Aquatic Ecosystem Monitoring Program, Faro Mine, Yukon

Prepared for:

Assessment and Abandoned Mines Branch
Government of Yukon
Whitehorse, Yukon

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EXECUTIVE SUMMARY

The Faro Mine complex (Faro complex), near Faro, Yukon, includes two mines: the Faro Mine and Mill (Faro site) and Vangorda/Grum Mines (Vangorda site), which are located approximately 12 km apart. All operations were terminated in April 1998 and environmental monitoring has been taking place under a site Water Licence (due to expire in February 2009), which allows for the continuation of care and maintenance activities and the development of a Final Closure and Reclamation Plan. As part of the closure planning process, Minnow Environmental Inc. was requested to outline a comprehensive, rational, site-wide, long-term environmental monitoring program.

Monitoring Framework

The goal of the long-term monitoring program (LTMP) is to track environmental conditions within and around the Faro complex over time, to assess the conditions relative to predictions, and to verify that remediation and treatment options implemented at the site are having the desired effect. It has been estimated that peaks in metal loadings from the tailings area will occur at various times over the next 300+ years (SRK 2005), so monitoring will be long-term and associated with considerable cumulative cost. Therefore, it will be important for the program to measure only what is necessary and relevant at any given time and to adapt to changes as they occur (e.g., potentially worsening water quality associated with acidification and metal leaching from waste rock and tailings). The initial scope of the LTMP should be commensurate with the relatively limited magnitude and spatial extent of mine-related effects that are currently evident (Minnow 2007). The frequency of monitoring must be sufficient to provide early warning of changes, particularly degradation, so that appropriate responses can be made (e.g., changes to monitoring, mitigation, or remediation). Similarly, reductions in the scope or frequency of monitoring should be considered in response to improving conditions.

The overall long-term monitoring program (LTMP) at Faro, Yukon, will be comprised of three sub-programs, each with its own sub-objectives. The aquatic ecosystem monitoring program, which is described in this document, will assess the chemical and biological condition of the aquatic environments receiving mine drainage. A perimeter monitoring program will also be developed to measure the concentrations and loadings of mine-related substances at the perimeter of the Faro and Vangorda sites where contaminants are released from the mine sites (source areas) to the natural environment (downstream surface waters). The objective of the third sub-program, the source area monitoring program, will be to track source conditions relative to predictions and monitor the performance of any

treatment systems and/or mitigation. This will include assessment of contaminant concentrations and movements within/from waste rock, pits, seeps, groundwater, surface water conduits, and the Faro tailings basin. The approach and framework for the aquatic ecosystem monitoring program presented in this document can be a template for developing the approach and framework for the other two sub-programs.

Aquatic Ecosystem Monitoring Sub-Program

The aquatic ecosystem monitoring sub-program of the LTMP will integrate biological and chemical information for a weight of evidence approach, including the following components:

- water chemistry,
- hydrology,
- (possibly) sediment chemistry,
- benthic invertebrate community monitoring, and
- fish community and population assessment.

However, before the details of the LTMP can be fully developed for most of the components, several additional, one-time studies will be required to fill critical data gaps. It is proposed that these be addressed through the implementation of an Interim Aquatic Ecosystem Monitoring Program (IAEMP) in 2007-2009. Results of the IAEMP will be reported at its conclusion and incorporated into the rationale for the LTMP components. The proposed schedule will ensure that the technical information required for developing the LTMP will be largely complete when the existing site Water Licence expires (February 28, 2009). Consequently, the goal will be to replace the monitoring stipulated by the current Water Licence with the new LTMP.

Interim Aquatic Ecosystem Monitoring Program (IAEMP)

The interim monitoring program will involve collection of additional information/data over the next two to three years, while monitoring requirements stipulated in the current Water Licence for the Faro complex continue to be fulfilled. Since biological monitoring under the Water Licence is scheduled to be conducted at the two mine sites in alternate years, it is recommended that data collection for the IAEMP be structured accordingly (i.e., Vangorda site in 2007 and at the Faro site in 2008). Depending on the findings, it is anticipated that all the necessary data may be available by the end of 2008, such that a final report, with recommendations for the LTMP can be completed in early 2009, roughly corresponding to

the expiry of the existing Water Licence. The components of the IAEMP are described below.

Surface Water Quality

Existing water quality data are inadequate to determine the optimum design for long-term water quality monitoring data at the Faro complex. Additional studies should be conducted in 2007-2009 (IAEMP) to collect the data necessary to rationalize a streamlined and effective long-term monitoring progam (LTMP). Changes to the water quality monitoring that are recommended for the IAEMP include:

- eliminate surface water monitoring stations that are not required by licence and do not meet specified criteria (listed in the report);
- increase the number of reference stations to develop or update background benchmarks;
- increase sampling frequencies to monthly to generate enough data to permit characterization of seasonal variability and allow the optimum frequency and timing of water sample collection for the LTMP to be determined;
- evaluate the potential for concentrations of antimony, boron, beryllium, chromium, mercury, molybdenum, selenium, tin, thallium, uranium, or vanadium to exceed Canadian water quality guidelines (CWQG), or alternative toxicity-based benchmarks, in surface waters in the future; and
- ensure laboratory method detection limits are sufficiently low to permit meaningful comparisons to CWQG.

