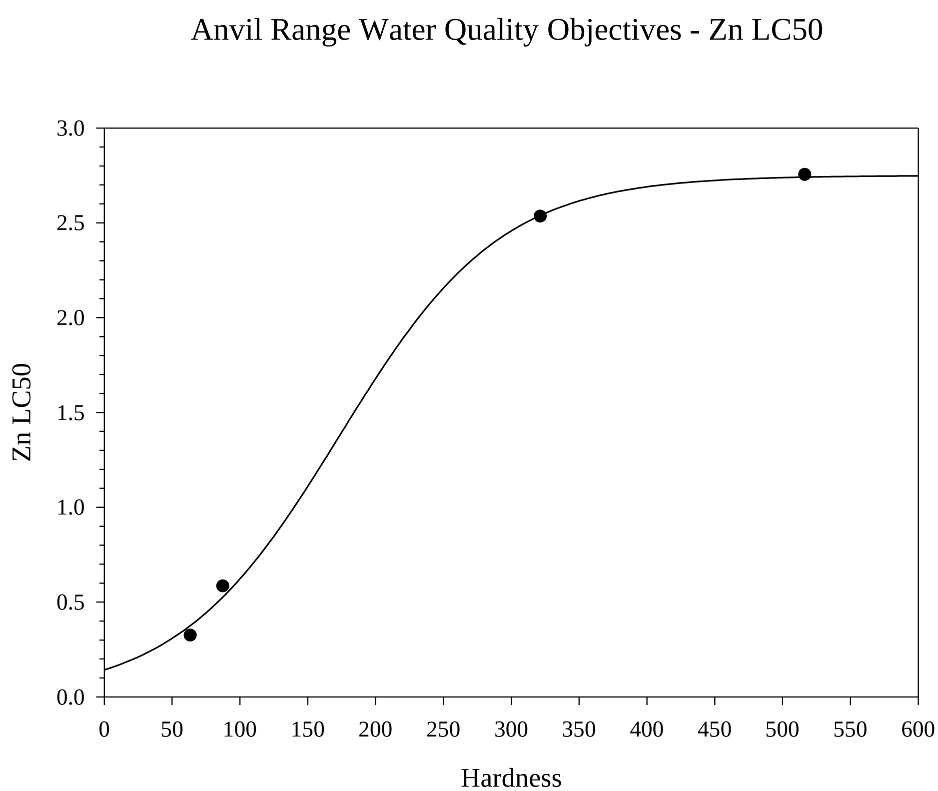
The curvilinear function describes a greater effect of hardness on zinc toxicity in low hardness water and a decreased effect at higher values as

Equation 1

$$\mathbf{LC50\ (mg/L = 2.7499/(1+e^{[(Hardness - 173.24)/59.55*-1]})}$$

$$\mathbf{P < 0.04,\ r^2 = 0.99}$$

Figure 4. Effect of hardness on toxicity of zinc to larval fathead minnows in Rose and Vangorda Creeks – curvilinear fit.



3.2 Summary

We therefore recommend that the SSWQO for the Anvil Range site:

a) incorporate water hardness as a toxicity modifying factor,

b) be derived using the combined data from testing of fathead minnow larvae in each creek, as responses from both creeks were similar and could be combined to produce one statistically significant slope function for the SSWQO and,
c) relate zinc toxicity to water hardness using a sigmoidal function, such as that which was derived using the combined data from testing of fathead minnow larvae in Rose and Van Gorda Creeks.

4. Intercept

The y-intercept of the zinc hardness relationship provides the baseline estimate of sensitivity that will be modified by the curvilinear function. It is intended to define the concentration of zinc that will protect aquatic life, the sensitive use defined for the Anvil Range waters, under all conditions at the site. Our approach was based on review of the toxicological data set of Nagpal (1997) to choose a sensitive and relevant toxicity endpoint, and application of a safety factor to account for species, responses, or exposure durations that were not captured by the lowest endpoint from the data base.

