Technical Summary – Derivation of Preliminary Site Specific Water Quality Objectives for Zinc for the Anvil Range Mine Site

Prepared for:
Faro Mine Closure Planning Office

Prepared by:
Gartner Lee Limited

Reference:	Date:
GLL 23843	**February 2006**

Distribution:

- **1 Faro Mine Closure Planning Office**
- **1 Deloitte & Touche Inc.**
- **1 Gartner Lee Limited**

Gartner Lee

Gartner Lee Limited

February 7, 2006

Faro Mine Closure Planning Office
419 Range Road
Whitehorse, Yukon

Dear Roger Payne/Bill Slater:

Re: Technical Summary – Derivation of Preliminary Site Specific Water Quality Objectives for Zinc for the Anvil Range Mine Site

As requested, we are pleased to submit to you the Technical Summary – Derivation of Preliminary Site Specific Water Quality Objectives for Zinc for the Anvil Range Mine Site for distribution for External Peer Review. This document incorporates the memo provided to you on December 1, 2005 along with a summary of the project history.

I trust that this information is self-explanatory. However, if you have any questions please do not hesitate to contact us.

Yours very truly,
GARTNER LEE LIMITED

Leslie Gomm, Ph.D., P.Eng.
Senior Environmental Engineer

LSG:lg

CC: Deloitte & Touche Inc. – Valerie Chort

Table of Contents

Page

List of Figures

List of Tables

1. Introduction

This document describes the derivation of a Preliminary Site Specific Water Quality Objective (SSWQO) for zinc in the receiving waters for the Anvil Range site. This document should be considered along with an understanding of the present day site conditions and the process underway for the development of a Final Closure and Reclamation Plan. Preliminary WQO's have also been considered for other contaminants of concern in the Anvil Range Waters, as described elsewhere.

This document describes the formal approach for deriving Site Specific WQO's, a series of site specific toxicity tests that were completed and how the results of these were used to derive the WQO as a variant of the formal procedures documented by CCME (2003). It includes a review and synthesis of relevant published studies on zinc toxicity and their interpretation for the Anvil Range waters. It also includes a trial application of the suggested Preliminary WQO for zinc to the two Anvil Range receiving waters – Rose Creek and Vangorda Creek.

1.1 Context for the Project

The Anvil Range site (including both the Faro and Vangorda Plateau mine sites) has been in existence since 1968/69 under various owners. The general layouts of the Anvil Range site, the Faro mine site and the Vangorda Plateau mine site are illustrated on Figures 1, 2 and 3, respectively.

Mine operations ceased in early 1998 and, since April 1998, the site has been under care and maintenance provided by Deloitte & Touche Inc., acting as court appointed Interim Receiver of Anvil Range Mining Corporation (the "Interim Receiver"). The Federal and Territorial Governments formally recognized, in January 2003, that the Anvil Range mine was not economically operable and would not be operated again. At that time, those parties committed to developing a Final Closure and Reclamation Plan (FCRP) for the mine property, jointly and in concert with First Nations. The Faro Mine Closure Planning Office is implementing this work.

Numerous closure planning projects have been completed for development of the FCRP. One of the topic areas being developed is closure objectives, which includes the consideration of receiving water quality objectives.is the development of closure objectives.
The current water licence (QZ03-059) specifies that the receiving WQO's for closure and reclamation are to comply with the Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines for the Protection of Freshwater Aquatic Life (CEQG-FWAL). This condition of the water licence (Part F, Item 58c) provides the framework within which WQO's for closure and reclamation may be determined.

The CCME Guidance documents provide two approaches to water quality objectives, generic water quality guideline values (WQG's) and a series of methods for deriving site specific objectives, where these are appropriate.

The WQG's can be used as a "first-pass" assessment of risk to FWAL based on an assessment of "generic" most-sensitive receptors and contingency factors. The WQG's are not, however, intended to be applied equally in all circumstances and at all sites, which is clearly stated in the CCME documentation. Site-specific WQO's are more appropriate for sites and conditions that vary substantially from those represented by the WQG's.

Gartner Lee's recent and current experience with closure of mine sites in Northern Canada is that the derivation of site specific objectives for soil and water is often necessary to respect unique biophysical conditions, land uses and both human and ecological receptors that vary substantially from those used in the derivation of the generic WQG's. In these circumstances, the derivation of site specific objectives is beneficial to all parties involved by ensuring that the best-suited environmental protection measures are implemented.

This report provides a derivation of a preliminary site specific WQO for zinc for the Anvil Range site based on the procedures published by the CCME. This report refers explicitly to "preliminary" WQO's because of the need for additional technical peer review, community review and decisioning from the Faro Mine Closure Planning Office regarding possible application in the FCRP.

1.2 Goals and Objectives for the Project

Within the context described above, the project was designed to achieve the following two goals:

1. Assess the need for derivation of site specific WQO's based on the CCME documentation; and
2. If necessary, derive preliminary WQO's using the procedures provided by CCME for the purpose of presentation and discussion with First Nations, technical peer reviewers, regulators and others.

Objectives a) though f) were designed to achieve the goals of the project as follows:

Goal 1. Assess the need for derivation of site specific WQO's based on the CCME documentation:

a) Review the site conditions against the CCME documentation;
b) Define parameters of interest; and
c) Assess the need for site specific objectives for the parameters of interest.

Goal 2. If necessary, derive preliminary WQO's using the procedures provided by CCME for the purpose of presentation and discussion with First Nations, technical peer reviewers, regulators and others:

d) Select appropriate derivation methodologies for the parameters of interest;
e) Undertake the appropriate derivations; and
f) Prepare a summary report that can be used as the basis for presentation and discussion with First Nations, technical peer reviewers, regulators and others.

1.2.1 Project Administration

The project is managed by the Interim Receiver on behalf of the Faro Mine Closure Planning Office. A preliminary workplan was developed by Gartner Lee and reviewed with the Interim Receiver. The preliminary workplan recommended the formation of a small technical working group that would be consulted through the project for technical input.

To that end, the technical working group was assembled and consulted on the preliminary workplan. The workplan, budget and schedule were finalized at that time. The scope of the project was generally defined to include the goals and objectives listed in Section 1 as applied to both Rose and Vangorda Creeks.

A project team was formed to carry out the project that consists of the following key personnel:

- Dr. Neil Hutchinson, Gartner Lee;
- Dr. Leslie Gomm, P.Eng., Gartner Lee;
- Mr. Eric Denholm, P.Eng., Gartner Lee; and
- Mr. Don MacDonald, MacDonald Environmental Sciences Ltd.

Dr. Hutchinson conducted the technical derivations, working closely with Mr. MacDonald as an internal peer reviewer, based on his knowledge in this field. Mr. MacDonald is a leading scientist with direct experience in the development and application of the CEQG and BC guidelines. Dr. Gomm and Mr. Denholm served as technical support persons providing their in-depth knowledge of the site.

Dr. Gomm's initial involvement with this project was as a member of the technical working group, working from the Yukon Type II Mines Projects Office. Subsequent to initiation of the project, Dr. Gomm joined Gartner Lee and contributed to the technical aspects of the project as a member of the project team.

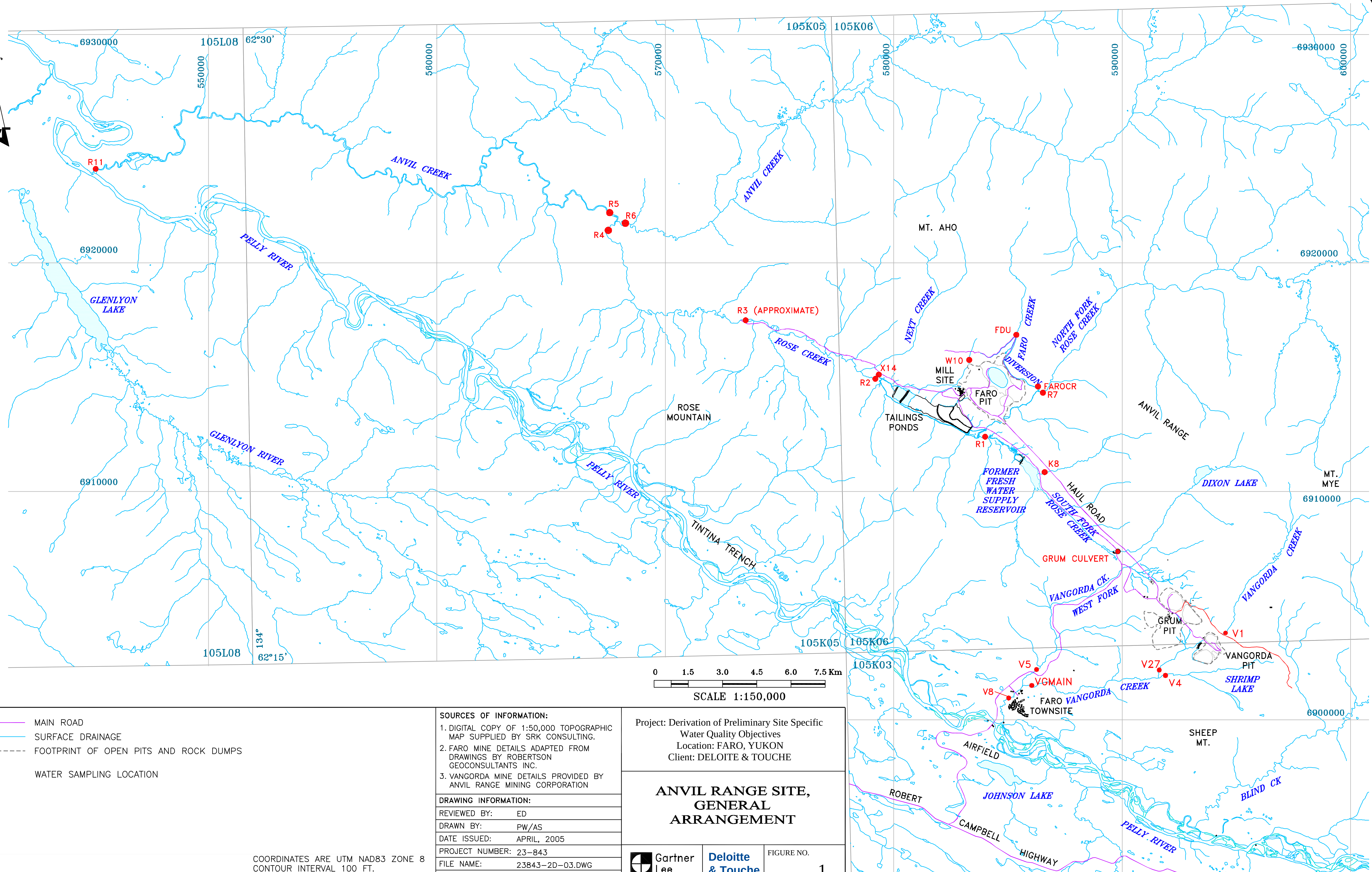
For the bulk of the project to date, the technical working group consisted of the following individuals:

- Benoit Godin, Environment Canada;

- Paul Jiapizian, Environment Canada;
- Frank Patch, Faro Mine Closure Planning Office;
- Bob Truelson, GY Water Resources;
- Valerie Chort, Interim Receiver; and
- Gartner Lee Project Team.

The working group was recently enlarged, at the request of the Faro Mine Closure Planning Office, to include representation from the Ross River Dena Council and the Selkirk First Nation.

Teleconference meetings and internal technical memorandum have been used to facilitate communications for the group.



MAIN ROAD
SURFACE DRAINAGE
FOOTPRINT OF OPEN PITS AND ROCK DUMPS
WATER SAMPLING LOCATION

COORDINATES ARE UTM NAD83 ZONE 8
CONTOUR INTERVAL 100 FT.

SOURCES OF INFORMATION:
1. DIGITAL COPY OF 1:50,000 TOPOGRAPHIC MAP SUPPLIED BY SRK CONSULTING.
2. FARO MINE DETAILS ADAPTED FROM DRAWINGS BY ROBERTSON GEOCONSULTANTS INC.
3. VANGORDA MINE DETAILS PROVIDED BY ANVIL RANGE MINING CORPORATION

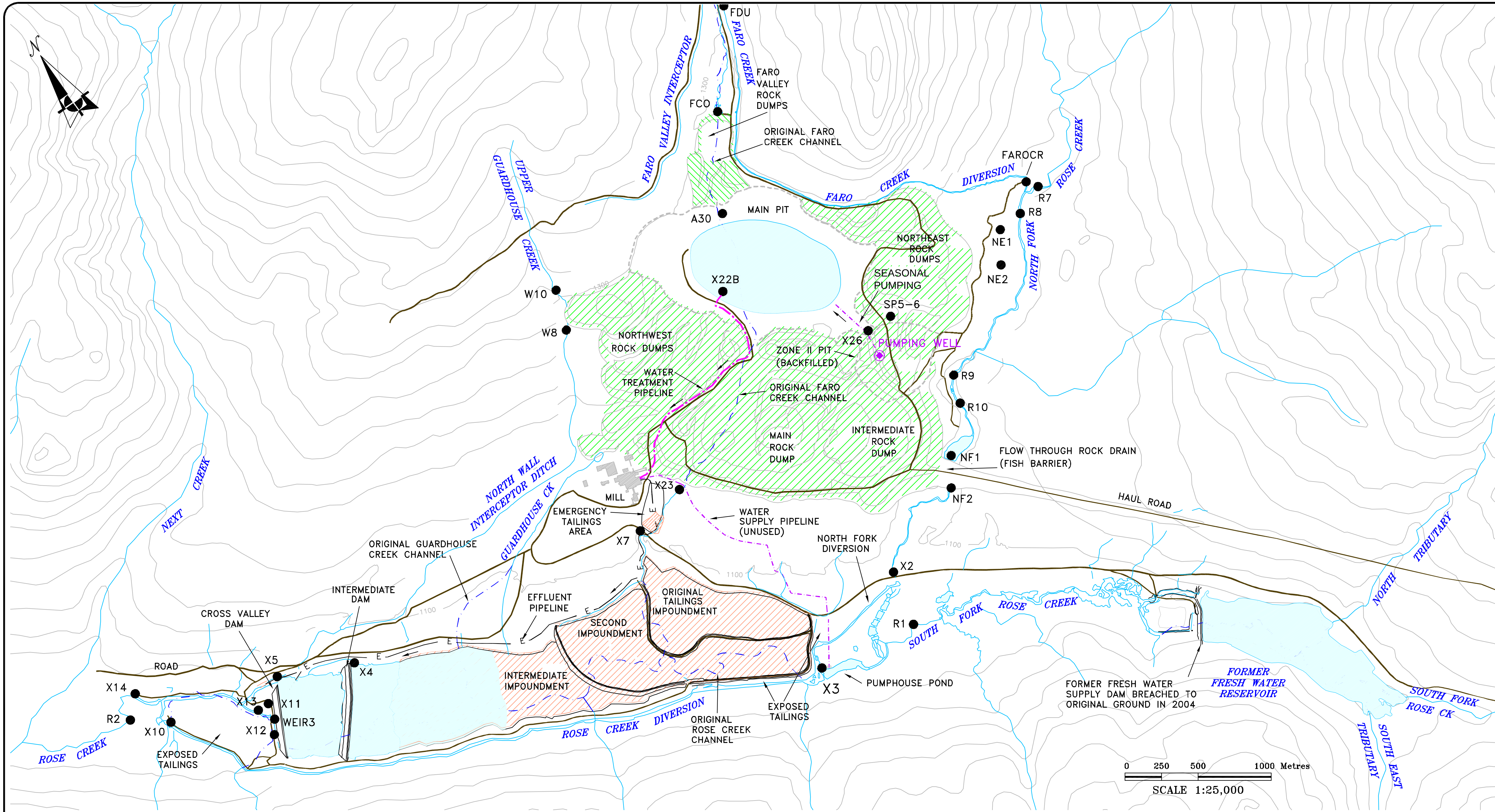
DRAWING INFORMATION:	
REVIEWED BY:	ED
DRAWN BY:	PW/AS
DATE ISSUED:	APRIL, 2005
PROJECT NUMBER:	23-843
FILE NAME:	23843-2D-03.DWG
REVISION:	0

Project: Derivation of Preliminary Site Specific Water Quality Objectives
Location: FARO, YUKON
Client: DELOITTE & TOUCHE

ANVIL RANGE SITE, GENERAL ARRANGEMENT

Gartner Lee
Deloitte & Touche

FIGURE NO. 1



LEGEND:

ROADS	SURFACE WATER
EXISTING SURFACE DRAINAGE	WASTE DUMPS
PRE-MINE DRAINAGE	TAILINGS IMPOUNDMENT
EFFLUENT PIPELINE	SURFACE WATER SAMPLING LOCATION
PIPELINE	
WATER TREATMENT PIPELINE	

SOURCES OF INFORMATION:

1. DIGITAL COPY OF 1:50,000 TOPOGRAPHIC MAP SUPPLIED BY SRK CONSULTING.
2. MAP COORDINATES ARE UTM NAD83 ZONE 8; CONTOUR INTERVAL 100 FT.
3. FARO MINE DETAILS ADAPTED FROM DRAWINGS BY ROBERTSON GEOCONSULTANTS INC.