The data will be evaluated at the conclusion of the IAEMP to determine the monitoring stations, parameters and sampling frequencies that should be incorporated into the LTMP.

Sediment Quality

The substrates of aquatic receiving environments near the Faro complex are generally coarse (sand, gravel, rocks) with limited, patchy deposits of finer particulates (e.g., fine sand, silt, clay). To date, sediment chemistry has usually involved analysis of metal content in the fine fraction (<0.15mm) of sediment sample collected from fine-particle deposits. While elevated metals (e.g., arsenic, lead, zinc) have been observed in fines at stations downstream of the Faro and Vangorda sites, it is not known: a) what proportion of whole (bulk) sediments the fines represent, b) what concentrations of metals are present in whole sediment samples, c) what proportion of total substrate area do the deposits of fine

sediments represent, nor d) if the sediments showing elevated metal concentrations are toxic to biota. Therefore, additional sediment characterization is recommended as part of the IAEMP, including analysis of particle size, metal content, and toxicity of whole sediments along with analysis of metal content in the fine fraction (0.15mm). Sediment samples should be collected for such analyses in the first year of the IAEMP to allow for possible follow-up activities in the second year, if required (e.g., possible characterization of the ecological importance of fine sediment deposits, if such deposits are found to be toxic in laboratory testing). The results of sediment characterization completed during the IAEMP will determine if sediment analyses should be continued as part of the LTMP, and, if continued, what type of analyses should be included.

Benthic Invertebrate Communities

Benthic invertebrates are good, community-level integrators of localized conditions over time, they are important components of aquatic food webs and there are standardized methods for their collection and evaluation. Therefore, benthic invertebrate community monitoring will be an important component of the LTMP. To date, benthic community assessments at the Faro and Vangorda sites have relied on deployment of artificial substrates, which have the advantage of controlling for natural differences in substrate among exposed and reference areas, but may bias collections toward organisms that happen to drift from upstream and colonize on the substrates over the short (typically 6-week) period they are deployed. The latter point may also partially explain why high year-to-year variability has been observed in previous benthic community assessments at Faro.

To determine the best long-term approach for benthic community monitoring, it is recommended that the IAEMP include parallel sampling of resident benthic communities at the same time that artificial substrates are retrieved in fulfillment of monitoring requirements at the Faro and Vangorda sites under the Water License. This would involve sample collection at each of the two sites in alternate years. A control-impact sampling design will be followed, in which community characteristics at exposure areas will be statistically compared to those at reference areas. This will necessitate field reconnaissance and exploratory sampling during the IAEMP to identify additional reference areas possessing similar habitat characteristics to the mine-exposed areas. In addition, the number of replicate samples collected per area will be increased from three to five to improve statistical power, and the samples will be taken sufficiently far apart to be considered stations within areas, rather than replicate samples within stations. Statistical comparisons will be made for a variety of community metrics such as density, number of taxa, Bray-Curtis similarity index,

Simpson's evenness index, and proportions of dominant taxa. Recommendations for the LTMP will be made on the basis of IAEMP results.

Fish

Fish tend to occupy the upper trophic levels of aquatic ecosystems and are often their most visible and valued components. Both population and community-level assessment can be used as indicators of longer-term exposure conditions (e.g., over years). Therefore, changes in fish community composition and relative species abundance should be tracked at key near-field locations near the Faro complex (R2 and V8) over time and compared to the communities at two or more reference areas possessing similar habitat characteristics. The recommended methods for fish community characterization are similar to those used in previous surveys with modifications to allow for greater standardization of fishing effort and quantification of results. In brief, block-netting should be used, if possible, to enclose sampling areas, with Moran-Zippin methods used to estimate relative species abundances.

In addition, fish health will be assessed using a sentinel species approach similar to that required for federal environmental monitoring programs, which will target collection of slimy sculpin. Fish collection during the IAEMP will focus on determining the appropriate seasonal timing (pre- or post-freshet in spring versus fall) and sampling design (lethal or non-lethal survey) for the LTMP.

Triggers for Change

Future increase or decreases in the scope and/or frequency of aquatic ecosystem monitoring, including surface water, should be triggered by temporal changes in loadings of key contaminants at stations around the perimeter of the Faro complex. It will be important that the selected stations capture all significant contaminant sources. Trigger values should be based on the change in loading predicted to result in a measurable change in downstream water quality for a given parameter. Specific follow-up actions should be identified so that stakeholders understand how the program will change as environmental conditions change. The loadings-based numeric triggers should be developed during the IAEMP so they can be agreed upon and implemented as part of the LTMP

Long Term Monitoring of Aquatic Ecosystems

Details of the aquatic ecosystem monitoring sub-program of the LTMP will be finalized based on data collected during the IAEMP. It is anticipated that the frequency of biological monitoring and reporting will be reduced to a 5-year cycle, although surface water quality data should continue to be assessed and reported annually. The costs associated with

additional data collection over the short-term (e.g., two to three years for the IAEMP) are expected to be greatly offset by savings realized by the implementation of a streamlined, scientifically defensible monitoring program over the longer term (e.g, hundreds of years for the LTMP). Both the scope and frequency of long-term monitoring should evolve in response to program findings. A rigorous quality assurance plan has been outlined to ensure all monitoring data will reliably serve the project objectives.