4.1 Fish

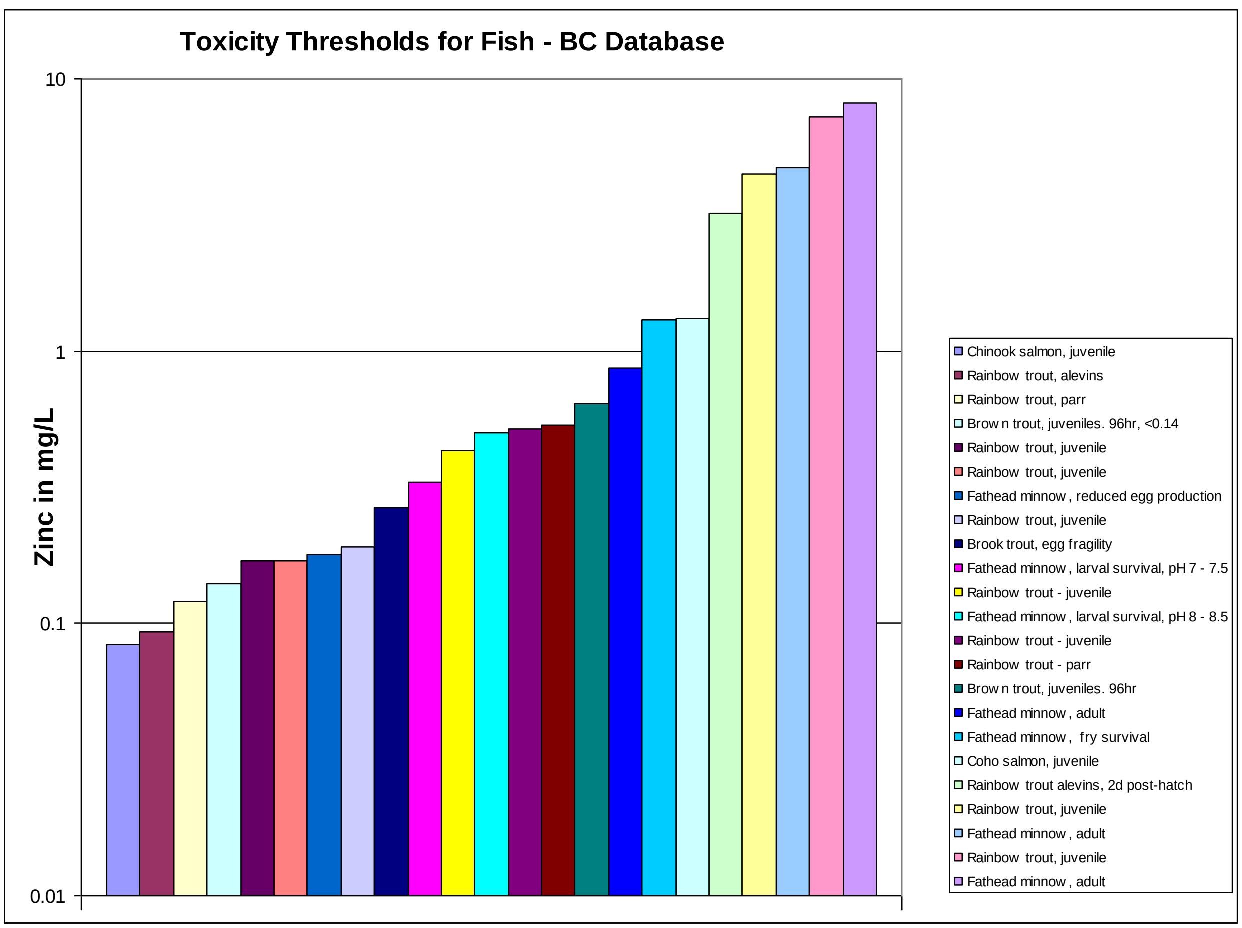
The dataset of Nagpal (1997) was reviewed to obtain zinc toxicity thresholds that could be used to derive an intercept for the SSWQO. The review focused on toxicity thresholds for salmonids, as the Anvil Range waters are cold-water habitats. They are frequented by salmonids: juvenile Chinook salmon (*Oncorhyncus tshawytscha*) and Arctic grayling (*Thymallus arcticus*), and these are considered VECs for protection of ecological function (i.e wildlife consumption) and human use of these waters.

Not all study results presented in Nagpal (1997) were considered appropriate for selection of the intercept. We selected results from peer reviewed studies, tests of salmonids, equivalent toxicity thresholds (96 hr or longer tests), sensitive endpoints (generally effects on early life stages), whole organism responses, pH levels that were appropriate to the Anvil Range waters (i.e. ~pH 7.0 – 8.5), and tests for which water hardness was reported and was within the range reported and expected for Anvil Range waters. The refined database, in order of decreasing sensitivity, is presented in Table 2 and in Figure 5.

Table 2. Summary of thresholds of zinc toxicity to fish from Nagpal (1997).

Threshold Zinc (mg/L)	Hardness (mg/L)	Response	Species and Life Stage	Source
0.084	20-21	96-hr LC50	Chinook salmon, juvenile	Finlayson & Verrue 1982
0.093	23	200-hr LC50	Rainbow trout, alevins	Chapman 1978b
0.097	23	200-hr LC50	Chinook salmon alevins	Chapman 1978b
0.12	23	200-hr LC51	Rainbow trout, parr	Chapman 1978b
0.14	10	96 hr LC50	Brown trout, juveniles. 96hr, <0.14	Everall et al. 1989
0.17	33	120 hr LC50	Rainbow trout, juvenile	Anadu et al. 1989
0.17	30.2	96 - 120 hr LC50	Rainbow trout, juvenile	Bradley & Sprague 1985
0.18	203	Five Month Exposure	Fathead minnow, reduced egg production	Brungs 1969
0.19	31.2	96 - 120 hr LC50	Rainbow trout, juvenile	Bradley & Sprague 1985
0.266	45.4	3rd Generation	Brook trout, egg fragility	Holcombe et al. 1979
0.33	290	96 hr LC50	Fathead minnow, larval survival, pH 7 - 7.5	Schubauer-Berigan, 1993
0.43	26	96 hr LC50	Rainbow Trout - juvenile	Sinely *et al*. 1974
0.5	290	96 hr LC50	Fathead minnow, larval survival, pH 8 - 8.5	Brungs 1969
0.52	47	96 hr LC50	Rainbow Trout - juvenile	Holcombe and Andrew, 1978
0.535	30	96 hr LC50	Rainbow Trout - parr	EPA 1980
0.64	204	96 hr LC50	Brown trout, juveniles. 96hr	Everall et al. 1989
0.87	20	96 hr LC50	Fathead, adult	Pickering and Henderson. 1966
1.3	203	20 day - reduced	Fathead minnow, fry survival	Brungs 1969
1.32	5	96 hr LC50	Coho, juvenile	McLeay 1976
3.2	87.8	48 hr LC50	Rainbow trout alevins, 2d post-hatch	Shazili and Pascoe 1986
4.46	387	96 - 120 hr LC50	Rainbow trout, juvenile	Bradley & Sprague 1985
4.7	50	96 hr LC50	Fathead minnow, adult	Mount 1966
7.21	"hard"	96 hr LC50	Rainbow trout, juvenile	Sinley et al, 1974
8.2	200	96 hr LC50	Fathead minnow, adult	Mount 1966