DRAWING INFORMATION:

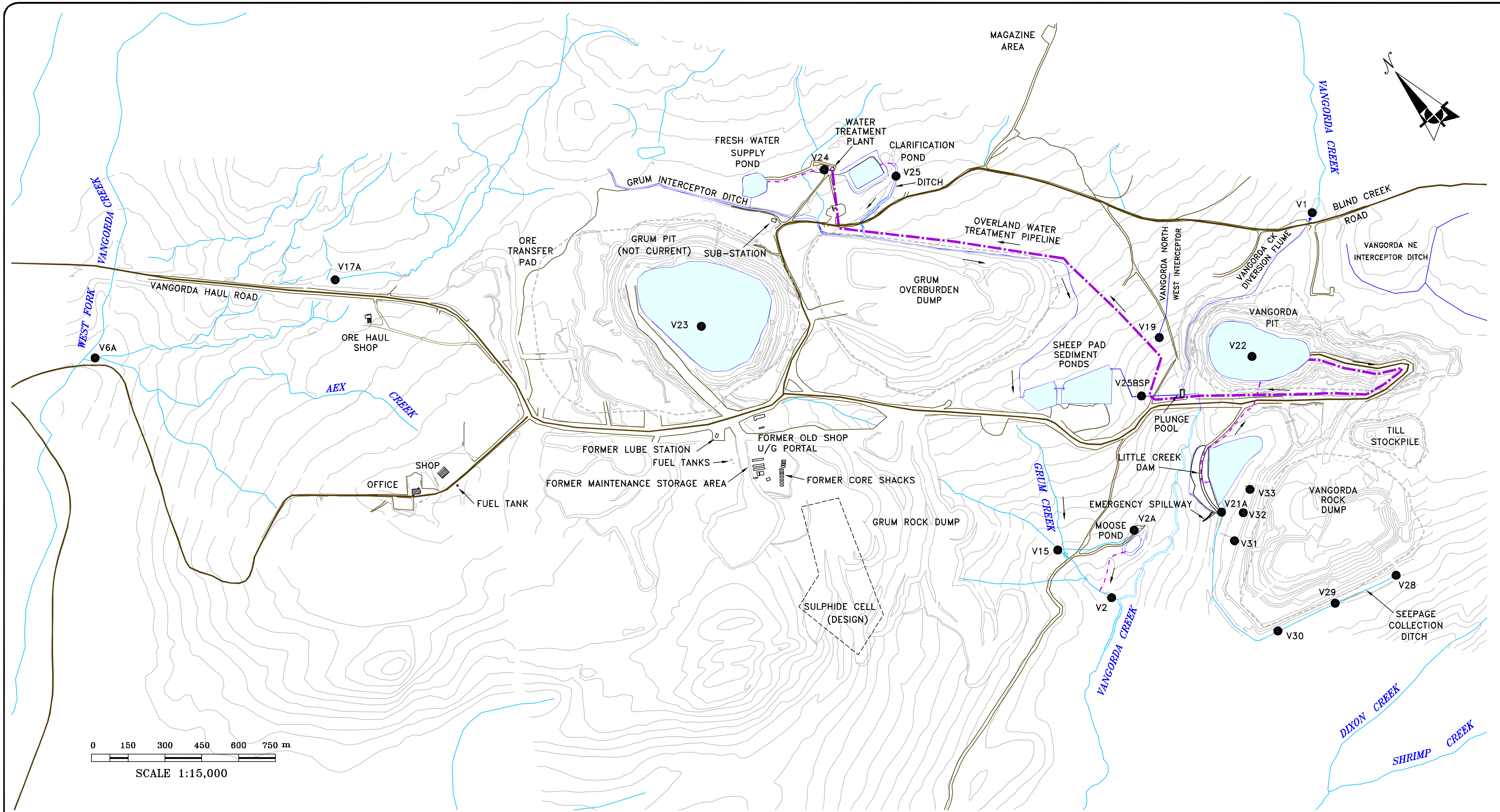
REVIEWED BY:	LH/ED
DRAWN BY:	PW/AS
DATE ISSUED:	APRIL, 2005
PROJECT NUMBER:	23-843
FILE NAME:	23843-2D-01.DWG
REVISION:	0

Project: Derivation of Preliminary Site Specific Water Quality Objectives
Location: FARO, YUKON
Client: DELOITE & TOUCHE

FARO MINE SITE GENERAL ARRANGEMENT

Gartner Lee | Deloitte & Touche

FIGURE NO. 2



LEGEND:

- ROADS
- EXISTING SURFACE DRAINAGE
- PRE-MINE DRAINAGE
- EFFLUENT PIPELINE
- PIPELINE
- WATER TREATMENT PIPELINE
- SURFACE WATER
- SURFACE WATER SAMPLING LOCATION

DRAIN #1 = V28
DRAIN #2 = V29
DRAIN #3 = V30
DRAIN #4 = V31
DRAIN #5 = V32
DRAIN #6 = V33

GROUNDWATER WELLS = V34 TO V38
PIEZOS. IN TOE BERM = V39 TO V47

SOURCES OF INFORMATION:

1. DIGITAL COPY OF 1:50,000 TOPOGRAPHIC MAP SUPPLIED BY SRK CONSULTING.
2. FARO MINE DETAILS ADAPTED FROM DRAWINGS BY ROBERTSON GEOCONSULTANTS INC.

DRAWING INFORMATION:

REVIEWED BY:	LH/ED
DRAWN BY:	PW/AS
DATE ISSUED:	APRIL, 2005
PROJECT NUMBER:	23-843
FILE NAME:	23843-2D-02.DWG
REVISION:	0

Project: Derivation of Preliminary Site Specific Water Quality Objectives
Location: FARO, YUKON
Client: DELOITE & TOUCHE

VANGORDA PLATEAU MINE SITE GENERAL ARRANGEMENT

Gartner Lee
Deloitte & Touche

FIGURE NO. 3

2. Project Management and Execution

The project managed by the Deloitte & Touche Inc. (in their capacity of the Interim Receiver for Anvil Range Mining Corporation) on behalf of the Faro Mine Closure Planning Office. The project is being conducted by Gartner Lee Ltd. on contract to the Interim Receiver.

2.1 Project Management, Workplan and Scope

A preliminary workplan was developed by Gartner Lee Ltd. and reviewed with the Interim Receiver. The preliminary workplan recommended the formation of a small technical working group that would be consulted through the project for technical input.

To that end, the technical working group was assembled and consulted on the preliminary workplan. The workplan, budget and schedule were finalized at that time.

The scope of the project was generally defined to include the goals and objectives listed in Section 1 as applied to both Rose and Vangorda Creeks.

2.2 Project Team

A project team was formed to carry out the project that consists of the following key personnel:

- Mr. Eric Denholm, P.Eng., Gartner Lee Ltd.;
- Dr. Neil Hutchinson, Gartner Lee Ltd.;
- Dr. Leslie Gomm, P.Eng., Gartner LeeLtd.; and
- Mr. Don MacDonald, MacDonald Environmental Sciences Ltd.

Mr. Denholm served as overall project manager and brought his many years of personal experience on the Anvil Range property to the project. Dr.'s Hutchinson and Gomm conducted the technical derivations based on their combined leading knowledge in these fields. Throughout these revisions, we have worked in close cooperation with Don MacDonald of Macdonald Environmental Sciences Ltd. Mr. MacDonald is a leading scientist with direct experience in the development and application of the Canadian Environmental Quality Guidelines and British Columbia Water Quality Guidelines. His constructive and critical insights, provided in his role as internal peer reviewer, have been extremely valuable to our work.

Dr. Gomm's initial involvement with this project was as a member of the technical working group, working from the Yukon Type II Mines Projects Office. Subsequent to initiation of the project, Dr.

Gomm joined Gartner Lee and contributed to the technical aspects of the project as a member of the project team.

2.3 Technical Working Group

The technical working group consists of the following individuals:

- Benoit Godin, Environment Canada;
- Paul Jiapizian, Environment Canada;
- Frank Patch, Faro Mine Closure Planning Office;
- Bob Truelson, GY Water Resources;
- Valerie Chort, Interim Receiver; and
- Gartner Lee Project Team.

Teleconference meetings and internal technical memorandum were used to facilitate communications for the group.

3. Approach to Derivations

Site Specific Water Quality Objectives were developed with the understanding that they must protect the Anvil Range receiving waters from three sources of contaminant stress during the closure period:

1. The annual discharge of treated water from the site. Metal (specifically zinc) contaminated water is collected from a variety of on-site sources over the year and held in the mine pits at the Faro and Van Gorda sites. The water is treated and discharged as a high alkalinity, high hardness effluent to the low alkalinity and low hardness receiving waters during the freshet in the spring and early summer months.

2. Any ongoing or future seepage of metals-enriched water to streams on site. This could occur year round and the receiving waters would vary in their water chemistry between the freshet and periods of base flow.

3. Any seepage of acid mine drainage that might occur in the future.

3.1 CCME Procedures and Guidance

The current water licence for the Anvil Range mine (QZ03-059) specifies that receiving water quality in Rose Creek shall comply with CCME guidelines. It is reasonable to consider this standard applicable to Vangorda Creek also, as was documented at the Water Licence Renewal Hearing (October 2003). The CCME documentation, however, allows for modification of the generic WQG's for application to specific sites with unique characteristics. Documentation by CCME (2003) and the Government of British Columbia (1997) provides protocols for the derivation of site specific objectives.

3.1.1 Overview

The general sequential approach is followed for the derivation of site specific WQO's:

a) Assess the need for site specific WQO's;
b) Select an appropriate Receiving Water Protection Strategy;
c) Identify parameters of interest;
d) Follow the prescribed process for assessment of information and derivation of preliminary WQO's; and
e) Adopt Preliminary WQO's.

Steps (a) through (c) are described in Sections 3.2 through 3.4. Steps (d) and (e) are described in subsequent sections.

3.2 Need for Site Specific Water Quality Objectives

The generic WQG's are provided to cover a wide range of environmental conditions, to protect the most sensitive forms of aquatic life with safety factors built in. While adoption of generic WQG's as objectives for a site represents the initial approach for the protection of aquatic life, the presence of unique water quality characteristics or species assemblages at certain sites may necessitate the derivation of site adapted or site specific water quality objectives.

There are two characteristics of the Anvil Range site that create the need for site-specific WQO's:

1. Natural conditions exceeding the generic WQG's; and
2. Naturally variable hardness and alkalinity.

An additional factor considered regarding the need for site specific WQO's is the freshwater aquatic community at the site. Arctic grayling are the species of greatest abundance, and are known to spawn downstream of the site in Rose and Vangorda Creeks. Burbot and slimy sculpin are also present. These species are not represented in the toxicity database used to derive the CCME and BC water quality objectives. The significance of this is not clear, as many of the most sensitive coldwater species of fish and invertebrate were used for objective development and the database, at least for zinc, is robust. The database also contains data from numerous studies of salmonids. Arctic grayling are members of the salmonid family so that toxicity values from the database are likely applicable. Chinook salmon are present in the receiving waters and are represented in the toxicity database, as are several invertebrate species which are relevant to the site. Therefore, although the toxicity database does not contain data for grayling, it does contain data from representative coldwater species for the site.

3.2.1 Natural Conditions Exceeding the Generic WQG's

There is no numerical information on water quality in Rose Creek prior to development of the Faro mine in 1968. There is a minor amount of water quality data for Vangorda Creek prior to development of the Vangorda and Grum mines. In both cases, water quality upstream of mine facilities has been monitored over an extended period of time and this water quality data provides the best reference for natural conditions in the creeks. This is with recognition that localized mineral exposures may have resulted in increased contaminant concentrations in the current mining areas even before mine development, such that the current upstream reference conditions may actually underestimate what would have been true "background" contaminant concentrations.

The data record since approximately 1995 shows that some water quality parameters at the upstream reference locations in both Rose and Vangorda Creeks occasionally exceed the generic WQG's. This creates the need for derivation of site-specific WQOs for those parameters. This is being done as a separate component of the project (Gartner Lee Ltd., 2005).

3.2.2 Naturally Variable Hardness and Alkalinity

Hardness and alkalinity in waters at the Anvil Range site are highly variable, thus modifying the toxicity of some parameters such as zinc (Zn) or copper. Two factors account for the variance. The first factor is the effects of freshet, during which time meltwater from snow dilutes baseflow, thus reducing hardness and alkalinity levels from those which occur during the winter.

The second factor is that the most significant source of zinc and sulphate is discharge of mine water that has been treated with lime, thus elevating pH, hardness and alkalinity in the discharge and, hence, the receiving water. The complex interaction of the effluent discharge with variable receiving water quality will alter the toxicity of some parameters, such as Zn and Cu.

Zinc is typically identified as the primary contaminant of concern in the aquatic environment at the Anvil Range Site (Gartner Lee Ltd., 2003) and is the metal that is most likely to impair aquatic life downstream of the site. The relationship of Zn toxicity to hardness is very well established. The Province of British

Columbia has derived a hardness correction factor that allows for direct derivation of a site specific water quality objective for Zn as follows:

- BC (2001) – maximum concentrations not to exceed 33 + 0.75 * (hardness - 90)
- BC (2001) – 30-day average concentration not to exceed 7.5 + 0.75 * (hardness –90)

Therefore, it would be feasible to develop a site specific water quality objective for Zn by using the hardness calculation provided by the Province of British Columbia[1]. This would allow for a rapid derivation of a WQO for zinc but lacks site specific validation against local conditions of hardness and alkalinity. Therefore, for the Anvil Range Site the BC approach has been presented for reference and comparison purposes but the derivation of a site-specific WQO following the CCME procedures is recommended.

3.3 Receiving Water Protection Strategy

Two distinct strategies are commonly used to establish Water Quality Objectives in Canada, the antidegradation strategy and the use protection strategy.

The antidegradation strategy is used to avoid any degradation of existing water quality where aquatic resources have national or regional significance. The receiving waters at the Anvil Range site, namely Rose and Vangorda Creeks, have not been identified as having any national or regional significance as they are not known to exhibit exceptional water quality or to support any rare or endangered species of aquatic or terrestrial life. In addition, both have been subjected to the discharge of mine effluents over extended periods such that any original significance will have been altered. Therefore, the antidegradation strategy is not considered appropriate for the Anvil Range site.