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1.0 INTRODUCTION

1.1 Background

The Faro Mine complex (Faro complex), near Faro, Yukon, includes two mines: the Faro Mine and Mill (Faro site) and Vangorda/Grum Mines (Vangorda site), which are located approximately 12 km apart (Figure 1.1). The complex was formerly owned by the Anvil Range Mining Corporation and produced lead and zinc concentrates to be extracted for lead, zinc, silver, and gold. The Faro site was mined between 1969 and 1992[1], while the Vangorda site was developed and mined between 1986 and 1998. All operations were terminated in April 1998, due to poor economic circumstances and projections, and the site went into receivership. Since then, management of the mine property has been under the direction of Deloitte and Touche Inc., acting as the court appointed Interim Receiver (the "Interim Receiver").

The Faro Mine Closure Planning Office (FMCPO) was instated to act on behalf of the federal and Yukon governments, Selkirk First Nation and Ross River Dena Council to work towards the preparation of a comprehensive closure plan for the abandoned Faro complex. Before the closure plan can be implemented, it will be subject to regulatory assessment and approval processes. The plan requires regulatory approval in the form of a Water Licence issued under the *Waters Act* by the Yukon Water Board and will need to be acceptable to relevant government agencies, the First Nations and the public. The assessment process will be carried out through the Yukon Environmental and Socio-Economic Assessment Board under the *Yukon Environmental and Socio-Economic Assessment Act* (YESAA).

Prior to 2004, activities at the Faro complex were regulated under separate Water Licences, QZ95-003 (Faro) and IN89-002 (Vangorda Plateau), which expired on December 31, 2003. A new Water Licence QZ03-059 (the "Water Licence") was then issued which combined activities at both mine sites into one licence that, in general, allows for the continuation of care and maintenance activities and the development of a Final Closure and Reclamation Plan. The current Water Licence has an expiry date of February 28, 2009.

Technical studies conducted at the site, which are nearing completion, have indicated that acidification and leaching processes have the potential to result in dramatic increases in metal loadings to surface waters downstream of the Faro complex over the next several to many decades (SRK 2004, 2005). Consequently, the closure process is proceeding to the

[1] Milling continued at Faro until shutdown of the entire operation in 1998.