Figure 5. Summary of thresholds of zinc toxicity to fish from Nagpal (1997).



The most sensitive response was a 96 hr LC50 of 0.084 mg/L for juvenile chinook salmon at a hardness of 20 mg/L (pH 7.1; Finlayson and Verrue 1992). The next most sensitive was a 200 hr LC50 of 0.093 mg/L for rainbow trout alevins at a hardness of 23 mg/L (Chapman 1978). One, more sensitive response, (96 hr LC50 of 0.066 mg/L; Cusimano and Brakke 1986) was not included because it was obtained at a very low water hardness of 9.1 mg /L which was not considered relevant to the Anvil Range waters.

The most sensitive response measured in site-specific tests in the Anvil Range waters was a 96 hr LC50 of 0.32 +/- 0.03 mg/L, for survival of larval fathead minnows at a total hardness of 64 mg/L. This was compared to the most sensitive salmonid response from the toxicity database (0.084 mg/L, Finlayson and Verrue, 1992) by solving the sigmoidal equation for the Anvil Range fathead minnow tests for a hardness of 20 mg/L. The equation predicted an LC50 of 0.19 mg/L zinc for fathead minnow larvae at 20 mg/L. Juvenile chinook salmon, which are present in Anvil Range waters, are therefore approximately 2.26 times as sensitive to zinc as are fathead minnows at the same water hardness. This, in turn, results in an estimated LC50 of 0.17 mg/L for juvenile Chinook salmon at 64 mg/L, calculated using the sigmoidal equation.

CCME (1999) provide the following guidance for derivation of a water quality guideline from toxicity data:

1. Guidelines can be derived from acute studies by converting short-term LC50 values to long-term no-effect concentrations.
2. When available, acute/chronic ratios (ACR) can be used to convert results of a short-term study to an estimated long-term no effect concentration. An ACR is calculated by dividing an LC50 by the no-observed-effect level (NOEL) from a chronic exposure test for the same species.
3. In the absence of an ACR, a universal application factor (AF) of 0.05 for non-persistent pollutants can be used as a substitute. CCME (1999) explicitly state, however, that the AF may be inappropriate for use with zinc.

The ACR is thus considered as a “safety factor” to convert an LC50 to a guideline or, in this case, a sensitive intercept for the hardness/toxicity relationship.

Table 3 summarizes additional data from the studies of Finlayson and Verrue (1992) and Chapman (1978). These studies were not true tests of chronic toxicity and so do not meet the strict CCME requirement of a NOEL from a chronic exposure. We do note, however, that three of the four tests reported responses from 200 hr (chronic) exposures. This, plus the fact that tests were of sensitive early life stages provides confidence that they provide a useful estimate of sensitivity.

A “safety factor” was therefore estimated from the ratio of the acute to chronic toxicity threshold concentrations from these tests. For these studies, safety factors of 0.48 – 0.7 were calculated as the ratio between the observed LC50 value (the concentration affecting 50% of the test organisms) and the reported LC10 (the concentration affecting 10% of the test organisms. The LC10 was considered an acceptable estimate of a “No Effect Concentration” as control mortality of 10% or less is considered acceptable in toxicity testing. (Environment Canada, 1990).). No data were reported for more sensitive responses. The safety factor thus represents a ratio of the acutely lethal concentration (for a sensitive early life stage) and the NOEL for the same life stage, derived from the same test population under the same conditions, as required by CCME (p. 8. CCME, 1999).

The average of the estimated ACR of 0.57 was rounded down to produce a safety factor of 0.5. This was reduced to 0.25 (by a factor of 2), to account for the absence of a NOEL concentration from a true test of chronic toxicity. Multiplying the most sensitive endpoint of 0.084 mg/L by 0.25 produces an intercept value of 0.021 for protection of fish in the Anvil Range waters.

Table 3. Development of “safety factor” for zinc toxicity.

Threshold Zinc (mg/L)	Low/No Response	Threshold Zinc (mg/L)	Response	Safety Factor	Species and Life Stage	Source
0.04	96 hr-LC10	0.084	96-hr LC50	0.48	Chinook salmon, juvenile	Finlayson & Verrue 1982
0.054	200 hr LC10	0.093	200-hr LC50	0.58	Rainbow trout, alevins	Chapman 1978b
0.068	200 hr LC10	0.097	200-hr LC50	0.70	Chinook salmon alevins	Chapman 1978b
0.061	200 hr LC10	0.12	200-hr LC50	0.51	Rainbow trout, parr	Chapman 1978b

4.2 Invertebrates

The dataset of Nagpal (1997) was reviewed to obtain zinc toxicity thresholds that could be used to derive an intercept for the protection of invertebrates in the Anvil Range receiving waters. The stream invertebrate community as a whole was considered a VEC for protection of the aquatic food web – to provide food for fish and hence wildlife and humans.