The use protection strategy requires that Water Quality Objectives are established to protect the designated uses of the aquatic system and recognizes that some degradation of water quality is permitted, so long as the designated uses are protected. The history of mining at the Anvil Range site supports the application of the use protection strategy for deriving water quality objectives at the site.

3.4 Parameters of Interest

Water quality "parameters of interest" were identified for consideration in the SSWQO Development Process. These included any parameters for which a SSWQO may have to be developed for the Anvil Range Site by any of the recommended CCME methods. From this list, 'Contaminants of Concern" were identified for more intensive WQO development, based on their concentrations in the receiving waters

[1] In later sections of this document, we show how our work on deriving the SSWQO for the Anvil Range Site concluded that it is not valid to apply the hardness-corrected BC Guideline for zinc.

and the characteristics of the receiving waters themselves. This document focuses on zinc as the primary contaminant of concern. Other metals are addressed by a separate process and documentation (Gartner Lee Ltd., 2005).

3.4.1 Criteria for Parameters of Interest

The starting point for identifying those parameters for which a site specific WQO may be appropriate is a complete listing of parameters of interest. The criteria for development of this list for the Anvil Range site are as follows:

- Is typically analysed in receiving water samples (i.e., data record is available);

and

- Is listed in Section 3 of the Water Licence (effluent discharge criteria); or
- Has a CEQG or BC guideline value for any of the local water uses; or
- Is identified as a potential result of acid rock drainage at the site (in the discussion following).

The parameters of interest for the Anvil Range site, based on these selection criteria, are listed in Table 1.

Table 1. Listing of Parameters of Interest

Parameters of Interest			
Aluminum (Al)	Calcium (Ca)	Manganese (Mn)	Sulphate (SO_4)
Ammonia (N)	Chromium (Cr)	Mercury (Hg)	Suspended Solids (TSS)
Antimony (Sb)	Cobalt (Co)	Molybdenum (Mo)	Thallium (Tl)
Arsenic (As)	Colour	Nickel (Ni)	Turbidity
Barium (Ba)	Copper (Cu)	pH	Uranium (U)
Beryllium (Be)	Cyanide (CN)	Selenium (Se)	Vanadium (V)
Boron (B)	Iron (Fe)	Silver (Ag)	Zinc (Zn)
Cadmium (Cd)	Lead (Pb)	Sodium (Na)	

The objective development process focussed on zinc as the contaminant of concern, as it was the only contaminant discharged from the mine site which:

- Showed concentrations in receiving water that exceed those in reference waters for the sites and;
- Showed concentrations in receiving waters that exceeded either or both of the CCME or BC Environment Guidelines for protection of freshwater life, and

- Has the potential to be toxic at the observed concentrations (i.e. Manganese and sulphate are also found at concentrations above reference levels but there is no CCME guideline for either contaminant).

3.4.2 Discussion of Acid Rock Drainage

The Project Team raised the possibility that other metals may be mobilized from the mine site over time, as acid generation progresses. Therefore, although zinc is the contaminant of concern right now, other metals may be mobilized at some point in the future. This is a possibility but it should also be noted that the intent of the closure plan is to mitigate acid drainage and metals mobilization, in order to decrease the long-term requirements to treat discharge water from the site and to ensure protection to the environment and human health. If it is assumed that this will also be a requirement for the closure plan, concerns regarding other contaminants of concern will be reduced to the extent of the mitigation provided in the FCRP.

Dr. Stephen Day, of SRK Consulting provided the following opinion on metal mobilization in acid conditions, given his specific understanding of the Anvil Range Site and a general understanding of the geochemistry of ARD:

> *"Zinc (Zn), manganese (Mn) and cadmium (Cd) are correlated. If zinc goes up, it's reasonable to expect cadmium and manganese to follow. We are predicting that this might happen with some components of the site. Copper is mobile under acidic conditions. Any area of the site that has not gone acid might release copper in the future. Again, we are expecting this in places. The same applies to cobalt (Co) and nickel (Ni). Lead's (Pb's) mobility is controlled by low solubility of $PbSO_4$. As sulphate (SO_4) decreases, lead may increase. This is a possible long term effect which is hard to quantify. Arsenic (As) is present in some of the highly acidic waters on site but as soon as iron (Fe) precipitates, arsenic co-precipitates. This is similar for antimony (Sb). We haven't picked up an issue for selenium (Se). Iron and aluminum (Al) are both major components of acid rock drainage but are quickly precipitated as pH increases. This is only an issue for acidic waters."*

These opinions were considered as follows:

Zinc, manganese and cadmium are correlated and so the presence of high zinc concentrations in the site drainage and pit water should be a cause for concern. Manganese is also elevated in site discharge waters and receivers and so will be considered in the objective setting process. It is present at levels below BC's hardness adjusted guideline in site receiving waters, however, and so can be addressed using the BC Guideline, without modification.

Cadmium concentrations are within CCME guideline levels or baseline concentrations in site receiving waters and are within the natural baseline levels in site discharges. Therefore, although cadmium is theoretically correlated with zinc in ARD, there is no evidence that it poses a special threat at the Anvil Range site at this time. There is no justification to include cadmium as a Contaminant of Concern and it can be addressed through either the existing guidelines or the CCME Background Concentration Approach (being developed separately, Gartner Lee Ltd., 2005). There is limited data on cadmium concentrations in the receiving waters on site and some concerns with the integrity of data in the database and so its inclusion should be reconsidered upon more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

Copper is either below CCME Guidelines or background reference concentrations in receiving waters on site but is elevated beyond CCME and reference levels in the site water discharges. It should therefore be considered as a Contaminant of Concern. Copper toxicity is altered by pH, alkalinity, hardness and Dissolved Organic Carbon in natural waters and so a site specific water quality objective should be considered. There is limited data on Cu concentrations in the receiving waters on site, however, and some concerns with the integrity of data in the database. Is inclusion should be reconsidered upon the more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

Chromium is either below CCME Guidelines or background reference concentrations in receiving waters on site but is elevated beyond CCME and reference levels in the site water discharges. It must therefore also be considered as a Contaminant of Concern. We note that there is limited data on Cr concentrations in the receiving waters on site and so its inclusion should be reconsidered upon more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

Iron and aluminum both appear to behave as predicted by Dr. Stephen Day above in that their solubility is controlled by pH in reference waters. Iron, for example, exceeds 2 mg/L in the discharge from the Faro site but decreases to < 0.3 mg/L in Rose Creek, immediately downstream of the discharge point. Iron is not considered a Contaminant of Concern.

Aluminum exceeds the CCME guideline in the site discharge but quickly declines to reference concentrations (< CCME) in the receiving waters downstream of the Faro Site. It appears to persist at some sites downstream of the Van Gorda Site and is worthy of closer examination and possible inclusion as a Contaminant of Concern. There is limited data on aluminum concentrations in the receiving waters on site and some concerns with the integrity of data in the database and so its inclusion should be reconsidered upon more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

Nickel concentrations in site discharge waters are elevated above reference levels but do not exceed the CCME Guideline in receiving waters. Ni is not considered a Contaminant of Concern.

Cobalt concentrations are elevated above the CCME Guideline in reference waters for the site, exceed the reference concentrations in discharge waters but appear to decrease with distance downstream form discharge points. Cobalt should be considered as a Contaminant of Concern. We note that there is limited data on cobalt concentrations in the receiving waters on site and some concerns with the integrity of data in the database and so its inclusion should be reconsidered upon more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

Lead concentrations are elevated above the CCME Guideline in reference waters for the site, exceed the reference concentrations in discharge waters but appear to decrease with distance downstream form discharge points. Lead should be considered as a Contaminant of Concern. We note that there is limited data on lead concentrations in the receiving waters on site and some concerns with the integrity of data in the database and so its inclusion should be reconsidered upon more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

Arsenic concentrations are elevated above the CCME Guideline in reference waters for the site, exceed the reference concentrations in some discharge waters but appear to decrease with distance downstream from discharge points. Aresenic should be considered as a Contaminant of Concern. We note that there is limited data on Arsenic concentrations in the receiving waters on site and some concerns with the integrity of data in the database and so its inclusion should be reconsidered upon more detailed review of the water quality data for the site. This is being done in a separate report (Gartner Lee Ltd., 2005).

3.4.3 Summary

Zinc is considered the primary Contaminant of Concern for the site, by virtue of its high concentrations in site discharge waters, its documented toxicity and evidence of high levels in receivers. Zinc toxicity is known to be modified by water hardness and alkalinity at the ranges experienced in the Anvil Range waters and so requires derivation of a site specific water quality objective. Copper, arsenic, cobalt, chromium and aluminum are potential Contaminants of Concern but existing data are limited, or compromised by concerns with data integrity in the database, such that their consideration is not automatically warranted. Nickel, cadmium and iron do not appear to pose sufficient threat that development of site specific objectives is warranted.

3.5 Most Sensitive Water Use

Following from the selection of the use protection strategy and the Contaminants of Concern the most sensitive use of water must be identified from the range of water uses for which WQG’s are provided. Under the use protection strategy, the most sensitive water use will provide the first determination of the degree to which water quality may be degraded for each parameter of interest.

The CCME provide generic WQG's for the following water uses:

- Community Drinking Water;
- Recreation and Aesthetics;
- Freshwater Life;
- Marine Life;
- Irrigation; and
- Livestock Watering.

The primary use of Rose and Vangorda Creeks is considered to be freshwater aquatic life. Therefore, the WQG's for freshwater aquatic life are considered to be a primary reference for this project.

Vangorda and Rose Creeks provide potential sources of drinking water to First Nation users and recreational users. The potential for a link between Vangorda Creek and the Town of Faro water supply pumps is the subject of a separate study being conducted for future submission to the Yukon Water Board. Therefore, WQG's for the protection of drinking water, with the exception of fecal coliform and other organic substances that are not linked to mining activities, are also considered to be a primary reference for this project.

Livestock watering is not a relevant use of Rose and Vangorda Creeks. However, wildlife does drink from the creeks and the WQG's for livestock watering would presumably protect wildlife that use creek water for drinking. Therefore, the CEQG guidelines for livestock watering are considered relevant to this project.
Recreation and aesthetics are valid uses of these water bodies although not entirely as contemplated in the CCME documents. "Recreation" use is contemplated by CCME as being in frequent direct contact with the water such as swimming. Secondary "recreational" uses would include somewhat less frequent contact through boating and fishing, for example. The current understanding of recreational use of Rose and Vangorda Creeks includes camping, hunting and fishing activities which are considered to be most similar to the secondary recreational uses contemplated by CCME. Therefore, the WQG's for the protection of recreational water use are considered relevant for this project in the context of anticipated "secondary" uses of the water.

Neither Rose nor Vangorda Creeks support marine life or irrigation as water uses and, therefore, these water uses are not relevant to this project.

In summary, the water uses recognized by CCME that are considered relevant to the Anvil Range site are as follows:

- Freshwater Life (a primary water use);
- Community Drinking Water (a primary water quality reference);

- Livestock Watering (assumed protective of wildlife drinking the water); and
- Recreation and Aesthetics (in the context of CCME "secondary" uses).

The Water Quality Objectives for Freshwater Aquatic Life for zinc are:

- CCME (2003) = 0.03 mg/L
- BC (2001) – maximum concentrations not to exceed (33 + (0.75 * (hardness - 90)))
- BC (2001) – 30-day average concentration not to exceed (7.5 + (0.75 * (hardness –90)))

For Drinking Water, the Objective is:

- CCME (2003) = 5.0 mg/L

For Irrigation, the Objective is:

- CCME (2003) = 1 – 5 mg/L

For Livestock, the Objective is:

- CCME (2003) = 50 mg/L

The WQO for zinc is lowest for the protection of aquatic life. Therefore, protection of freshwater life from Zn will also protect other, less sensitive uses.

4. Methods for Deriving Site Specific Objectives

There are four procedures recommended by the CCME (2003) for deriving site specific water quality objectives:

1. Background Concentration Procedure;
2. Recalculation Procedure;
3. Water Effect Ratio Procedure; and
4. Resident Species Procedure.

These are each described briefly in the following sections.

4.1 Background Concentration Procedure

The background concentration procedure is generally applicable where natural concentrations in the subject waters are greater than the generic WQG's. In these circumstances, achieving the generic WQG's in the receiving water may not be possible.

This procedure uses various statistical representations to calculate the natural background concentrations of the parameters of interest in the subject waters. In this procedure, the background concentration then becomes the Preliminary Water Quality Objective.

Natural water quality at the Anvil Range site is known to contain occasional exceedances of the generic WQG's and, therefore, the background concentration procedure may be appropriate for some parameters at this site. Development of SSWQO using the background concentration procedure is provided as a separate report (Gartner Lee Ltd. 2005). It is not appropriate for zinc, however and so other procedures were reviewed.

4.2 Recalculation Procedure

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 the generic WQG's. The procedure uses the toxicity database used to derive the generic WQG's but modifies the database by omitting data on species that are not 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 that in the species that occur at the study site.

The Water Quality Objective Development process is intended to protect the most sensitive life stages of the most sensitive species inhabiting a water body. The generic WQG's are, therefore, most influenced by the most sensitive species in the complete toxicity database. The recalculation procedure is most relevant where the most sensitive species in the database do not reside at the site under question. (i.e. the recalculation generally results in increasing the Water Quality Objective to account for waters where more sensitive species do not reside). The recalculation procedure cannot, by definition, result in an objective that is more sensitive than the generic objective.

The toxicity database used to derive the WQG for zinc shows that the most sensitive species and life stages are salmonid fish, and that chinook salmon are among the most sensitive species. Salmonids (grayling and chinook salmon) are present in the receiving waters at the Anvil Range site and the generic objective is set at a level to protect them. There is not, therefore, any real difference in the sensitivity range of the species used to develop the generic objectives, and those species present in Rose and Vangorda Creeks. Both sets contain sensitive species. Although the the recalculation procedure was not used to derive a Site Specific Water Quality Objective for zinc in the Anvil Range receiving waters, elements of the procedure were adopted, as described in later sections of this report.

4.3 Water Effect Ratio Procedure

The water effect ratio (WER) procedure is generally applicable at sites where the natural conditions of the water vary substantially from the test waters used to derive the generic WQG's. The WER procedure is based on the premise that physical and chemical characteristics of water can vary among sites and thus influence the bioavailability and toxicity of contaminants. For example, the toxicity of zinc is highly dependent on the pH, hardness and alkalinity of water. These factors are not considered in the generic WQG for zinc, although the BC objective does account for the effect of hardness on toxicity. The toxicity database used to derive the generic WQG may contain studies done at water quality conditions that differ from those at the site. The WER procedure provides a powerful means of accounting for such differences to modify the generic objective to make it more relevant to water quality conditions at the site under consideration.

The WER procedure requires conducting toxicity studies in both the site water and in "standard" laboratory water, using either indicator species (i.e. those species for which standard toxicity testing procedures exist and which are representative of species found at the study site) or species that are resident at the study site. The WER is the ratio of the toxicity of the contaminant of concern in water from the study site to its toxicity in the standard lab water. The site specific WQO is then calculated by multiplying the generic water quality objective by the WER. This provides a direct measure of the influence of physical and chemical characteristics of water from the study site on the toxicity of the contaminant of concern. For example, if hardness reduced the toxicity of zinc by a factor of two in water from the study site, then the WER of 2 would be applied to double the numeric value of the generic water quality objective.