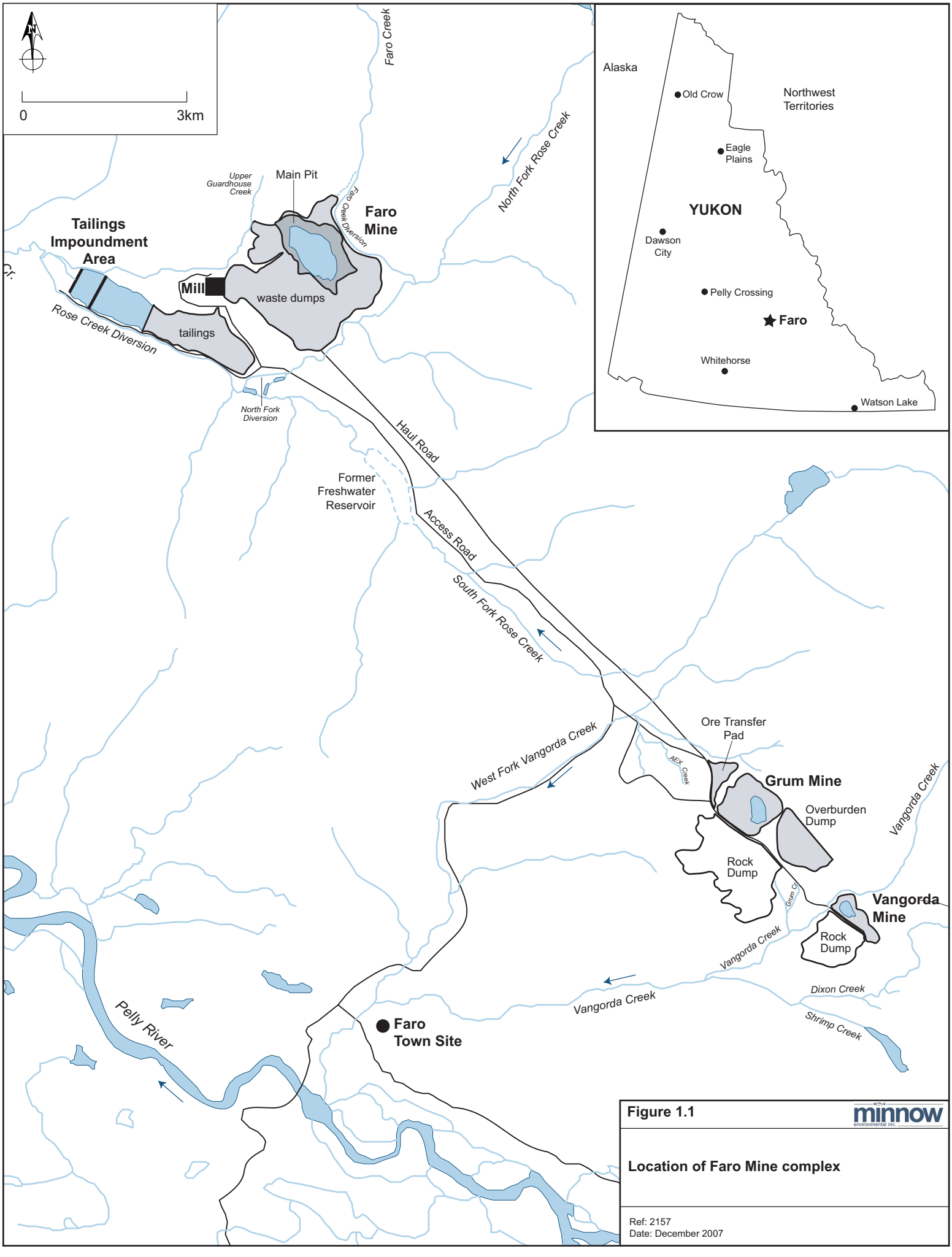

Figure 1.1

Location of Faro Mine complex

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regulatory and development assessment phases with considerable focus on identifying the mitigation measures required to protect the aquatic ecosystem downstream of the mines. Related to this, the FMCPO has requested that Minnow Environmental Inc. assist it in identifying the requirements of a comprehensive, consolidated, and rational site-wide environmental monitoring program. Such a program will need to meet the needs of the environmental assessments, closure planning, and regulatory processes in the short-term and provide adequate information to evaluate environmental conditions and the performance of mitigation and treatment systems in the long-term. Based on guidance from the FMCPO and input from other consultants familiar with the site, it was decided that efforts should initially be directed toward the development of an aquatic ecosystem monitoring program (the subject of this report). The associated framework will then be used as a template for development of monitoring programs for locations reflecting off-site migration of mine-related contaminants (perimeter monitoring) and for source areas (e.g., pits, tailings, waste rock). The new monitoring program will eventually replace requirements currently listed in the site Water Licence, although the specific process and schedule will depend on how this can best be accomplished within the overall closure planning process.

1.2 Project Objectives and Overview

The objective of the project was to develop a long-term aquatic ecosystem monitoring program for the Faro complex. The most cost effective monitoring design will identify the minimum sample types, sample locations and sampling frequencies necessary to adequately evaluate chemical and biological conditions in surface water downstream of the mines and track changes in these over time. To identify the optimal design, sufficient data need to be available to show that collection of additional or different samples will not provide additional insight. If the existing data are inadequate to answer key questions regarding current conditions, additional data will need to be collected and assessed (in the short-term) before the optimal long-term design can be finalized.

Review of historical study information for the Faro complex, and the results of a recent ecological impact assessment study (Minnow 2007), indicated that there are key information gaps that will need to be addressed in order to optimize the long-term monitoring program design. The costs associated with additional data collection over the short-term (e.g., two to three years) are expected to be greatly offset by savings realized by the implementation of a streamlined, scientifically defensible monitoring program over the longer term (e.g, hundreds of years).

This report outlines the general framework for the Long-Term Monitoring Program (LTMP) and also identifies the elements of an Interim Aquatic Ecosystem Monitoring Program (IAEMP) to be implemented in the short-term. The IAEMP will involve collection of the missing data needed to answer key technical questions and allow for development of a streamlined, scientifically defensible LTMP. At the conclusion of the IAEMP, likely in early 2009, a report will be prepared to present the IAEMP results and provide detailed recommendations for the LTMP.

1.3 Report Organization

Section 2.0 describes the overall framework and approach for the LTMP. The approaches for monitoring of water and sediment quality in the IAEMP and LTMP are presented in Sections 3.0 and 4.0, respectively. Sections 5.0 and 6.0 outline the approaches for monitoring of benthic invertebrate and fish community health, respectively. The quality management plan and reporting requirements associated with the LTMP are presented Sections 7.0 and 8.0, respectively. Section 9.0 provides a summary of the monitoring components outlined in previous sections, with a tentative implementation schedule. References cited throughout the report are listed in Section 10.0.

2.0 LTMP FRAMEWORK

2.1 LTMP Objectives

The goal of the LTMP is to track environmental conditions within and around the Faro complex over time, to assess the conditions relative to predictions, and to verify that remediation and treatment options implemented at the site are having the desired effect. It has been estimated that peaks in metal loadings from the tailings area will occur at various times over the next 300+ years (SRK 2005), so monitoring will be long-term and associated with considerable cumulative cost. Therefore, it will be important for the program to measure only what is necessary and relevant at any given time and to adapt to changes as they occur (e.g., potentially worsening water quality associated with acidification and metal leaching from waste rock and tailings). The initial scope of the LTMP should be commensurate with the relatively limited magnitude and spatial extent of mine-related effects that are currently evident (Minnow 2007). The frequency of monitoring must be sufficient to provide early warning of changes, particularly degradation, so that appropriate responses can be made (e.g., changes to monitoring, mitigation, or remediation). Similarly, reductions in the scope or frequency of monitoring should be considered in response to improving conditions.