4.2.1 Site-Specific Background Studies

Although it is important to derive a SSWQO that will protect the invertebrate community in Rose and Van Gorda Creeks, benthic invertebrate surveys taken on site (Laberge 2003; 2004) and experimental evidence from a local stream (Limnotek 1993) show that a) the benthic community on site shows no evidence of impairment at present and b) experimental additions of up to 0.3 mg/L of zinc have not impaired the benthic community. Results for experimental studies reported in Nagpal (1997) must therefore be interpreted carefully for applicability to conditions on site.

For Rose Creek, benthic surveys (Laberge 2004) showed increased abundance, increased species richness and increased numbers of pollution sensitive taxa in recent years, all indicative of recovery since the mid 1990s. Station R2, immediately downstream of the tailings pond and the discharge point for treated effluent showed particularly good evidence of recovery.

Comparisons between reference sites and those downstream of mine activities showed no differences in the benthic communities. Diptera (winged fly) larvae including chironomids which are, in general, pollution tolerant, were the dominant taxon at all sites. Pollution sensitive species were also present all sites. High concentrations of zinc were found in the stream sediments at some sites downstream of mine activities but these did not appear to be bioavailable, based on assessment of the benthic community health at the same sites. The report concluded that “effluent from the tailings system currently has minimal, if any, impact on the receiving environment”.

For Van Gorda Creek, benthic surveys (LaBerge 2003) showed that pollution sensitive taxa (mayflies, stoneflies and caddisflies) were most common at site V27, immediately downstream of most mine activities. The report concluded that metals did not appear to be bioavailable or harmful to the benthic community the communities were stable over time and that they showed “no perceptible impacts” from mining activity.

Limnotek (1993) conducted a controlled exposure to zinc in artificial channels (“mesocosms”) containing waters from Blind Creek, near the Anvil Range site. Natural insect communities were allowed to populate and colonize the artificial channels for five weeks before the experiment started. Zinc was then added to the channels to maintain concentrations of 0.005, 0.010, 0.025, 0.060, 0.150 and 0.300 mg/L for three weeks and the benthic community enumerated at the end of the zinc exposure. Cd, Cu and Pb concentrations were < 0.001 mg/L in the Blind Creek test waters. Total hardness of the test water was approximately 70 mg/L.

The Limnotek study reported no observable effects of zinc exposure on periphyton, benthic invertebrate abundance or taxa richness in the treatment channels, except for a decline in phytoplankton biomass accrual at 0.3 mg/L. Sequential extractions of sediments and high pH (mean pH 9.2) in the test waters suggested precipitation of carbonate and hydroxy complexes of zinc from the water column, although the study reported excellent correspondence between measured and nominal zinc concentrations and that >85% of zinc was present in the dissolved form.

Although these results suggest that stream invertebrates are not particularly sensitive to zinc in Anvil Range waters, they are somewhat qualified by observations of overall low densities of benthic invertebrates in the creek and in the mesocosms, and of a dominance of the stream community by pollution tolerant chironomids, especially Orthocladinae. These simplified communities may have reduced the resolution of some effects in the Limnotek study.

Overall, the benthic communities at the Anvil Range sites do not appear to be impaired by present-day conditions and may not be particularly sensitive to zinc. These factors should be considered in development of the SSWQO.

4.2.2 Database Review

Toxicity testing done in support of the SSWQO development included *Ceriodaphnia* and *Selenastrum*, to ensure that invertebrates (food source for fish) and primary producers were considered in the SSWQO. Toxicity testing showed that a) these species were sensitive to zinc toxicity and b) toxicity of zinc was not altered by water hardness. The latter finding may reflect the inherent sensitivity of the species tested, as our review of the fish toxicity database (see above) showed that hardness was less protective of those species and life stages of fish that were more sensitive to zinc.

Our review of Nagpal (1997) and other literature found no published studies on water hardness as a factor modifying the toxicity of zinc to invertebrates. No studies were reported in which zinc toxicity to invertebrates was determined over a range of hardness values within one experiment. Our assessment is that the lack of published information on zinc/water hardness relationships reflects a lack of investigation and not necessarily the lack of a relationship.

The mechanism of zinc toxicity in fish is ionoregulatory failure caused by disruption of the gill surface. Water hardness, specifically calcium ion, reduces the rate of loss of physiological ions through the gill, thus reducing zinc toxicity. From a mechanistic basis, therefore, it is reasonable to expect that zinc toxicity is related to water hardness in invertebrates (which also have gills), as well as in fish.