The WER procedure is considered to be relevant to conditions on the Anvil Range site, where hardness and alkalinity vary seasonally. In addition, the aquatic species of concern are salmonids and these are well represented with standard toxicity testing procedures for salmonids and other sensitive species such as fathead minnows. There are therefore suitable test species and methods available to apply the WER procedure. The WER procedure was therefore adopted as the primary means of developing a SSWQO for the Anvil Range site.

4.4 Resident Species Procedure

The resident species procedure is generally applicable at sites where the resident aquatic species are not represented in the toxicity database. The procedure is designed to directly account for the sensitivity of species that occur at the study site and for the influence of site water characteristics on toxicity. It involves generating a complete toxicity data set, using established national protocols, for the contaminant of concern using site water and resident species. As such, it represents a direct and complete derivation of a site specific WQO.

The Resident Species Procedure is very costly, lengthy and involves some heightened technical risk as regards culturing test stock of site-specific species. The CCME protocol requires the use of six species (three fish, two invertebrate and one algal or plant species). For sites such as Anvil Range site with substantial annual variations in water characteristics, tests would have to be repeated to cover the ranges in receiving water quality. In addition it is very costly and time intensive to develop care and culture techniques for a new species. There are no existing protocols or experience for the culture and testing of Arctic grayling, slimy sculpin or burbot (species present at the Anvil Range site) and, therefore, these would need to be developed with no assurance that these species would survive transit from the site, or adapt well enough to culture facilities, to produce reliable toxicity data.

The species present at the Anvil Range site (arctic grayling, a salmonid species) are well represented in the toxicity database with data on other salmonids. The effort and cost required to generate data specific to the species may not result in information that does not already exist in the salmonid database. The specific effects of water characteristics on toxicity are more appropriately addressed, for the Anvil Range site, through the WER Procedure.

The Resident Species Procedure is not, therefore, considered appropriate for the Anvil Range site.

5. Deriving the SSWQO

Section 4 provided a general description of the water effects ratio (WER) procedure. The procedure is considered appropriate for the Anvil Range site based on the highly variable natural hardness in Rose and Vangorda Creeks. Further, the toxicity database contains species that are considered to be representative of the species present at the site.

Zinc is typically identified as the parameter of most concern at the Anvil Range site because of its chemical mobility, potential aquatic toxicity and general availability in mine water, soil, rock and tailings. For example, the water treatment systems at the site are primarily focused on removal of zinc and it has been well documented that the effective removal of zinc results in full compliance with other regulated parameters. Additionally, there is a well documented relationship where the toxicity of zinc can be affected by varying hardness, such as is naturally present in Rose and Vangorda Creeks.

Therefore, zinc is considered the primary parameter of interest as regards the WER procedure for the Anvil Range site.

There are other parameters such as copper, manganese and sulphate, which are also present in mine water, are also potentially toxic in the aquatic environment and for which toxicity can be affected by hardness. However, these parameters have not been dominant in the creek water as has been zinc and, in some cases such as sulphate, no WQG is provided by CCME. Further, the scope of work to carry out the WER procedure would increase in direct proportion to the number of parameters being studied. Therefore, these other parameters were not assessed under the WER procedure. The possibility remains to re-assess the appropriateness of the WER procedure for these parameters in the future.

The working hypothesis that informed our investigations was that the large natural ranges in total hardness of the waters in Vangorda and Rose Creeks would modify the toxicity of zinc discharged to these waters. Therefore, tests of zinc toxicity carried out over the natural range of hardness in the creek waters, combined with testing of the discharged effluent itself, would allow derivation of site and seasonally specific water quality objectives to guide closure planning.

5.1 Approach

The WER Procedure requires conducting toxicity studies in both the site water and in “standard” laboratory water, using either indicator species (i.e. those species for which standard toxicity testing procedures exist and which are representative of species found at the study site) or species that are resident at the study site. The WER is the ratio of the toxicity of the contaminant of concern in water from the study site to its toxicity in the standard lab water. The site specific objective is then calculated by multiplying the generic water quality objective by the WER. This provides a direct measure of the influence of physical and chemical characteristics of water from the study site on the toxicity of the contaminant of concern. For example, if hardness reduced the toxicity of zinc by a factor of two in water from the study site, then the WER of 2 would be applied to double the numeric value of the generic water quality objective.

The steps carried out for the Anvil Range site were as follows:

1. Toxicity testing using three approved species and controlled laboratory exposures to zinc in the two receiving waters for the Anvil Range complex. (Rose Creek and Vangorda Creek). This testing was done during the late winter baseflow period of higher hardness (April 2004) and the early summer period of runoff of lower hardness (June 2004) to capture a range in receiving water characteristics sufficient to set hardness-specific objectives, if warranted.
2. Toxicity testing using the same three species on samples of the treated effluent discharged to each creek in August of 2004. This allowed comparison with zinc-only exposures to assess whether or not a) there were additional toxicants in the effluent besides zinc and b) if other characteristics of the whole effluent such as alkalinity would modify zinc toxicity.

3. Review of the hardness-corrected zinc guideline for the Province of British Columbia to assess its suitability for application at the Anvil Range site.

4. Analysis and synthesis of the results of 1,2 and 3 to derive recommendations for site specific water quality objectives for the long-term discharge of zinc to Rose Creek and Vangorda Creek.

5. Refinement of the objective development process to incorporate a curvilinear effect of water hardness on zinc toxicity and to modify the WER approach, following review of the draft approach and results with the Technical Working Group in 2005.

6. Toxicity Testing

A series of tests were carried out to assess the toxicity of zinc, both on its own and in the effluent from the Anvil Range site, to fish, invertebrates and algae in the Anvil Range receiving waters.

6.1 Choice of Species and Tests

Considerations for the choice of test species included the need for a sensitive organism to protect receiving waters and the need to assess fish, invertebrate and plant species to get a wide range of responses of relevance to the entire ecosystem. This follows the general approach taken in other Canadian jurisdictions and best addresses First Nations suggestions for a holistic approach to environmental protection.

The following toxicity tests were considered:

- rainbow trout *(Oncorhyncus mykiss)* juvenile survival as representative of salmonid fish in the receiving waters,
- rainbow trout egg, larval and alevin survival, or fathead minnow (*Pimephales promelas)* larval hatch, survival and growth as representative of fish reproduction - a sensitive ecosystem process in the receiving waters;
- reproduction, survival and growth of the water flea (*Ceriodaphnia dubia*) or survival of a mayfly species as representative of invertebrates, the intermediate levels of the food chain in the receiving waters,
- Growth of the alga *Selenastrum capricornutum* as representative of primary producers (i.e algae growing attached to rocks) in the receiving waters.

One consideration in the choice of test species was the remote location of the Anvil Range site relative to testing laboratories. This increases the travel time for delivery of samples to the lab and the logistical issues with large volume samples and frequent samples. Discussions with toxicity testing labs established that the rainbow trout tests were not suitable, as they are longer duration tests that would require large volumes of water (180-220 L per week) to be transported from the site to the test facility in Vancouver.

The most appropriate combination of sensitive and chronic biological response, shorter test time and lower water volume requirements were considered to be the following tests:

1. Fathead Minnow 7 day larval survival and growth test (EPS 1/RM/22 1992/1997);
2. *Ceriodaphnia dubia* (water flea) Three brood (7 day) Survival and Reproduction Test (EPS 1/RM/21 1992/1997); and
3. *Selanastrum capricornutum* (algae) 72hr Growth Inhibition Test (EPS 1/RM/25 1992/1997).

These toxicity tests were therefore used to assess the toxicity of zinc in the receiving waters from the Anvil Range site.

6.2 Methods

6.2.1 General Methods

Toxicity testing was carried out by Vizon SciTec Inc. in Vancouver BC. The laboratory is fully accredited[2] and submitted complete summaries of test procedures and the necessary quality assurance/quality control (QA/QC) documentation with each report. Only the key features of toxicity testing are presented here. Detailed methods are provided in the documentation of test procedures cited above and in the reports from the contract toxicity laboratory. These reports have been retained by Gartner Lee Ltd. but are available for review, as needed. One exception, a *Ceriodaphnia* test in August 2004 was subcontracted to EVS Consultants Ltd., in Vancouver, which is also fully accredited.

For the tests of zinc toxicity in April and June, toxicity testing began with a “rangefinder test”, in which organisms were exposed to a geometric range of zinc concentrations (i.e., 0.001, 0.01, 0.1, 1.0 and 10 mg/L) to determine the approximate toxic concentrations. These concentrations were then used to set a

[2] Standards Council of Canada (SCC) in cooperation with the Canadian Association of Environmental Analytical Laboratories (CAEAL).
Recognized by the Standards Council of Canada (SCC) as a Good Laboratory Practices (GLP) facility compliant with OECD Principles of GLP.
BC Ministry of Water Land and Air Protection (BCWLAP) under the Environmental Data Quality Assurance (EDQA) Regulation.
State of Washington Department of Ecology (WDOE) to perform analysis for the parameters listed in the Scope of Accreditation Report for Vizon SciTec Inc. using ASTM, SM and EPA analytical test methods.

narrower range of concentrations for a definitive test of toxicity. In all cases, the intent was to set a range of zinc concentrations sufficient to include total survival, total mortality and one or more partial responses. It was not always possible, however, to achieve this, as described below.

Chemical analyses were carried out on selected samples of test water, creek water and whole effluent to confirm zinc concentrations and other water quality characteristics such as total hardness, alkalinity, Dissolved Organic Carbon, pH or sulphate concentrations. All toxicity summaries were calculated from the definitive tests using measured chemistry.

All tests were run using two controls. The first control, exposure of test organisms in laboratory water, was run to confirm laboratory procedures and the health of test organisms. A second control was run in the waters of Rose and Vangorda Creeks, without the addition of zinc or effluent. It served as a control on the effects of the specific toxicants added.

6.2.2 April Testing

Water from each of Rose Creek and Vangorda Creek was collected into 22 L containers by Gartner Lee Ltd. at 1230 hours on April 2 and transported to Whitehorse, YT on the same day. Samples were shipped from Whitehorse to Vancouver by air and received by the lab on April 5, 2004. Samples were kept refrigerated in the dark until testing started. Test were conducted by spiking zinc into each receiving water as a concentration series The rangefinder test was started on April 7, 2004 and the definitive testing on May 13. All toxicity summaries were calculated from the definitive tests using measured chemistry.

Rangefinding tests showed complete survival of fathead minnow larvae at 1.0 mg/L of zinc and complete mortality at 10 mg/L in waters from both creeks over 96 hrs. Definitive tests were therefore made up using nominal zinc concentrations of 0.0, 0.625, 1.25, 2.5, 5.0 and 10 mg/L of zinc. Concentrations were measured at Day 0, Day 1, Day 6 and Day 7 and confirmed that measured zinc concentrations ranged from 90% - 103 % of nominal concentrations with an excellent fit ($r^2 > 0.99$) between the two.

Rangefinding tests showed complete survival of Ceriodaphnia at 0.05 mg/L of zinc and complete mortality at 0.5 mg/L in waters from both creeks over 7 days. Definitive tests were therefore made up using nominal zinc concentrations of 0.0, 0.005, 0.02, 0.05, 0.2 and 0.5 mg/L of zinc. Concentrations were measured at Day 0, Day 1, Day 5 and Day 6 and confirmed that measured zinc concentrations ranged from 86% - 132 % of nominal concentrations with an excellent fit ($r^2 > 0.99$) between the two for Vangorda Creek. Rose Creek contained 0.053 mg/L of zinc prior to spiking, such that measured concentrations exceeded nominal concentrations but, nevertheless, an excellent fit between the two was obtained.

It was not possible to complete rangefinding tests for the alga *Selenastrum capricornutum.* Definitive testing for each creek was carried out at nominal zinc concentrations of 0.0, 0.0009, 0.0063, 0.0186, 0.0546, 0.1682, 0.5, 1.5 and 4.55 mg/L. Concentrations were measured once over the 72 hour tests and showed excellent correspondence between measured and nominal concentrations for both creeks and high zinc concentrations in Rose Creek, as for the *Ceriodaphnia* tests.

6.2.3 June Testing

Water from each of Rose Creek and Vangorda Creek was collected into 22 L containers by Gartner Lee Ltd. at 1320 hours on June 1, 2004 and transported to Whitehorse, YT on the same day. Samples were shipped from Whitehorse to Vancouver by air and received by the lab on June 6, 2004. Samples were kept refrigerated in the dark until testing started. Tests were conducted by spiking zinc into each receiving water as a concentration series. The rangefinder tests were started on June 9-10, 2004 and the definitive testing on June 17 - 18. All toxicity summaries were calculated from the definitive tests using measured chemistry.

Rangefinding tests showed complete survival of fathead minnow larvae with no added zinc and complete mortality at 1.25 mg/L of added zinc in waters from both creeks over 96 hrs. Definitive tests were therefore made up using nominal zinc concentrations of 0.0, 0.13, 0.25, 0.4, 0.7 and 1.25 mg/L of zinc. Concentrations were measured at Day 0, Day 1, Day 5 and Day 6 and confirmed that measured zinc concentrations ranged from 90% - 100 % of nominal concentrations with one exception (40% for the nominal 0.13 mg/L exposure for Rose Creek) and an excellent fit ($r^2 > 0.99$) between the two.

Rangefinding tests showed complete survival of Ceriodaphnia at 0.08 mg/L of zinc and complete mortality at 0.2 mg/L in waters from both creeks over 7 days. Definitive tests were therefore made up to span these nominal zinc concentrations. The testing laboratory made an error in calculating the zinc concentration in the stock solution, however, such that nominal zinc concentrations were 0.0, 0.014, 0.018, 0.025, 0.034 and 0.046 mg/L of zinc. Concentrations were measured at Day 0, Day 1, Day 5 and Day 6 and showed that measured zinc concentrations ranged from 76% to 137% of the revised nominal concentrations.

As a result of these calculation errors, no mortality occurred in the *Ceriodaphnia* testing from June and the only estimates of mortality and reproduction that were available were those from the rangefinding tests. The June testing protocol for *Ceriodaphnia* was therefore repeated with samples of creek water taken in August.

Rangefinding tests for the alga *Selenastrum capricornutum* were carried out from June 10 to 13, 2004 and showed progressively decreasing growth between nominal concentrations of 0.0063 and 0.5 mg/L. Definitive testing for each creek was carried out at nominal zinc concentrations of 0.0, 0.009, 0.018, 0.036, 0.071, 0.142, 0.248, 0.567, 1.136, 2.273 and 4.546 mg/L. Concentrations were measured at the start of each 72 hour test and showed excellent correspondence between measured and nominal concentrations for both creeks after accounting for zinc concentrations in each creek at the start.

6.2.4 August Testing - Retesting of Zinc in Creek Water for *Ceriodaphnia*

The August testing was carried out to repeat the testing of zinc toxicity to *Ceriodaphnia* to make up for the errors in the June testing. All toxicity summaries were calculated from the definitive tests using measured chemistry.

The rangefinder tests were started on September 17, 2004 and the definitive testing on October 13, 2004. All toxicity summaries were calculated from the definitive tests using measured chemistry.

Rangefinding tests showed complete survival of *Ceriodaphnia* at 0.05 and 0.01 mg/L of zinc in Vangorda and Rose Creek waters, respectively and complete mortality at 0.1 mg/L in waters from both creeks over 4 days. Definitive tests were therefore made up at nominal concentrations of 0.006, 0.016, 0.04, 0.1 and 0.25 mg/L. Concentrations were measured at Day 0, Day 1, Day 5 and Day 6 and showed that measured zinc concentrations ranged from 94% to 128% of the nominal concentrations, after accounting for 0.013 mg/L of zinc present in Rose Creek waters.

6.2.5 August Testing – Effluent Dilution Series

The August testing was carried out to fulfill the original intent of testing a dilution series of treated effluent in water from each creek. All toxicity summaries were calculated from the definitive tests using measured chemistry.