The overall LTMP will be comprised of three sub-programs, each with its own sub-objectives (Figure 2.1). The aquatic ecosystem monitoring program, which is the focus of this document, will assess the chemical and biological condition of the surface water environments receiving mine drainage. A perimeter monitoring program will also be developed to measure the concentrations and loadings of mine-related substances at the perimeter of the Faro and Vangorda sites where contaminants are released from the mine sites (source areas) to the natural environment (downstream surface waters). The objective of the third sub-program, the source area monitoring program, will be to track source conditions relative to predictions and monitor the performance of any treatment systems and/or mitigation. This will include assessment of contaminant concentrations and movements within/from waste rock, pits, seeps, groundwater, surface water conduits, and the Faro tailings basin. Following the completion and approval of the aquatic ecosystem monitoring program, the other two programs will be developed using a similar approach and framework.

2.2 General Approach

This document outlines the rationale and approach for an aquatic ecosystem monitoring program that will be implemented as part of the LTMP at Faro. The program will integrate

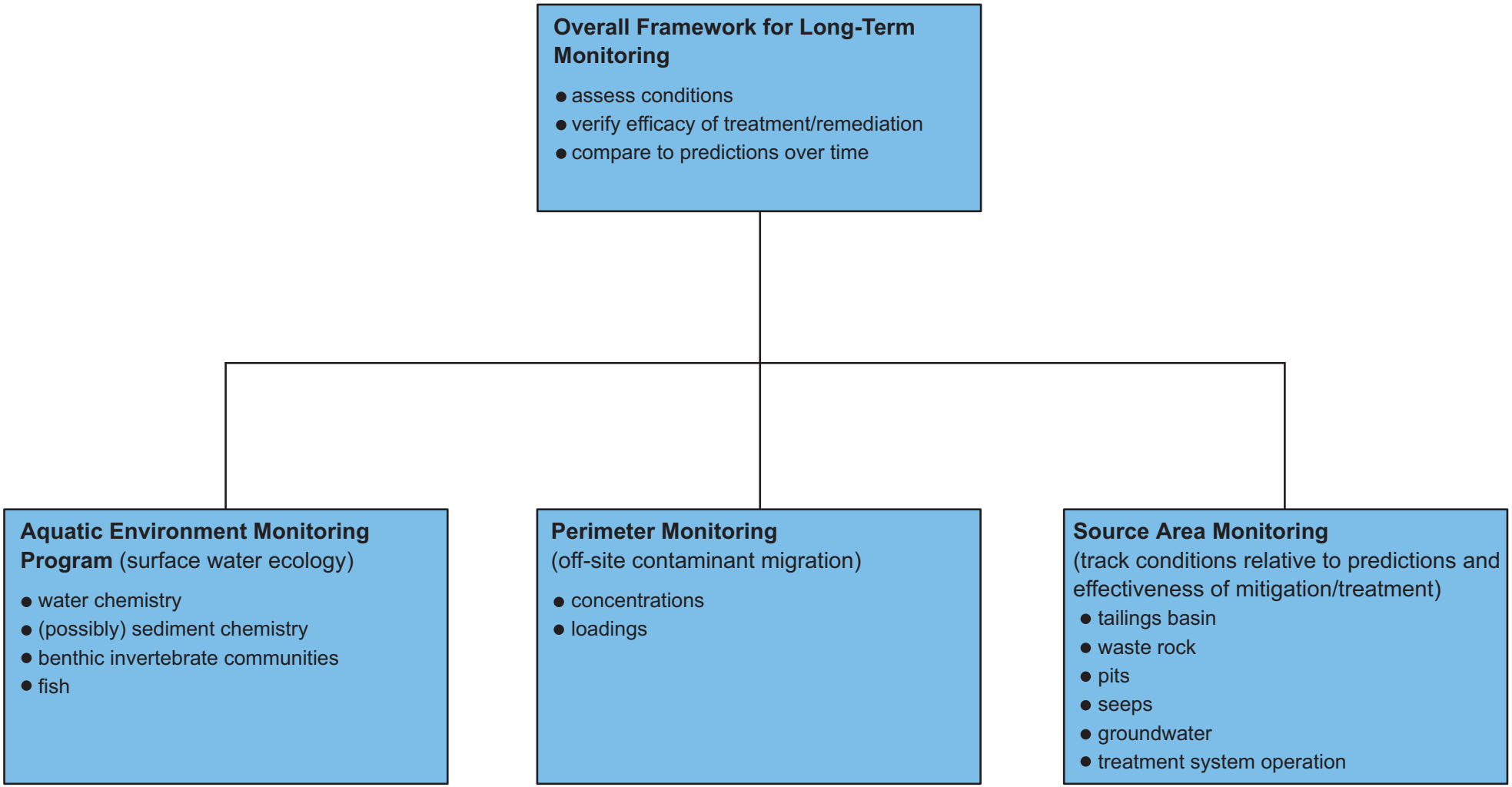

Figure 2.1

Framework for long-term monitoring at Faro Complex, Yukon

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biological and chemical information for a weight of evidence approach, including the following components:

- water chemistry,
- hydrology,
- (possibly) sediment chemistry,
- benthic invertebrate community monitoring, and
- fish community and population assessment.

For the biological components, an environmental effects monitoring (EEM) approach, similar to that applied to operating mines in Canada (Environment Canada 2002) is proposed.