For *Ceriodaphnia*, an average LC50 of 0.08 mg/L of zinc was obtained for survival, while for reproduction (brood production) the average IC25 was 0.06 mg/L. For *Selenastrum,* an IC25 of 0.04 mg/L was obtained for growth reduction. These metrics show the potential sensitivity of the receiving waters but may not be directly applicable to the waters on site for the following reasons:

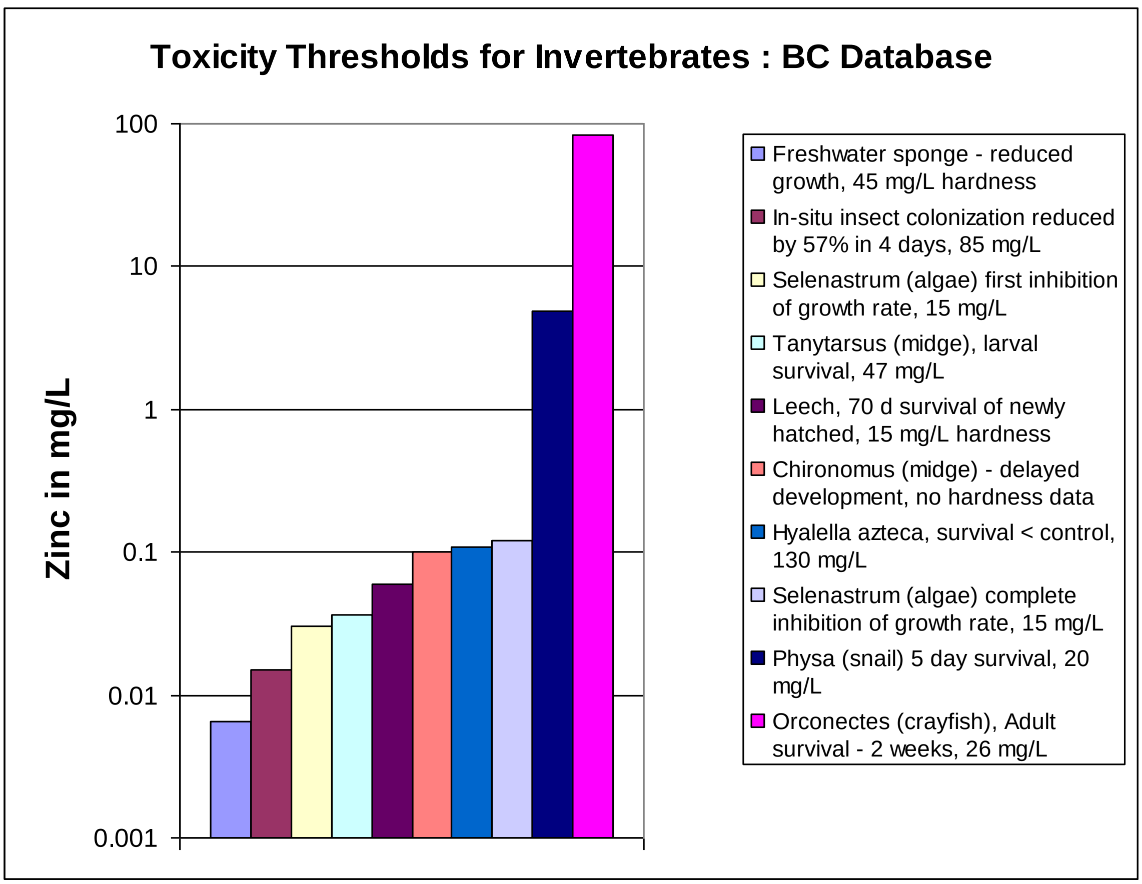
1. *Ceriodaphnia* is a zooplankton species and is found in still water and lake environments and not in running waters. It is not representative of species in the receiving waters and so its response can be discounted if other, more suitable invertebrate data can be found. It is acknowledged that surveys of benthic invertebrates at the Anvil Range site have documented the presence of zooplankton. Laberge (2002), for example, reported that cladocerans and copepods made up 0.04% – 1.5% of the numbers of individuals in 10 of 12 artificial substrate samples taken from Rose Creek. Most of these were the cladoceran *Bosmina longirostris.* These individuals were most likely “washed down” into Rose Creek from ponds on the mine site or further upstream, as Pennak (1978) reported that cladocera are abundant everywhere *“Aside from streams, brooks and grossly polluted waters..”* Zooplankton are also excluded from running waters by their planktonic nature and slow swimming speeds and there is no need to consider them when setting WQOs for running waters (Prof. N.D. Yan, York University, Toronto, ON. pers. comm., Nov. 2005). Their occurrence in Rose Creek is therefore considered incidental. Nevertheless, the toxicological response of *Ceriodaphnia* may be important as a surrogate for unknown or unexamined ecological processes or species.
2. *Selenastrum* is a planktonic algal species and is rarely important in stream systems where internal photosynthesis occurs via algae such as diatoms attached to rocks in the stream.
3. Ecologically, the energy input to small stream systems is characterised by mostly allocthonous energy inputs (i.e leaf litter etc from outside the water body) as opposed to autocthonous energy inputs from photosynthesis within the water body. Therefore, protection of internal photosynthesis as a VEC in thre Anvil Range waters is not of high ecological relevance, but may be important as a surrogate for unknown or unexamined ecological processes.

We therefore reviewed the Nagpal (1997) database for the most sensitive whole organism response from each reported test or series of tests to invertebrates. Our review focused on species of relevance or potential relevance to the Anvil Range receiving waters. Results are arranged in order of decreasing sensitivity in Table 4 and Figure 6.

Table 4. Summary of thresholds of zinc toxicity to invertebrates. From Nagpal (1997).