Water from each of Rose Creek and Vangorda Creek and treated effluent from each of the Faro and Van Gorda pit discharges was collected into 22 L containers by Gartner Lee Ltd. at 1430 hours on August 27, 2004 and transported to Whitehorse, YT on the same day. Samples were shipped from Whitehorse to Vancouver by air and received by the lab on August 30, 2004. Samples of effluent were tested for total and dissolved zinc, alkalinity, total hardness, ammonia and nitrite nitrogen, sulphate, Dissolved Organic Carbon and Total Suspended Solids upon arrival (August 30 and 31) and upon initiation of testing on September 9, 2004. Samples were kept refrigerated in the dark until testing started.

No rangefinder tests were carried out for the effluent testing. Effluents from the Faro and Vangorda mine sites were mixed with Rose and Vangorda Creek waters, respectively, at ratios of 0% (creek water), 25%, 50%, 70%, 85% and 100% (full effluent).

Tests for fathead minnows and *Ceriodaphnia* were started on September 9-10, 2004 and completed September 16, 2004. All toxicity summaries were calculated from the definitive tests using measured chemistry from samples taken on Day 0, Day 1, Day 5 and Day 6. Tests on *Ceriodaphnia* were subcontracted to EVS Consultants. Testing on *Selenastrum* was carried out from September 10-13, 2004 and the need to add nutrients to the algal culture meant that the dilution series ran from 0% (creek water), to 22.7%, 45.5%, 63.6%, 77.3% and 90.9 % effluent. Toxicity summaries were calculated for the *Selenastrum* test using measured chemistry from samples taken on Day 0.

6.3 Results

Results are presented for each series of tests as summaries of toxicity endpoints and water chemistry. Survival of fathead minnow larvae and *Ceriodaphnia dubia* is presented as the LC50: concentration of zinc calculated to be lethal to 50% of the test organisms in a particular test. Growth of fathead minnow larvae (measured as dry weight following 24 hrs drying at 60^{o}C), reproduction of *Ceriodaphnia* (measured as brood production in tests) and growth of *Selenastrum* (as cell count) were all summarized as the IC25: concentration of zinc calculated to result in 25% inhibition of each response in a particular test.

6.3.1 April Testing – Zinc in Vangorda and Rose Creeks

The April sampling captured the "late winter baseflow" period of flow in each creek, prior to substantial dilution of low flows with melt water from the spring freshet. There were substantial differences in water chemistry between Vangorda and Rose Creeks (Table 2). Total Hardness in Rose Creek ranged from 509 to 517 mg/L (the lower value of 446 mg/L for the algae test reflects the dilution of creek water to 90% by the addition of growth medium for the test). Calcium concentrations were ~ 70 mg/L and 143 mg/L in Vangorda and Rose Creeks, respectively, and magnesium was 31 mg/L in both creeks (Table 2).

Alkalinity was higher in Vangorda Creek, at approximately 190 mg/L compared to 135 mg/L in Rose Creek. pH ranged from 7.9 to 8.4 in fathead minnow tests, 7.7 to 8.5 in *Ceriodaphnia* tests and 8.1 to 8.3 in the Selenastrum tests.

Table 2. Water Chemistry for Vangorda and Rose Creeks, April 2004.

	Total Alkalinity (mg/L)		Total Hardness (mg/L)		Total Calcium (mg/L)		Total Magnesium (mg/L)	
	VanGorda Creek	Rose Creek	VanGorda Creek	Rose Creek	VanGorda Creek	Rose Creek	VanGorda Creek	Rose Creek
Fathead Minnow								
Mean	193	135	322	517	68.5	142	30.8	30.2
S.D.	4.8	2.9	9.8	5.2	2	2.8	0.86	0.63
Ceriodaphnia dubia								
Mean	185	135	312	509	70	144	31.7	30.7
S.D.	1.9	1.13	4.1	4.9	2	2.2	1.22	0.58
Selenastrum capricornutum								
Mean	172	126.9	317	446	60.2	130	28.0	28.4
S.D.	3.1	4.3	36.4	45.3	1.5	2.6	0.69	0.88

Table 3. Toxicity Testing Results, April 2004 Samples

	VanGorda Creek		Rose Creek	
Fathead Minnow	Survival LC50 mg/L Zn	Growth IC25 mg/L Zn	Survival LC50 mg/L Zn	Growth IC25 mg/L Zn
LC50 / IC25	2.53	>2.41	2.75	>2.59
LCL	2.35	n.a.	2.68	n.a.
UCL	2.68	n.a.	2.8	n.a.
NOEC	1.14	0.51	1.3	2.59
LOEC	2.41	1.14	2.59	>2.59
Ceriodaphnia dubia	Survival LC50 mg/L Zn	Reproduction IC25 mg/L Zn	Survival LC50 mg/L Zn	Reproduction IC25 mg/L Zn
LC50 / IC25	0.077	0.068	0.073	0.06
LCL	0.069	0.033	0.062	0.059
UCL	0.109	0.079	0.108	0.069
NOEC	0.047	0.047	0.102	0.061
LOEC	0.175	0.175	0.242	0.075
Selenastrum capricornutum		Growth IC25 mg/L Zn		Growth IC25 mg/L Zn
IC25		0.016		0.069
LCL		0.012		0.052
UCL		0.02		0.083
NOEC		0.006		0.058
LOEC		0.019		0.07

LCL - Lower Confidence Limit (95%)
UCL - Upper Confidence Limit (95%)
NOEC - No Obseved Effect Concentration
LOEC - Lowest Observed Effect Concentration

Survival and growth of fathead minnows were similar in the waters from each creek: LC50 results were 2.53 and 2.75 for Vangorda and Rose Creeks respectively. Larval growth was not affected at lethal concentrations and so the threshold of growth impairment could not be determined (Table 3).

The thresholds for survival and reproduction of *Ceriodaphnia* were similar in each creek with LC50 results of 0.077 and 0.073 mg/L of zinc and IC25 results of 0.068 and 0.06 mg/L for Vangorda and Rose Creeks respectively.

Growth of *Selenastrum* was much more sensitive to zinc in the waters of Vangorda Creek, where 25% inhibition of cell growth occurred at 0.016 mg/L, than in Rose Creek where 0.069 mg/L of zinc produced the same response. This pattern was consistent in all responses (Table 3).

6.3.2 June Testing – Zinc in Vangorda and Rose Creeks

The June sampling captured the spring freshet period of flow in each creek, showing substantial dilution of low flows with melt water. There were substantial differences in water chemistry between Vangorda and Rose Creeks (Table 4). Total Hardness in Rose Creek was diluted approximately 10-fold from the April baseflow period, from ~500 mg/L to ~ 64 mg/L (Table 4). Total hardness in Vangorda Creek was reduced approximately four-fold, from approximately 310 mg/L to 90 mg/L. Alkalinity was lower in Rose Creek than in Vangorda Creek, as it had been in the April sampling, and was reduced by approximately four-fold in each creek from the April period. Calcium concentrations were approximately 23 mg/L and 18 mg/L in Vangorda and Rose Creeks, respectively, and magnesium was 8 mg/L in Vangorda Creek and 4-5 in Rose Creek (Table 4).

Table 4. Water Chemistry for Vangorda and Rose Creeks, June 2004

		Total Alkalinity (mg/L)		Total Hardness (mg/L)		Total Calcium (mg/L)		Total Magnesium (mg/L)	
		VanGorda Creek	Rose Creek	VanGorda Creek	Rose Creek	VanGorda Creek	Rose Creek	VanGorda Creek	Rose Creek
Fathead Minnow									
	Mean	54.9	32.7	87.7	64.0	23.0	17.9	7.9	3.9
	S.D.	1.0	1.3	1.5	0.0	0.3	0.1	0.1	0.0
Ceriodaphnia dubia									
	Mean	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	S.D.								
Selenastrum capricornutum									
	Mean	53.9	35.2	92.0	64.7	21.2	16.9	8.6	5.1
	S.D.	1.3	1.3	0.0	1.6	0.3	0.1	0.1	0.0

Table 5. Toxicity Testing Results, June 2004 Samples

	VanGorda Creek		Rose Creek	
Fathead Minnow	Survival LC50 mg/L Zn	Growth IC25 mg/L Zn	Survival LC50 mg/L Zn	Growth IC25 mg/L Zn
LC50 / IC25	0.58	0.87	0.32	0.27
LCL	0.50	0.73	0.29	n/a
UCL	0.66	0.88	0.35	n/a
NOEC	0.381	n/a	<0.253	0.25
LOEC	0.663	n/a	0.253	0.39
Ceriodaphnia dubia	Survival LC50 mg/L Zn	Reproduction IC25 mg/L Zn	Survival LC50 mg/L Zn	Reproduction IC25 mg/L Zn
LC50 / IC25	>0.035	>0.035	>0.044	>0.044
LCL	n/a	n/a	n.a.	n.a.
UCL	n/a	n/a	n.a.	n.a.
NOEC	0.035	<0.019	0.044	0.044
LOEC	>0.035	0.019	>0.044	>0.044
Selenastrum capricornutum		Growth IC25 mg/L Zn		Growth IC25 mg/L Zn
IC25		0.034		0.043
LCL		0.029		0.039
UCL		0.037		0.048
NOEC		0.027		0.024
LOEC		0.044		0.041

LCL - Lower Confidence Limit (95%)
UCL - Upper Confidence Limit (95%)
NOEC - No Obseved Effect Concentration
LOEC - Lowest Observed Effect Concentration

The dilution of each creek by melt water had a clear influence on toxicity of zinc. Toxicity to fathead minnows was increased by a factor of 4 to 5 in the low hardness waters of June. LC50 results for Vangorda and Rose Creeks were 0.58 and 0.32 mg/L of Zn respectively and IC25 values for growth were 0.87 and 0.27 mg/L (Table 5).

No results were obtained for exposure of *Ceriodaphnia dubia* in June. A laboratory error in formulating the stock zinc solution produced exposures in which no effects were observed at the highest tested concentrations of 0.035 and 0.044 mg/L of Zn (Table 5). Testing was therefore repeated in August using water samples collected at that time.

Growth of *Selenastrum* in the lower hardness waters was no different than in the baseflow period of higher hardness for Vangorda Creek. The IC25 statistic for growth was 0.034 mg/L of zinc for both tests. Zinc was more toxic in the lower hardness waters of Rose Creek in June: the IC25 was reduced from 0.069 in April to 0.043 mg/L in June.

6.3.3 August Testing - Retest of *Ceriodaphnia*

Waters from Vangorda and Rose Creeks were re-sampled on August 27, 2004 and shipped to Vancouver for toxicity testing. Comparison of chemistry results (Table 6) to those from June (Table 4) revealed a different proportion of runoff entering each creek as compared to June. Runoff into Vangorda Creek had increased, such that its waters were more dilute in August, showing substantial reductions in total hardness, alkalinity, calcium and magnesium between the two sample periods. Runoff into Rose Creek had declined and hardness, alkalinity, calcium and magnesium all increased by more than two-fold between the sampling periods. They were still far below the concentrations observed in April (Table 2), however, indicating a substantial contribution of melt water.

Table 6. Water Chemistry for Vangorda and Rose Creeks, August 2004

		VanGorda Creek	Rose Creek
Total Alkalinity (mg/L)			
	Mean	26.0	96.7
	S.D.	0.6	1.0
Total Hardness (mg/L)			
	Mean	28.7	130.0
	S.D.	1.6	0.0
Total Calcium (mg/L)			
	Mean	10.5	33.7
	S.D.	0.1	4.0
Total Magnesium (mg/L)			
	Mean	1.58	7.89
	S.D.	0.01	0.10

Table 7. Toxicity Testing Results for *Ceriodaphnia,* August 2004 Samples

	VanGorda Creek		Rose Creek	
Ceriodaphnia dubia	Survival LC50 mg/L Zn	Reproduction IC25 mg/L Zn	Survival LC50 mg/L Zn	Reproduction IC25 mg/L Zn
LC50 / IC25	0.071	0.053	0.105	0.056
LCL	0.05	0.006	0.098	0.02
UCL	0.101	0.059	0.122	0.069
NOEC	0.042		0.051	
LOEC	0.102		0.105	

LCL - Lower Confidence Limit (95%)
UCL - Upper Confidence Limit (95%)
NOEC - No Obseved Effect Concentration
LOEC - Lowest Observed Effect Concentration

Although total hardness in Vangorda Creek in August was approximately 10% of that in April, the toxicity thresholds for *Ceriodaphnia* were unchanged. The LC50 results were 0. 077 and 0.071 mg/L of zinc for April and August testing respectively (Table 3, Table 7) and the IC25 results for reproduction were 0.068 and 0.053 mg/L. Total hardness in Rose Creek in August was approximately 25% of that in April but zinc was less toxic. LC50 results were 0.073 and 0.105 mg/L in April and August, respectively, and IC25 results were 0.06 and 0.056 mg/L.

6.3.4 August Testing – Whole Effluent Toxicity

The results of the whole effluent dilution series testing in August confirmed that treatment systems at the mine sites were effective, to the point where the treated effluent from each site was not acutely toxic to fathead minnows. The LC50 for survival and IC25 for growth of fathead minnow larvae were both >100% effluent (Table 8). This finding is substantiated in the compliance record for toxicity testing of the annual effluent discharge, which is reported to show consistent survival of rainbow trout in 100% effluent from each site (E. Denholm, Gartner Lee Ltd., pers. comm.).

Table 8. Results of Whole Effluent Toxicity Testing, August 2004

	Effluent	Creek	Fathead Minnow Survival LC50	Fathead Minnow Growth IC25	Ceriodaphnia Survival LC50	Ceriodaphnia Reproduction IC25	Selenastrum Growth Inhibition IC25
Rose Creek			>100%	>100%	<25%	<25%	>91%
Hardness	580	150	580		258		580
Alkalinity	97	46					
Zinc	0.11 - 1.14	0.019	>0.412		<0.043		>0.412
Van Gorda Creek			>100%	>100%	>100%	53%	67%
Hardness	1200	53	1200		1200	661	535
Alkalinity	52	26					
Zinc	0.05- 0.055	0.004	>0.05		>0.05	0.028	0.044

> 100% denotes no effect of 100% effluent in test : no response threshold could be calculated
< 25% denotes that no organisms survived lowest dilution : no response threshold could be calculated

Table 9. Summary of Toxicological Responses and Measured Zinc Concentrations in Toxicity Tests of Effluent in VanGorda Creek (mg/L).

		Fathead Minnow				Ceriodaphnia				Selenastrum	
		Average Zn in mg/L	Std. Dev.	Survival (%)	Dry Weight (mg)	Average Zn in mg/L	Std. Dev.	Survival (%)	Mean Brood Production	Zinc mg/L	Mean Cell Yield
Lab Control				95	0.42			100	23.2		50
Percent Effluent	0	<0.005	0.003	77	0.47	<0.005	0.000	100	11.3	<0.005	74
	25	0.014	0.002	93	0.41	0.014	0.002	100	17.4	0.011	94
	50	0.029	0.001	95	0.49	0.026	0.001	90	11.0	0.026	60
	70	0.039	0.002	98	0.50	0.036	0.004	70	8.9	0.036	59
	85	0.046	0.002	88	0.44	0.038	0.005	100	10.0	0.046	48
	100	0.054	0.004	90	0.47	0.048	0.002	80	3.5	0.048	42

Table 10. Summary of Toxicological Responses and Measured Zinc Concentrations in Toxicity Tests of Effluent in Rose Creek (mg/L).