The general monitoring framework involving the components listed above is presented in subsequent sections of this report. However, before the details of the LTMP can be fully developed for most of the components, several additional, one-time studies will be required to fill critical data gaps. It is proposed that these be addressed through the implementation of an Interim Aquatic Ecosystem Monitoring Program (IAEMP) in 2007-2009. Results of the IAEMP will be reported at its conclusion and incorporated into the rationale for the LTMP components. The proposed schedule will ensure that the technical information required for developing the LTMP will be largely complete when the existing site Water Licence expires (February 28, 2009). Consequently, the goal will be to replace the monitoring stipulated by the current Water Licence with the new LTMP.

As noted throughout this document, future increases or decreases in the scope and/or frequency of aquatic ecosystem monitoring should be triggered by temporal changes in loadings of key contaminants at perimeter stations (specific triggers to be developed in the IAEMP), so it will be important that the stations selected for monitoring of loadings capture all significant contaminant sources. Both the source area and perimeter monitoring programs should be harmonized as much as possible with the aquatic ecosystem monitoring program with respect to sampling locations and frequency, as well as the parameters measured. This will ensure any future environmental impacts can be directly linked to applicable sources.

Effluent quality is expected to change gradually over time, with peaks in metal loadings predicted at various times over the next 300+ years. Therefore, the monitoring program must have a long-term perspective. After the IAEMP is completed, a five-year monitoring interval will likely be recommended for the biological monitoring requirements of the LTMP and completion of the associated comprehensive study reports (see Section 8.2). This frequency

is consistent with the gradual change expected in effluent quality over time and an appropriate time interval over which measurable biological change may be detectable. Water concentrations and source loadings associated with aquatic ecosystem, source area, and perimeter monitoring programs should be reported annually to provide early warning of changing conditions (Section 8.1). Annual reports should report any major changes observed in concentrations and/or loadings relative to previous years, and/or any issues encountered (e.g., missed samples, data quality problems, etc., as outlined in Section 7.0). Surface water data should also be summarized in the five-year comprehensive report, where interpretation can be integrated with the results of biological monitoring components (Section 8.2). If the first few cycles of monitoring (e.g., 20 years monitoring on a 5-year cycle) confirm that mine-related impacts are minor and that conditions continue to be relatively stable, it would be appropriate to reduced the monitoring frequency (e.g., once every 10 years), with a trigger to increase the frequency based on specific increases in the loadings of key mine-related parameters (to be developed during the IAEMP).

The development of loadings-based numeric triggers, noted above, will allow the monitoring program to be flexible and responsive to changing conditions. Triggers will be developed for some or all perimeter monitoring stations and possibly also for key source area stations. Each trigger value should be based on the change in loadings for key parameters predicted to result in a measurable change in downstream water quality. For example, it may be determined that a 100-fold increase in annual loading from a given source would be required to double the receiving water concentration downstream. Depending on the parameter and locations involved, this magnitude of change may be considered to sufficient to trigger additional or more frequent monitoring. Thus, a trigger could be set that specifies the action to be taken if and when the trigger threshold is exceeded. It is recommended that the triggers be developed as part of the IAEMP.

The following sections outline the general framework for the LTMP and also describe the recommended content and schedule for the IAEMP. Specific monitoring stations referenced throughout the document are shown in Figure 2.2. Once the IAEMP has been completed this document should be updated so it presents the framework and implementation details of the LTMP only.

Figure 2.2

minnow environmental inc.

Historical and proposed surface water monitoring stations

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A1/R11
P4 (new)
P3 (new)
R5
R6
R4
Anvil Creek
R3
Rose Creek
Next Creek
Faro Creek
FC
Faro Valley Interceptor
FVW
FDU
FCO
Upper Guardhouse Creek
North Wall Interceptor Ditch
W10
W8
Faro Creek Diversion
North Fork Rose Creek
X14
R2
X10
X5
NWI
Main Pit
FCD/FDL
FAROCR
R8
R7
Mill
waste dumps
R9
R10
NF1
tailings
Rose Creek Diversion
X2
NF2
X8
R1
North Fork Diversion
Haul Road
Former Freshwater Reservoir
K8
Access Road
South Fork Rose Creek
Pelly River
Grum Corner
VR (new)
V6
V17A
Ore Transfer Pad
West Fork Vangorda Creek
AEX Creek
Grum Pit
Vangorda Creek
Overburden Dump
Rock Dump
Grum Creek
V1
Vangorda Pit
V2
Rock Dump
V20
V27
Vangorda Creek
V4
Dixon Creek
Shrimp Creek
V5
VGMAIN
Faro Town Site
V8
P2 (new)
P1 (new)
Pelly River
Vangorda Creek

0 3km

3.0 SURFACE WATER MONITORING

3.1 Current Conditions

Mine-related influence on water quality is evident to the mouths of both Anvil Creek and Vangorda Creek at the Pelly River based on elevated concentrations of substances such as calcium, magnesium, manganese, sodium, strontium, and sulphate relative to background (reference) stations (Minnow 2007). This does not necessarily indicate that effects on biota are occurring in these creeks as a result of such elevated concentrations; no Canadian Water Quality Guidelines (CWQGs) exist for these substances, based on their lower toxicity relative to most substances for which a CWQG has been established. Concentrations of substances having a CWQG have typically been less than guideline and/or background concentrations, suggesting mine-related effects on biota are negligible at the present time (Minnow 2007).