Threshold Zinc (mg/L)	Hardness (mg/L)	Response	Species and Life Stage	Source
0.0065	45	reduced growth	Freshwater sponge	Francis & Harrison 1988
0.015	85	colonization reduced by 57% in 4 days	In-situ insect community	Clements et al. 1988
0.03	15	first inhibition of growth rate	*Selenastrum capricornutum* (algae)	Bartlett *et al*. 1974
0.0368	47	larval survival, embryogenesis and hatching	*Tanytarsus dissimilis* (midge)	Anderson et al. 1980
0.06	15	70d LC50 newly hatched	*Erpobdella octulata* (leech)	Willis 1989
0.1	none given	delayed development of instars	*Chironomus riparius* (diptera, chironomidae)	Timmermans *et al*. 1992
0.108	130	10 week survival-early instar	*Hyallela azteca*	Borgmann *et al*., 1983
0.12	15	complete growth rate inhibition	*Selenastrum capricornutum* (algae)	Bartlett *et al*. 1974
4.9	120	adult-5 day LC50	*Physa heterotropha* (pond snail)	Wurtz 1962
84	26	two week LC50 - adults	*Orconectes* (crayfish)	Mirenda 1986

Figure 6. Summary of thresholds of zinc toxicity to invertebrates. From Nagpal (1997).



The most sensitive response in the invertebrate data base was that of a freshwater sponge (*Ephydatia fluviatilis*), for which Nagpal (1997) reported growth inhibition at 0.0065 mg/L zinc in water of 45 mg/L hardness. This species and study was not considered for the SSWQO for the Anvil Range site for several reasons:

1. Review of the source document (Francis and Harrison, 1988) suggested methodological and interpretive concerns that advised against using the reported response. The greatest concern was that the authors reported that growth was a more sensitive toxicity endpoint than mortality. The lethal response was delayed, occurring 10 days after exposure to concentrations that had no effects on growth rate over that time period. Zinc concentrations > 1 * 10^{-7} M (>0.0065 mg/L) were reported as toxic, mortality was documented at 4* 10^{-7} M (0.026 mg/L) but effects on growth rate were only reported at a concentration of 9*10^{-7} M (0.06 mg/L). The fact that growth was a less sensitive indicator than mortality, and that it occurred only after 10 days of exposure advises against using these results.
2. It is not known if this, or other species of sponges are found in the Anvil Range receiving waters. *Ephydatia fluviatilis* is reported as more common in standing waters and as “seldom found in extremely rapid waters”(Pennak, 1978).
3. Sponges are not considered a Valuable Ecosystem Component (VEC). Although they are filter feeders, of bacteria, protozoa and organic detritus, this function is filled by many other forms of aquatic life that would e present in the Anvil Range waters.

The toxicity end point for sponges was therefore not used for SSWQO development for Anvil Range.

The next, most sensitive response reported in the database was in-situ colonization of a stream benthic community. This showed 57% reduction after four days of exposure to 0.015 mg/L of zinc at a water hardness of 85 mg/L (Clements *et al.*. 1988). This would be a significant ecological response in the Anvil Range waters, as the stream benthic community is well documented and ecologically important. The Clements *et al.* study was carried out, however, in a stream contaminated with a mixture of metals. They reported that exposure to Cu and Zn in stream mesocosms reduced the number of taxa, the number of individuals and the abundance of dominant taxa within 4d. Zinc concentrations of 0.015 mg/L (50% of its CCME Guideline) occurred with corresponding Cu concentrations of 0.012 mg/L (6 times its CCME Guideline). The pH of the exposure waters was >8.9, which in itself exceeds the CCME Guideline and would stress aquatic life. We did not, therefore include the Clements *et al.* (1988) response for consideration as an intercept because it represented joint exposure to Cu and Zn.

Growth inhibition of *Selenastrum capricornutum* was reported at 0.03 mg/L of zinc (Bartlett *et al.* 1974) but this response was not considered, as described above.

The ten-day LC50 for embryogenesis, hatching and larval survival of the chironomid midge *Tanytarsus dissimilis* was 0.037 mg/L of Zn (range = 0.026 – 0.054 mg/L) at a hardness of 47 mg/L (Anderson *et al.*. 1980). This response was chosen as a suitable intercept because chironomids are common and dominant in the Anvil Range Creeks and are important in the food chain. Although the study did not report a NOEL concentration it represented a true test of chronic exposure over the most sensitive life stages. The test exposed eggs that were 16 hrs old and ended 7 days after hatching, or after 10 days of exposure. Application of a reduced ACR "safety factor" of 0.5 is therefore recommended for this intercept because:

1. The Anderson *et al.* study covered very sensitive life stages for the chironomid over a ten day exposure, which was equivalent to 2/3 of their life cycle at the exposure temperatures, and
2. Results of the Limnotek (1993) study of zinc toxicity in Anvil Range waters showed no response of the stream benthic community to additions of up to 0.3 mg/L of zinc. That study showed that the stream community was dominated by chironomids and so the findings are relevant to the SSWQO.
3. The intercept value must also protect less sensitive invertebrates in the receiving waters.

An intercept value of 0.019 mg/L of zinc is therefore recommended for protection of the stream invertebrate community at the Anvil Range site.