		Fathead Minnow				Ceriodaphnia				Selenastrum	
		Average Zn in mg/L	Std. Dev.	Survival (%)	Dry Weight (mg)	Average Zn in mg/L	Std. Dev.	Survival (%)	Mean Brood Production	Average Zn in mg/L	Mean Cell Yield
Lab Control				98	0.46			100	24.1		60
Percent Effluent	0	0.017	0.005	90	0.52	0.017	0.002	100	19.8	0.017	88
	25	0.041	0.012	98	0.46	0.043	0.008	0	1.6	0.037	68
	50	0.047	0.021	95	0.48	0.032	0.006	0	0.0	0.027	151
	70	0.186	0.196	95	0.51	0.041	0.005	0	0.0	0.041	122
	85	0.089	0.075	95	0.48	0.049	0.033	0	0.0	0.024	130
	100	0.325	0.396	97	0.50	0.019	0.016	0	0.0	0.023	140

These toxicity results reflect the treatment system performance, particularly for discharge from the Vangorda complex into Vangorda Creek. Total zinc concentrations ranged from 0.045 – 0.06 mg/L in 11 samples of the 100% effluent taken during the testing procedure (summarized in Table 9). Two measurements of dissolved zinc in the whole effluent samples showed 0.037 and 0.051 mg/L, such that most of the zinc present in the effluent was dissolved. The concentration of Total Suspended Solids in the effluent sample was <1 mg/L. Consistent effluent treatment produced low zinc concentrations and a non-toxic effluent.

Toxicity results for the Faro effluent appear to reflect treatment performance, but the analytical results are variable. The treatment system for the Faro discharge was turned on the day before sampling and did not appear to have stabilized at the time of sampling. Total zinc concentrations were highly variable, both between samples and between tests (Table 10, 11) and the concentration of Total Suspended Solids was 10.6 mg/L. As a result, the dilution series used in toxicity tests were irregular (Table 11), such that it was not possible to determine how toxic the effluent was. This was particulary problematic in that fathead minnows showed no response to the effluent but *Ceriodaphnia* showed complete mortality at 25% effluent. Dissolved zinc levels in whole effluent were low (0.018 – 0.041 mg/L).

Table 11. Total Zinc Concentrations in Whole Effluent from Faro Discharge

	Total Zinc	Dissolved Zinc
Effluent Sample at Arrival	0.414, 0.11	0.041
Effluent Sample at Test Initiation	1.14	0.018
100% Effluent - Fathead Test	0.325	
100% Effluent - Ceriodaphnia Test	0.019	
100% Effluent - Selenastrum Test	0.023	

All concentrations in mg/L.

Zinc concentrations measured during toxicity tests showed a high degree of variation, both between tests (i.e. Fathead minnow vs *Ceriodaphnia*, Table 11) and were poorly related to the nominal dilution factors of effluent with creek water (Table 10). This was especially apparent at high concentrations of effluent (i.e., 70% and 100% Table 10).

The variable results for measured zinc concentrations in the Faro effluent tests appear to reflect resuspension of non-toxic particulate zinc in exposure vessels. This conclusion is supported by the high TSS concentrations in the whole effluent, the similarity between measured concentrations of dissolved zinc in whole effluent (Table 11) and total zinc in some of the test samples (Table 10) and consistent observations of lower zinc concentrations in samples of 100% effluent exposures taken on Day 1 of testing than in samples taken on Day 0, when testing was begun. This suggests that disturbance of the particulate matter in the whole effluent introduced high zinc levels into total zinc analyses. This particulate zinc, however, is of low toxicity and served only to confound interpretation.

The lack of toxicity of effluent to fathead minnows therefore reflects low levels of dissolved zinc in the discharge, such that tests of both the Faro and Vangorda effluents exposed fish to similar (i.e. < 0.055 mg/L) zinc concentrations (i.e. 0.018 – 0.041 mg/L, Table 10).

Ceriodaphnia also survived exposure to 100% effluent from the Vangorda discharge (Table 9, LC50 > 100%) but reproduction was impaired at effluent concentrations of 53% (~0.028 mg/L zinc). *Ceriodaphnia* reproduction is therefore a sensitive indicator of zinc toxicity.

Ceriodaphnia were very sensitive to exposure to the Faro effluent discharge, as total mortality was observed at 25% (~0.017 mg/L, Table 11) of the whole effluent concentration (< 0.043 mg/L, Table 10) and reproduction reduced by 92% from that in controls. Linear extrapolation suggests that total reproductive failure would occur at an effluent concentration of 27%, (~0.046 mg/L) suggesting an IC25 of ~ 7% effluent. Rose Creek water contained 0.019 mg/L of zinc (Table 8) such that addition of 7% effluent would produce an estimated IC25 of approximately 0.026 mg/L, very similar to that of 0.028 mg/L calculated for the Vangorda discharge. Nevertheless, we note that measured concentrations of zinc in the *Ceriodaphnia* tests showed little relation to the nominal dilution factor and so caution in interpretation is warranted.

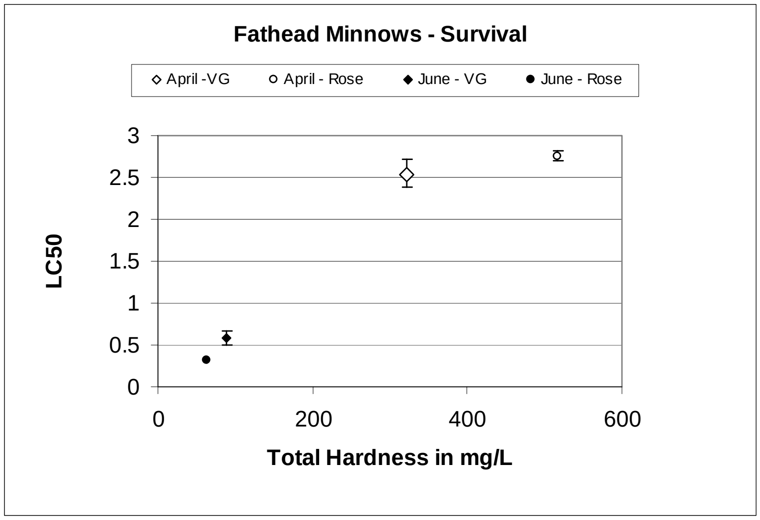
Selenastrum showed no response to exposure to 91% Faro effluent (Table 10), again suggesting that the low levels of dissolved zinc present were not toxic. It was not possible to expose the alga to 100% effluent, because of the need to make up the exposure volume with nutrient medium. Inhibition of *Selenastrum* growth was observed at 67% strength of Vangorda effluent (Table 9), corresponding to 0.044 mg/.L of total zinc.

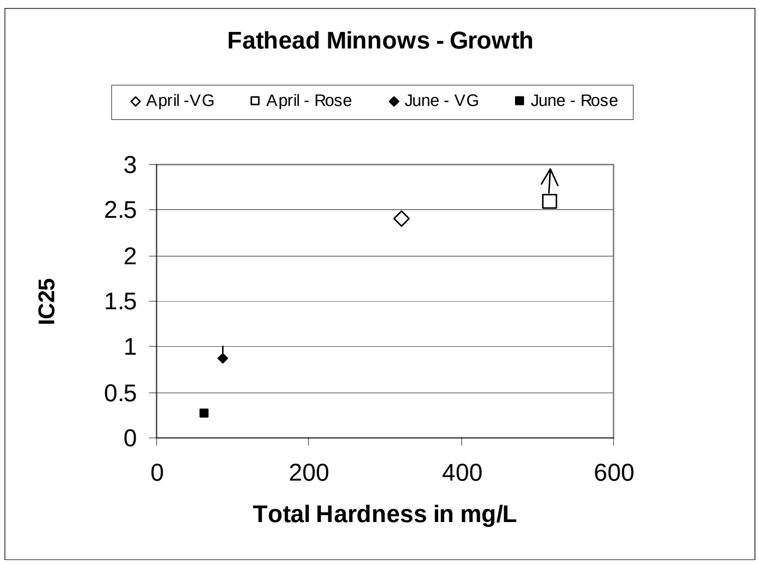
6.3.5 Synthesis of Toxicity Test Results

Fathead Minnow

Fathead minnow larvae showed a clear and consistent response to the hardness of the receiving waters, as shown in Figure 4, below, for survival (top) and growth (bottom). They were not sensitive to zinc exposure, however, as toxic thresholds ranged from 0.3 to 0.9 mg/L in softer waters in June to >2.5 mg/L in the harder waters during base flow. Exposure of fathead minnow larvae to the effluent dilution series showed no effects on survival or reproduction at the highest tested zinc concentrations of 0.041 to 0.055 mg/L. The lack of response prevents comparison of the whole effluent toxicity results to the zinc-only tests.

Figure 4. Hardness-Related Response of Fathead Minnow Larvae to Zinc in Rose and Vangorda Creek Waters





Ceriodaphnia Dubia

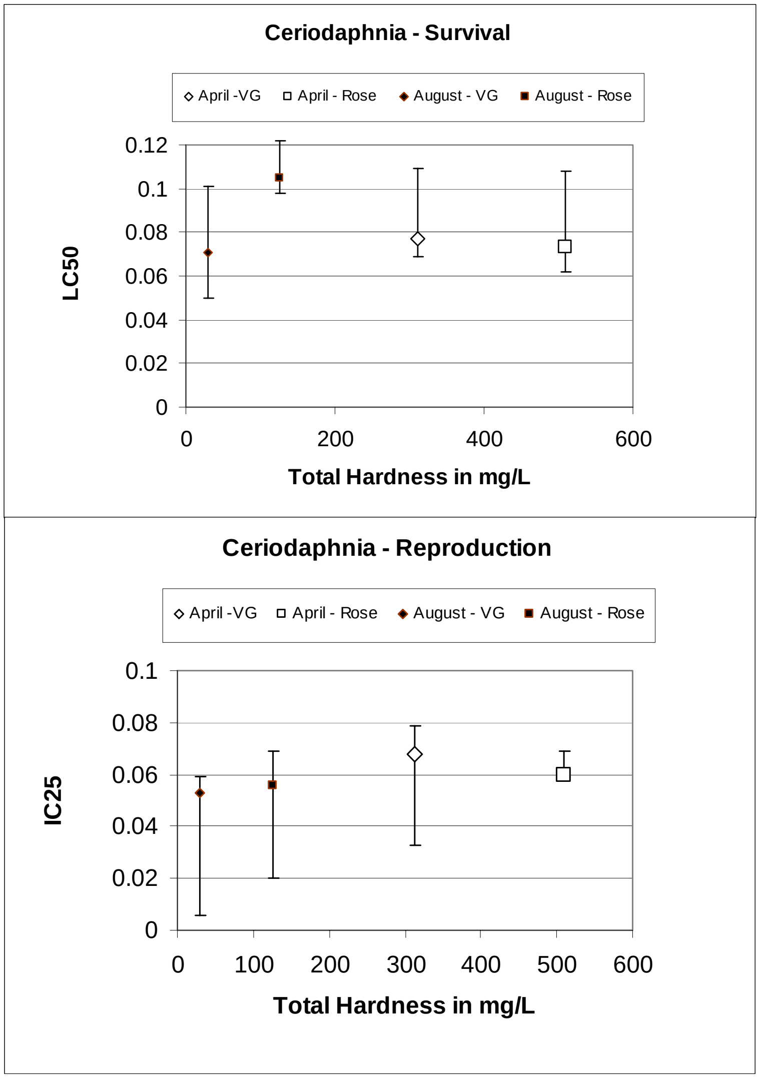
Neither survival nor reproduction of *Ceriodaphnia dubia* showed a consistent relationship with hardness in Rose and Vangorda Creeks (Figure 5). Although there is some evidence of a slope for reproduction the relationship was not significant ($p>0.39$). Our review of the literature did not reveal any published relationships of zinc toxicity with total hardness for invertebrates. The average LC50 value for survival was a zinc concentration of 0.081 mg/L and the average IC25 value for reproduction was 0.059 mg/L.

These concentrations may therefore represent the intercept values for zinc and hardness relationships for *Ceriodaphnia* growth and reproduction in the receiving waters at the Anvil Range site.

Exposure of *Ceriodaphnia* to whole effluents showed a more sensitive response than did exposure to zinc only. Reproduction was impaired at effluent concentrations corresponding to 0.028 mg/L of zinc (Vangorda) and 0.026 mg/L (Faro, where there is some uncertainty because of analytical concerns), compared to the average LC50 of 0.059 mg/L for zinc exposure.

Mortality was a less sensitive indicator. *Ceriodaphnia* survived whole effluent concentrations of 0.055 mg/L at Vangorda, compared to the average LC50 of 0.081 mg/L for exposure to zinc only. *Ceriodaphnia* appeared very sensitive to effluent at Faro, as the LC50 was < 0.043 mg/L but these results are somewhat compromised by analytical problems.

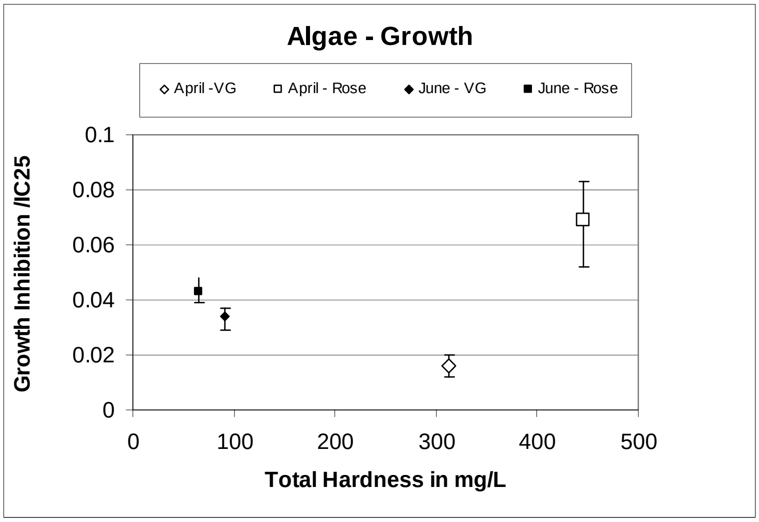
Figure 5. Hardness-Related Response of *Ceriodaphnia* Survival (top) and Reproduction (bottom) to Zinc in Rose and Vangorda Creek Waters



Selenastrum capricornutum

Growth of the alga *Selenastrum capricornutum* did not show a consistent relationship with hardness in Rose and Vangorda Creeks (Figure 6). The average IC25 for cell growth was 0.041 mg/L. This concentration may therefore represent the intercept value for zinc and hardness relationships for algal growth in the receiving waters at the Anvil Range site. It is supported by the measured response of algal growth to Vangorda effluent, which was impaired at the IC25 corresponding to an effluent concentration of 0.044 mg/L of zinc.

Figure 6. Hardness-related response of *Selenastrum* Growth to Zinc in Rose and Vangorda Creek Water



Summary

In summary, toxicity testing of zinc and whole effluents in the waters from Vangorda and Rose Creeks showed:

- Toxicity relationships with hardness for less-sensitive responses such as fathead minnow growth and survival.
- No hardness relationships for sensitive responses such as survival and growth of the invertebrate, *Ceriodaphnia dubia* and the alga *Selenastrum capricornutum.*
- Reproductive impairment of *Ceriodaphnia dubia* at zinc concentrations of 0.059 mg/L (zinc only) and 0.026 – 0.028 mg/L (zinc in effluent).
- Growth impairment of *Selenastrum* at zinc concentrations of 0.041 mg/L (zinc only) and 0.044 mg/L (zinc in effluent).
- That invertebrate (*Ceriodaphnia)* reproduction is the most sensitive indicator of zinc toxicity at the Anvil Range site.