3.2 Considerations for Future Monitoring

Water quality monitoring is central to an integrated environmental monitoring program for the Faro complex since the ultimate fate of most mine-related contaminants will be downstream surface water bodies, although groundwater transport will also be significant close to source areas. Future increases in metal loadings to surface waters will appear as increases in surface water concentrations before measurable changes in biological communities are apt to be observed. Therefore, the frequency of surface water monitoring should be greater than that of biological monitoring. Selected surface water monitoring locations should provide unique information and only contaminants that are currently or predicted to become elevated relative to background, and CWQG if applicable, should be routinely monitored and reported.[2]

3.3 Sampling Methods

3.3.1 Sample Collection

Methods for water sample collection are outlined in Appendix B, Section B.1.0, and provide a basis for developing standard operating procedures (SOPs) for the Faro monitoring program

[2] Broader suites of parameters (e.g., full ICP scan) should occasionally be measured at key source area and/or perimeter stations to identify any potential new parameters of concern. These should be added to the surface water monitoring program if present at concentrations that might affect aquatic biota.

(Section 7.1). Similar methods have been reviewed and approved by provincial and federal regulators for monitoring programs being conducted at other mine sites across Canada.

3.3.2 Total Versus Filtered Metals

Water quality monitoring conducted at the Faro site in recent years has included analysis of both total and filtered metal concentrations, where the latter is defined as the concentration of metal in a water sample that is passed through a 0.45 um filter. The need for measurement of both forms in surface water should be reconsidered, since this practice increases the costs for sample collection and data management and doubles the cost of laboratory analysis. Methodological differences can result in significant variation in the concentrations of metals reported as being in the dissolved form, such as filter diameter, filter manufacturer, volume of sample processed, and amount of sediment in the sample (Horowitz et al. 1996). Although filtered metal concentrations are generally considered a more relevant indicator of the metal concentrations present in a form that might be harmful to aquatic biota (i.e., bioavailable; Prothro 1993), the metal species passing through a 0.45 um filter are not necessarily truly dissolved (i.e., colloidal forms may also pass through; EVS 1997). Also, different metal species in filtered samples can vary widely in toxicity (Campbell 1995, Deaver and Rodgers 1996, DiToro et al. 2005).

To date, total concentrations of most metals measured in surface waters near Faro have been less than respective CWQG. Generally, a higher level of environmental protection can be assumed if total metal concentrations are less than a CWQG, since the filtered metal concentration must then also be less than the CWQG (whereas converse cannot be assumed). Also, since total and filtered metal concentrations strongly correlate at the Faro site, measurements of total metal levels will be adequate to track general water quality conditions across space and time. Therefore, it is recommended that total concentrations be measured and reported for the LTMP. If future concentrations increase above CWQG, and particularly if they exceed predictions for a given location, it may become relevant to monitor filtered metal concentrations. In the short term, measurement of filtered metal concentrations will be required under the site Water Licence. It is recommended that all samples be filtered in the field following strictly standardized methods (e.g., Hall 1998 and Appendix B1.3), with the resulting samples being analyzed to the same low MDLs (<CWQG) such that the data can be evaluated, and the above recommendations re-visited, at the conclusion of the IAEMP.

3.4 Sampling Locations

In a regulatory framework, monitoring stations at an industrial site are often added over time in response to specific concerns, events (e.g., spills), or information needs which may no longer be relevant. Therefore, it was appropriate to review all surface water stations that are currently required by the site's Water Licence, and those that are voluntarily monitored, to determine if each one is still relevant and should be included in the LTMP. Each station was recommended for inclusion in the LTMP if it:

- is located on a surface water body which does or could be expected to support fish;
- does not represent a source (e.g., seep) nor can it be considered a perimeter station (the point at which a contaminant enters the natural environment from the area of mine disturbance) since long-term monitoring programs for these types of stations will be developed separately;
- currently shows elevated concentrations of one or more mine-related parameters or is the closest downstream station showing no elevation in mine-related parameter concentrations (i.e., defining the spatial extent of influence) or is a suitable reference station; and
- provides unique information relative to all other stations;

As noted below (Section 3.4), efforts are underway to improve analytical method detection limits (MDLs) for surface water samples and to collect additional reference station data within and near the Rose/Anvil and Vangorda watersheds. Such data will be used to better characterize natural background concentrations for each parameter and to assist in selection of reference areas most suitable for the LTMP (including biological sample collections). This will be done as part of the IAEMP, culminating in recommendations for the LTMP. However, based on a review of the existing monitoring stations, a total of 29 surface water monitoring stations is tentatively recommended for inclusion in the LTMP (Table 3.1). One of the key changes proposed is the addition of stations in lower Anvil Creek and in the Pelly River to delineate the spatial extent of mine-related influence on water quality. Monitoring of these stations should be initiated as part of the IAEMP, such that a decision can be made at the conclusion of the IAEMP as to whether monitoring should continue as part of the LTMP.

Other recommendations for the LTMP include the elimination of some stations that are presently required under Water Licence (Table 3.1). Changes that would necessitate modification to the site Water Licence should be deferred and revisted in accordance with the

Table 3.1: Summary of recommended changes to surface water monitoring program at Faro Complex, Yukon.