5. Summary and Derivation of SSWQO

A WQO is intended to protect the stream community as a whole and the stream communities at the Anvil Range sites consist of fish and invertebrates. We therefore recommend one WQO to protect fish and invertebrates as VEC in the Anvil Range receiving waters. Our review concluded that zinc concentrations of 0.021 mg/L would protect fish and 0.019 mg/L would protect invertebrates. Adoption of an intercept of

0.019 mg/L as the low hardness intercept for the hardness/toxicity correction is therefore recommended for the Anvil Range waters.

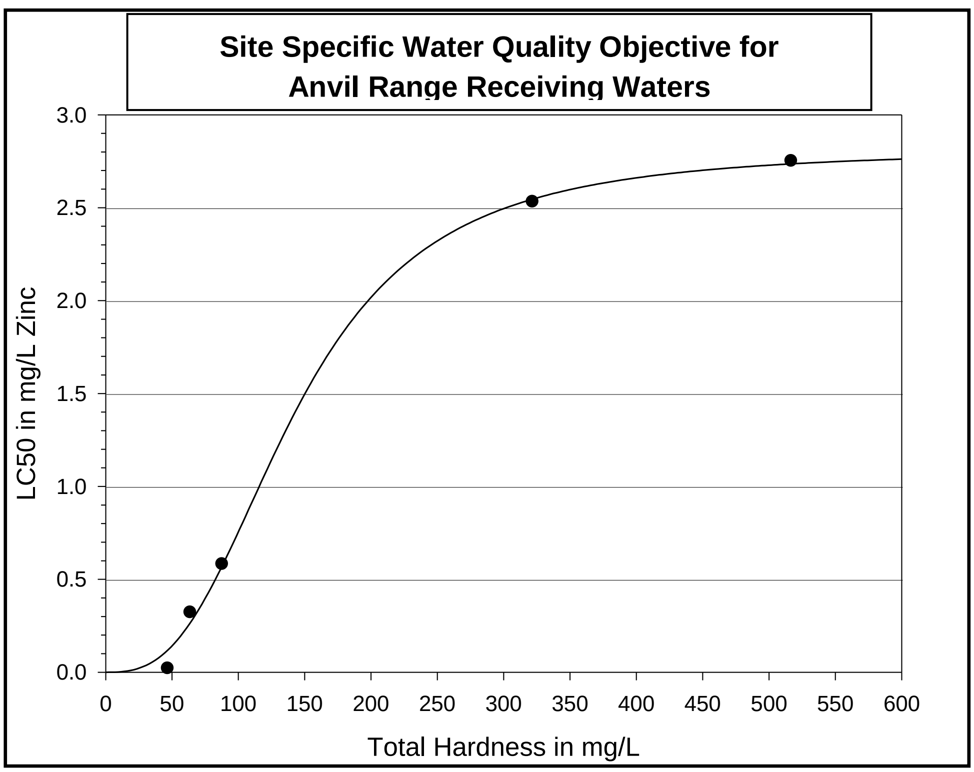
The final step of the SSWQO derivation was to recalculate the sigmoid equation (Equation 1, above) describing hardness and zinc toxicity, but to include the derived intercept for invertebrates, to protect aquatic life that was more sensitive than fathead minnows. Addition of the intercept value of 0.019 mg/L zinc at 47 mg/L total hardness produced the following equation (Figure 5), which is recommended as the SSWQO for the Anvil Range waters.

Equation 2

$$\text{LC50 (mg/L} = 2.8123/(1+(\text{Hardness}/143.206)^{-2.7895})$$

$$p < 0.002,\ r^2 = 0.99$$

Figure 7. SSWQO for protection of aquatic life in Anvil Range receiving waters.