7. Derivation of Site Specific WQO

The original intent of using the WER procedure was to develop water quality objectives for the Anvil Range site that incorporated seasonal changes in receiving water quality, specifically water hardness. Water hardness was chosen because it has a known and documented influence on zinc toxicity and it varies by factors of 10 or more over the course of a year in Rose and Vangorda Creeks.

The CCME Guideline (CCME 2003) for exposure of freshwater aquatic life to zinc is 30 μg/L and it is not hardness dependent. The WER approach was intended to modify the CCME Guideline, based on site specific studies done at the Anvil Range site. This would produce site specific water quality objectives based on varying water hardness at the Anvil Range sites, similar to the hardness-corrected guideline used in the Province of British Columbia. Site specific testing was therefore carried out to assess the effect of water hardness and other factors at the Anvil Range site.

7.1 Province of British Columbia – Hardness Corrected Guideline

Results obtained from the Anvil Range site toxicity testing were compared with the BC Guideline, to see how the BC approach could be used to guide derivation of the SSWQO for Anvil Range.

The Province of British Columbia developed a hardness-adjusted Zn Guideline for protection of freshwater aquatic life and the derivation is provided in Nagpal (1997). The BC approach provides two hardness-corrected guidelines:

1. Average 30 day Concentration (μg/L): 7.5+0.75*(Hardness – 90); and
2. Maximum Concentration (μg/L): 33 + 0.75*(Hardness – 90).

The first guideline is better suited to the extended discharge periods contemplated for the long-term closure timeframe at the Anvil Range site, where the second would be suitable for assessment of short term increases, such as those experienced during periods of treated effluent discharge.

The Anvil Range test results and review of the rationale for the BC Guideline in Nagpal (1997) suggest that a hardness-dependent guideline may not be appropriate for the Anvil Range receiving waters. The BC Guideline for 30-day exposure was developed as follows:

1. The intercept of 7.5 μg/L was derived from a literature toxicity threshold of 15 μg/L with a safety factor of 0.5. The 15 μg/L threshold was taken from Marshall *et al.* (1983), who found that additions of 15 μg/L zinc to enclosures in Lake Michigan (total hardness ~ 90 mg/L) for a two week period produced significant reductions in chlorophyll "a", primary production, zooplankton

community diversity and several species of crustacean and rotifer zooplankton. Reductions in the numbers of some zooplankton species resulted in increased numbers of other, more tolerant species.

2. The guideline was developed from an assumption of a linear effect of hardness on zinc toxicity at hardness levels above 90 mg/L and no effect below 90 mg/L. However,

   - Our synthesis of the results from the Anvil Range testing on fathead minnow larvae, showed that a linear response was apparent below a hardness of 100 mg/L, but not at the low zinc concentrations that define the sensitive toxicity thresholds for early life stages. These data do not support the assumption of no hardness effect on zinc toxicity at hardness < 90 mg/L.

   - The data in the rationale document (Nagpal 1997) do not support the assumption of a linear hardness response above 90 mg/L. Marshall *et al.* (1983) only studied toxicity of Zn at one hardness level (~ 90 mg/L, that of Lake Michigan water). The supporting text in the rationale document states that the hardness relationship that makes up the BC Guideline (slope of 0.75) was developed using the Marshall data point (15 µg/L Zn and 90 mg/L hardness) and one point from Brungs (1969): an LC50 of 180 µg/L for fathead minnows at a hardness of 150 – 250 (stated average of 203 mg/L). This represents data from two separate tests (one an in-situ exposure and one a single species laboratory bioassay), two different toxicity endpoints and different taxonomic groups (fish, crustacean zooplankton and algal production) in waters that differed in more than hardness.

   - We could not duplicate the calculation of the slope of 0.75 using the data cited in Nagpal (1997):
     1. the slope should express zinc toxicity (y axis) over hardness (x-axis) and so the slope calculated from these data is (180-15)/(203-90) = 1.46
     2. The closest we could get to the slope of 0.75 was by using the same data and reversing the numerator and the denominator (Hardness over toxicity or (203-90)/(180-15) = 0.68.)

This analysis suggests that use of the hardness-corrected BC Guideline at the Anvil Range site is not appropriate and supports our decision to use site-specific testing and develop the SSWQO for the Anvil Range waters independently of the BC Guideline.

7.2 Anvil Range Guideline Development

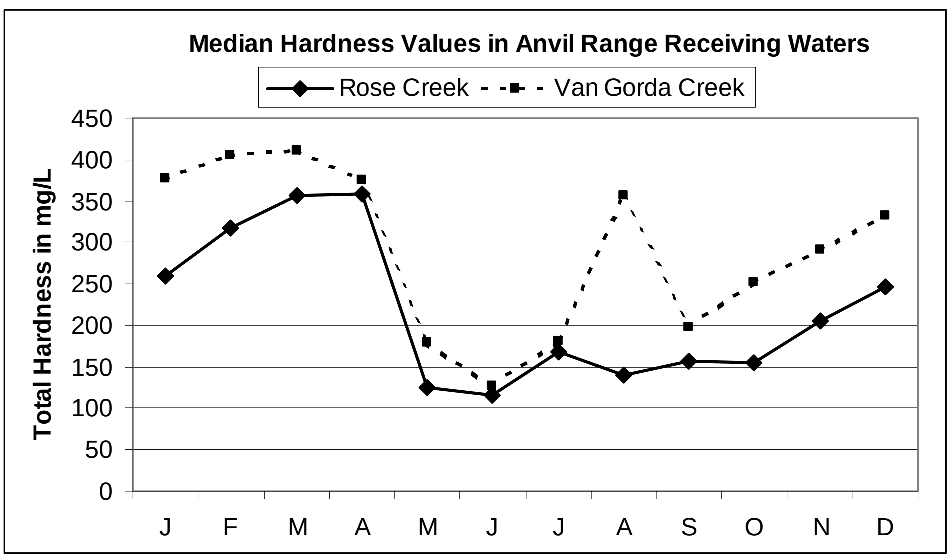
7.2.1 Background

Our original approach for SSWQO development intended to use 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 7), such that a single WER could not be used to derive a SSWQO. The ratio would have to vary with water hardness.

Figure 7. Annual variation in total hardness for Anvil Range receiving waters.



As such, we reviewed the hardness-dependent zinc guideline of the Province of British Columbia as a model to develop a hardness-dependent WQO for zinc on site and concluded that is derivation did not support its use (Section 7.1).

The final SSWQO development was 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 produced a “slope function” to account for the varying water hardness on site. We 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 order to develop a sensitive and protective intercept for the zinc toxicity function. In the end, these efforts resulted in one SSWQO, expressed as a mathematical function, that covers both Faro Creek and Vangorda Creek and all Valued Ecosystem Components (VECs) in the receiving waters.

The SSWQO for the Anvil Range waters therefore incorporates 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 (see Section 6). The intercept was derived using the recalculation procedure, applied to the toxicity database for the BC WQO for Zn (Nagpal, 1997).

7.2.2 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 Section 6.0. Linear responses of zinc toxicity and hardness were observed, as follows:

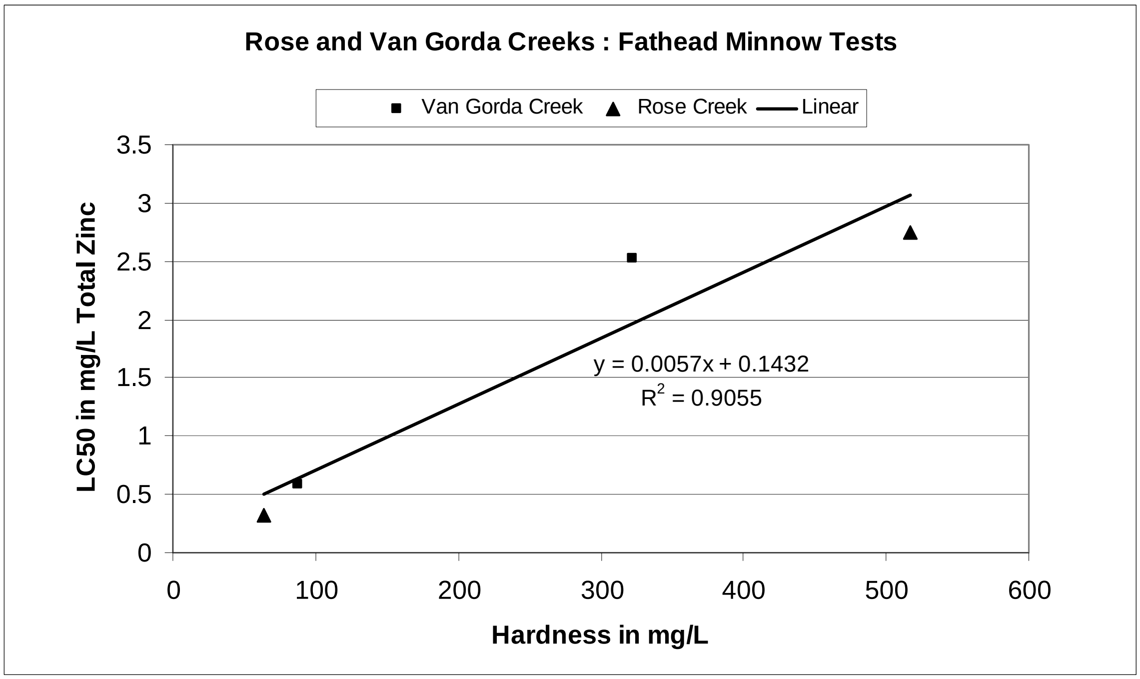
Rose Creek : LC50 (mg/L) = 0.0054 * (hardness) – 0.0233
Van Gorda Creek : LC50 (mg/L) = 0.0083 * (hardness) – 0.1533

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 8) and was described by:

Anvil Range Receiving Waters

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

Figure 8. 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.

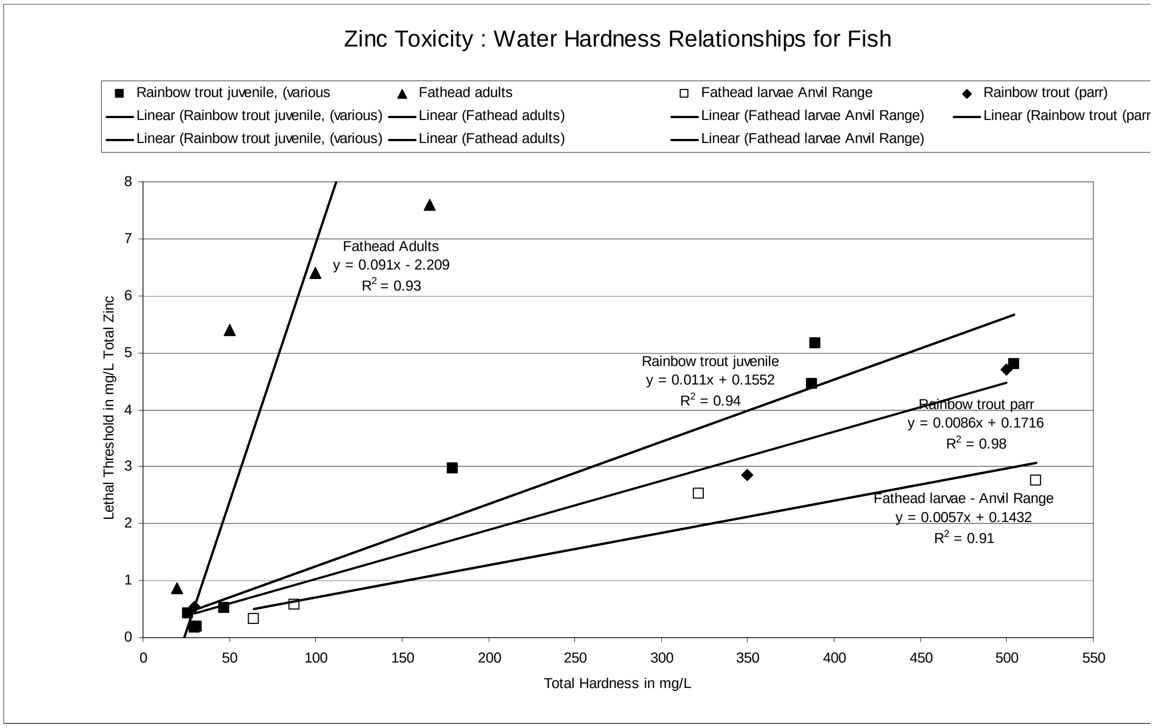
The data set of Nagpal (1997) was used to compare the slope functions derived for the Anvil Range tests with those found by other investigators. The data set was edited to obtain data for zinc toxicity and hardness derived for tests using identical species, life stages and toxicity thresholds (Table 12), so that the slopes reflected the influence of hardness on zinc toxicity after standardizing for important biotic factors modifying toxicity (Sprague, 1986).

Table 12. 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 8) 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 (Table 12). 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 9.) showing that the fathead minnow larvae were more sensitive than the rainbow trout parr.

Figure 9. 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.

7.2.3 Zinc Toxicity vs Water Hardness –Curvilinear Function

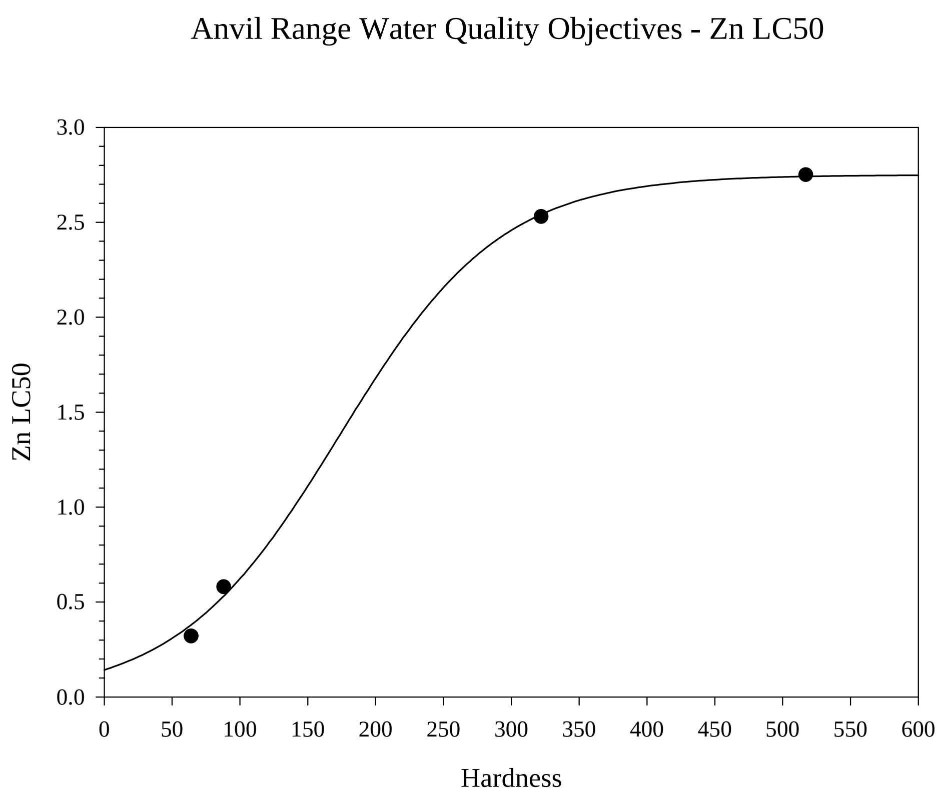
Although the zinc toxicity/hardness relationship can be described a s linear function, review of the data from the Anvil Range tests and the literature suggested that a curvilinear function was appropriate and provided better descriptive power (r^2 = 0.99, Figure 10, vs 0.91, Figure 8). The data points from the Anvil Range tests on fathead minnow larvae produced a sigmoidal curvilinear function relating toxicity of zinc to water hardness (Figure 10). 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

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

$$P < 0.04,\ r^2 = 0.99$$

Figure 10. Effect of hardness on toxicity of zinc to larval fathead minnows in Rose and Vangorda Creeks – curvilinear fit.