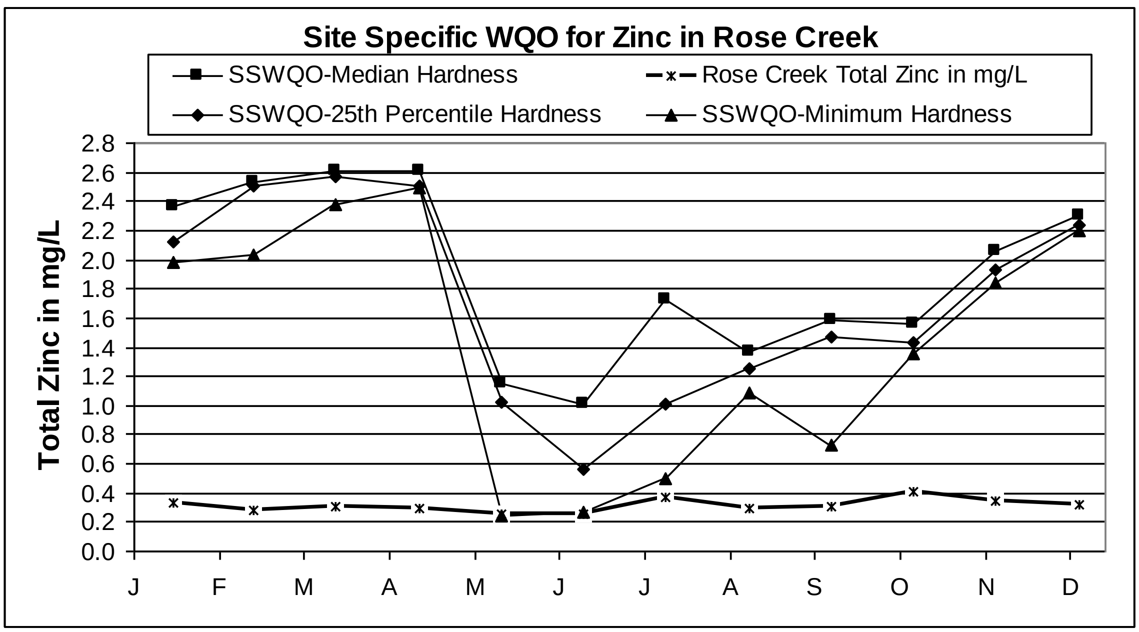


5.1 Implementation

Median, 25th Percentile and minimum monthly measurements of hardness in Rose Creek (Stn. X14 - downstream of diversion channel) and Van Gorda Creek (Stn. V8 – downstream of Faro townsite) were used to generate site specific WQOs for each creek using Equation 2 (Figure 7, Figure 8). The median monthly zinc concentrations for each creek at the same sites were then plotted to show the implications for compliance under existing site conditions.

5.1.1 Rose Creek

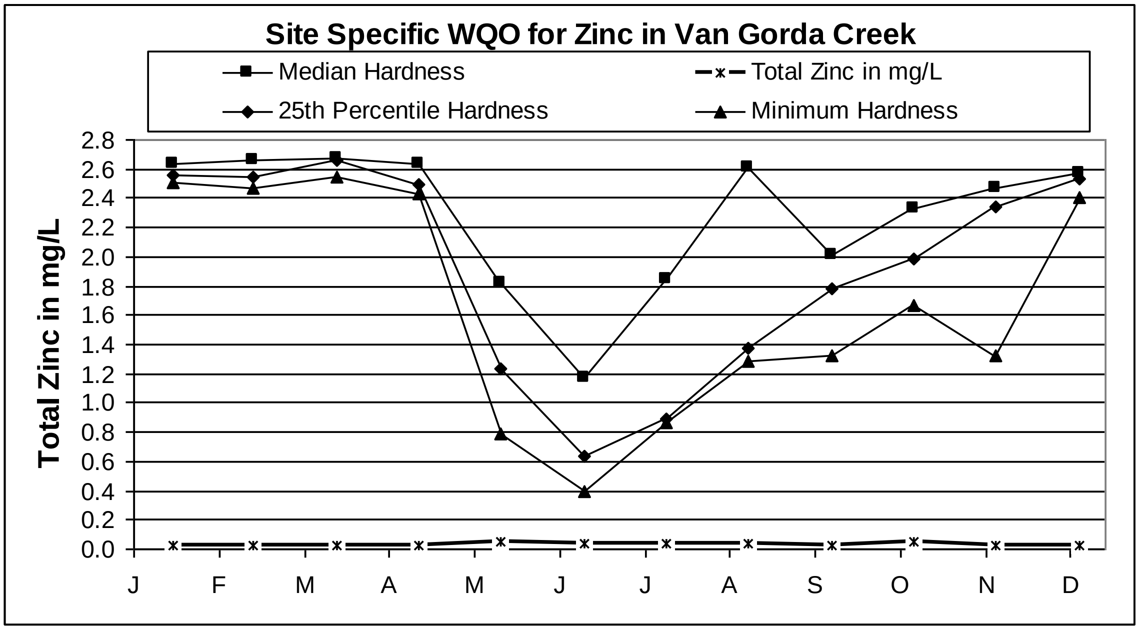
Figure 7. Implementation of SSWQO in Rose Creek.



Zinc concentrations remain well below the SSWQO calculated for all hardness values observed in Rose Creek except for minimum values measured during the early stages of the freshet in May and June.

5.1.2 Van Gorda Creek

Figure 8. Implementation of SSWQO in Van Gorda Creek.



Zinc concentrations remain well below the SSWQO calculated for all hardness values in Van Gorda Creek in all months.

6. Conclusions

Use of site specific data on zinc toxicity to fathead minnow larvae and data on zinc toxicity from published, peer-reviewed studies, as presented in the database for the Province of British Columbia (Nagpal, 1997) were used to derive a Site Specific Water Quality Objective for the Anvil Range Receiving Waters. Data relating zinc toxicity to water hardness was best quantified as a sigmoidal equation, to account for a large effect of hardness on zinc toxicity at low hardness levels, and a decreased effect as hardness levels increased. An intercept toxicity threshold of 0.019 mg/L zinc, at a hardness of 47 mg/L value, was calculated by applying a safety factor of 50% to results of a study on chronic toxicity of zinc to chironomid fly larvae, an important ecological component of the Anvil Range waters.

The final SSWQO is described as:

$$\mathbf{LC50\ (mg/L = 2.8123/(1+(Hardness/143.206)^{-2.7895})}$$
$$\mathbf{p < 0.002,\ r^2 = 0.99}$$

A trial application of the SSWQO to measured water quality conditions in Rose Creek and Van Gorda Creek showed that both creeks were in compliance with the SSWQO for all conditions except when minimum hardness levels are observed in Rose Creek during peak freshet conditions.

We note that the resultant equation does generate every high concentrations of zinc as a SSWQO during periods when hardness is high in either creek. This reflects the high levels of hardness observed in the creeks during periods of baseflow, and is supported by benthic invertebrate surveys in the receiving waters, and by toxicity tests carried in the Anvil Range waters.

NJH:njh