7.3 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.

7.3.1 Fish

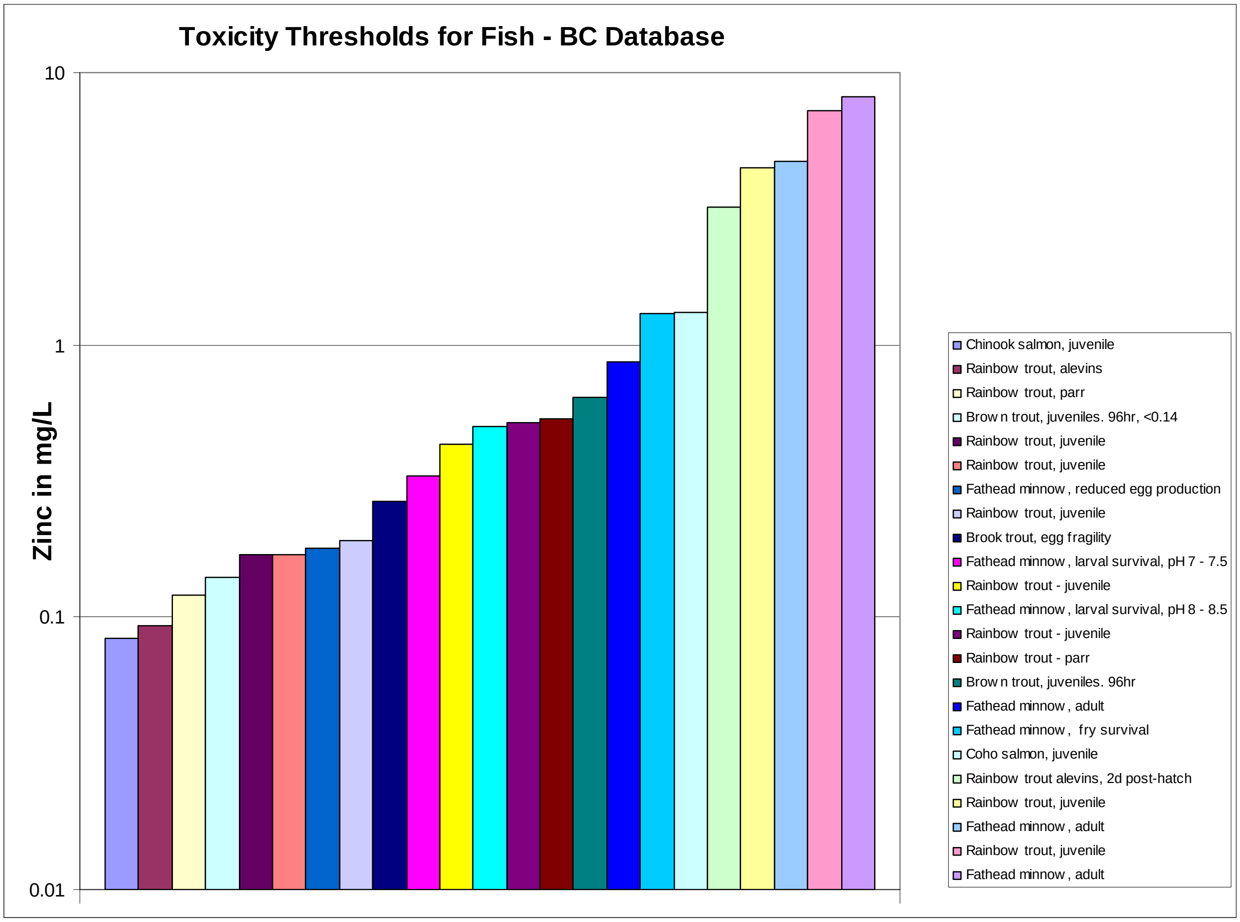
The dataset of Nagpal (1997) was reviewed to obtain zinc toxicity thresholds that could be used to derive an intercept for the SSWQO. The review focused on toxicity thresholds for salmonids, as the Anvil Range waters are cold-water habitats. They are frequented by salmonids: juvenile Chinook salmon (*Oncorhyncus 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 13 and in Figure 11.

Table 13. 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 11. 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 14 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 14. 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

7.3.2 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.

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.

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

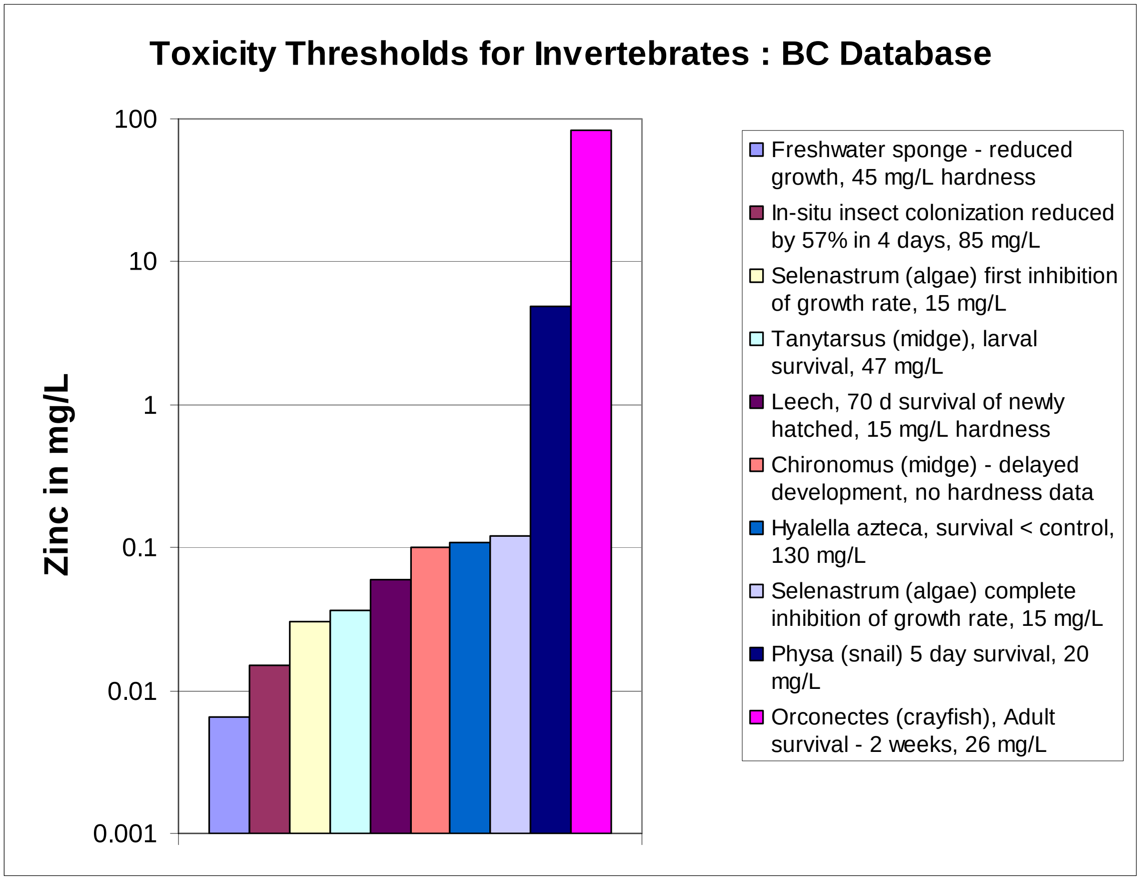
photosynthesis as a VEC in thre Anvil Range waters is not of high ecological relevance, but may be important as a surrogate for unknown or unexamined ecological processes.

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 15 and Figure 12.

Table 15. 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 12. 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.

7.4 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.

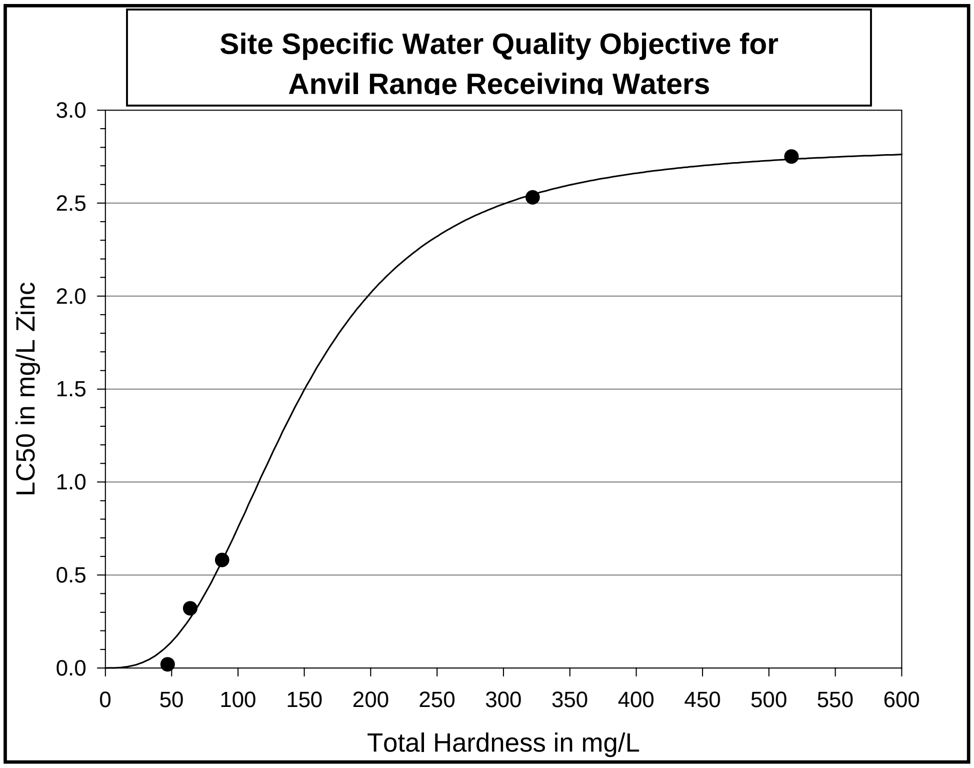
The final step of the SSWQO derivation was to recalculate the sigmoid equation (Equation 1, above) describing hardness and zinc toxicity, but to include the derived intercept for invertebrates, to protect aquatic life that was more sensitive than fathead minnows. Addition of the intercept value of 0.019 mg/L zinc at 47 mg/L total hardness produced the following equation (Figure 13), which is recommended as the SSWQO for the Anvil Range waters.

Equation 2

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

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

Figure 13. SSWQO for protection of aquatic life in Anvil Range receiving waters.



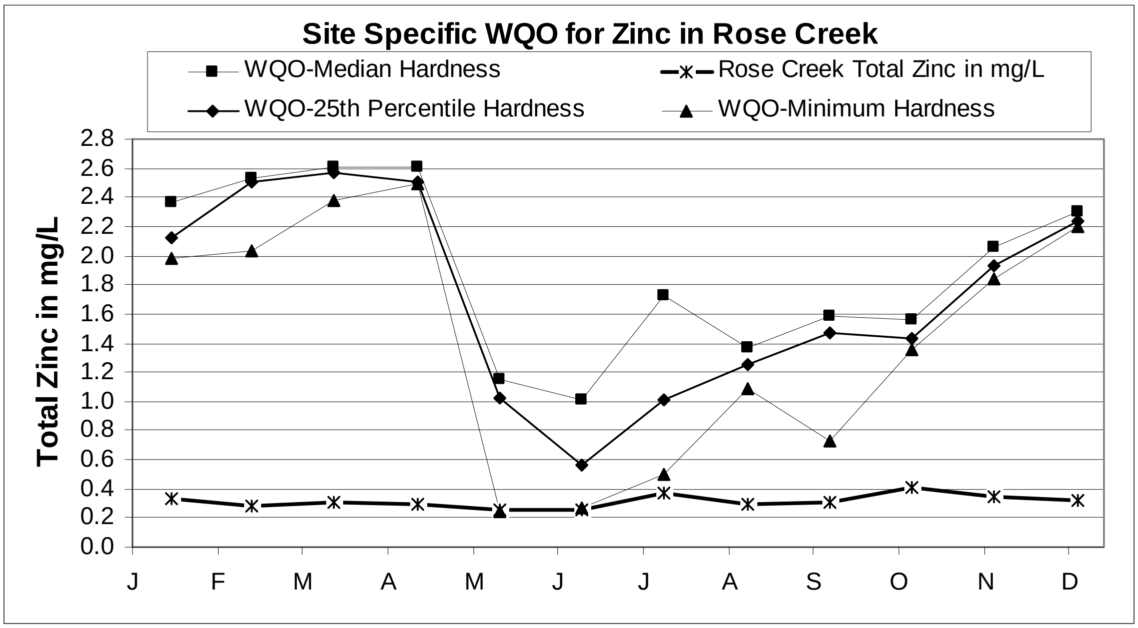
7.5 Example Implementation

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 14, Figure 15). 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.

7.5.1 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.

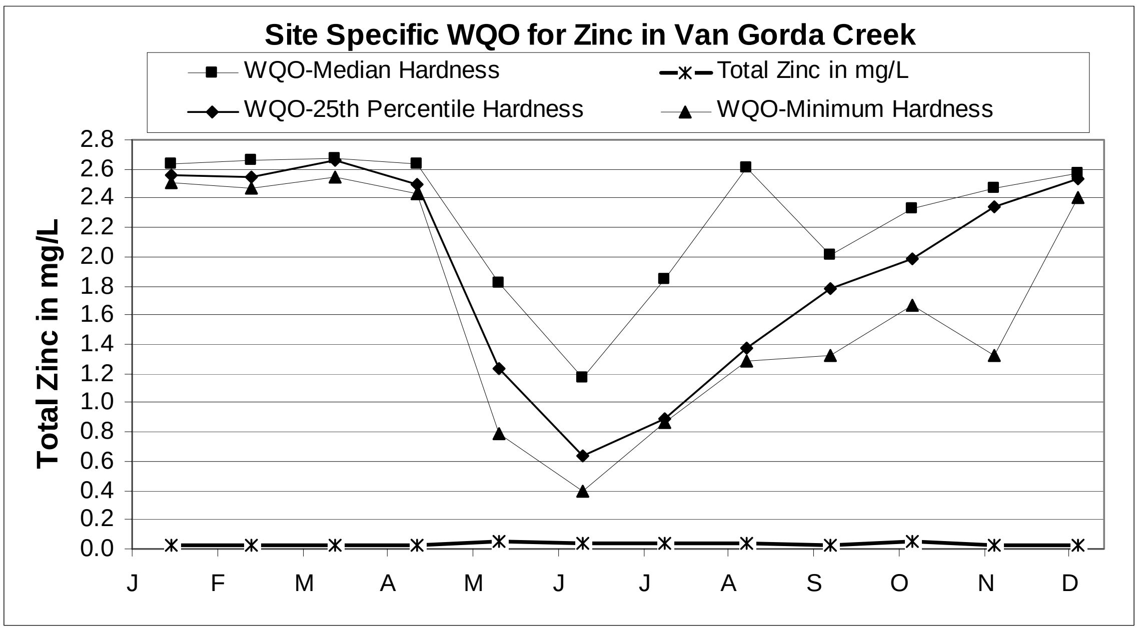
Figure 14. Implementation of SSWQO in Rose Creek.



7.5.2 Van Gorda Creek

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

Figure 15. Implementation of SSWQO in Van Gorda Creek.



8. 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:

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

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.