Water Body	Database Station ID	Station Description (in existing database)	License Require-ment	Total visits (to mid 2006)	Add, Retain or Eliminate in LTMP	Rationale for Retaining or Eliminating Station
Faro Creek Area	FC	Faro Creek above diversion channel		24	A	Not measured since 1996. Background water quality in Faro Creek, similar information to FDU, but FDU may be slightly influenced by its location in the upper diversion and by drainage from the North Valley Interceptor. Retain FC and eliminate FDU.
	FDU	FDU, Faro Creek Diversion U/S Valley Dump	✓	16	E	Actively monitored. Almost background water quality in Faro Creek. Potentially slightly influenced by its location in the upper diversion and by drainage from the North Valley Interceptor. Retain FC and eliminate FDU.
	FDU2	Faro Creek Diversion at corner		1	E	Not actively monitored. Short-term purpose served and no longer relevant.
	FVW	Faro Valley Intercept		5	E	Not monitored since 1992. Essentially clean water, but FC would better represent reference conditions.
	FCD	Mid Faro Ck. Diversion adjacent NE Waste Dumps		28	E	Not monitored since 2004. Information similar to that provided by FAROCR.
	FDL	Mid Faro Creek Diversion	✓	5	E	Actively monitored. Similar location to FCD, and data similar to FAROCR.
	FAROCR	Faro Cr. Diversion u/s confluence with North Fork Rose Cr.	✓	47	R	Actively monitored. Reflects potential effects on Faro Creek of any drainage from NE waste dumps or input from the waste rock lining the diversion channel d/s of FDU. Location needs to be moved upstream slightly - may be influenced by flooding in Rose Cr. Ensure sampling not confused with R7.
North Fork Rose Creek	R7	N Fork of Rose Creek above Faro Ck Diversion	✓	118	R	Actively monitored. Background station with good long-term records. Also a benthic station.
	R8	N Fork of Rose Creek 900 m below Faro Ck Div.	✓	97	R	Actively monitored. Reflects combined background water quality of Faro Creek and North Fork Rose Creek, plus any inputs to Faro Creek diversion. Required for evaluation of quality between here and X2.
	R9	N Fork of Rose Creek adjacent BH1 and BH2	✓	99	E	Actively monitored. Reflects potential input from Northeast Dumps, although little influence on water quality to date.
	R10	North Fork of Rose Creek u/s of rock drain	✓	91	E	Actively monitored. Reflects Zone 2 outwash, although little influence on water quality to date.
	NF1	North Fork Rose Creek Site 1 u/s of Haul Road	✓	22	E	Actively monitored. Reflects upstream inputs and additional clean water drainage from southeast.
	NF2	North Fork Rose Creek Site 2 d/s of Haul Road	✓	26	R	Actively monitored. Reflects potential inflow under Haul Road, although little influence on water quality to date.
	X2	N Fork of Rose Creek u/s of mine access road	✓	285	R	Actively monitored with good long-term records. Input from upstream sources and groundwater via S-series wells evident.
Guardhouse Creek and North Wall Interceptor	W10	Upper Guardhouse Ck u/s of NW Dump	✓	16	R	Actively monitored. Provides background re: Upper Guardhouse Cr. - which flows through the toe of a waste rock dump immediately after W10.
	W8	Upper Guardhouse Creek d/s of NW Dump	✓	24	E[a]	Actively monitored. Identifies potential loading from the Upper Northwest Dump to Upper Guardhouse Cr. Similar to NWI and NWINT.
	NWI	North Wall Interceptor		4	E	Not monitored since 1996. Similar to W8 and NWINT. Not a natural channel.
	NWINT	NW Interceptor ditch u/s of X5		9	E[a]	Not monitored since 1999. Similar to W8 and NWI. Not a natural channel.
South Fork Rose Creek and Tailings Diversion	Grum Corner	Tributary of Rose Creek upstream of the site of the freshwater dam	✓	0	A (from GCULV)	No data in database under this name. Drinking water station for Ross River First Nation. Same as GCULV, but should be tracked under name used in license.
	GCULV	Grum Culvert-Ross River resident usage		27	R (as Grum Corner)	Actively monitored. Drinking water station for Ross River First Nation. Data should be tracked as 'Grum Corner' consistent with license.
	K8	Ross River resident usage	✓	30	R	Actively monitored. Drinking water station for Ross River First Nation. Consult RR residents to consider moving upstream of haul road to avoid influence of road drainage.
	FWSD1	Fresh Water Supply Dam - Station One		11	E	Only monitored 2004-2005 for TSS during construction activities associated with FWSD removal. Represented background water quality.
	FWSD5	Fresh Water Supply Dam - Station Five		10	E	Only monitored 2005-2005 to evaluate effects of FWSD removal project (TSS).
	FWSD6	Fresh Water Supply Dam - Station Six		2	E	Only monitored twice (2004, 2006). May be influenced by storage of material near FWSD that is potentially acid generating.
	R1	Rose Creek upstream of Pumphouse Pond	✓	17	R	Actively monitored. May be influenced by upstream tributaries draining across Haul Road but otherwise clean. Benthic invertebrate community health monitoring station.
	SFORKROSE	S Fork Rose Creek upstream of pumphouse		1	E	Not actively monitored. Short-term purpose served and no longer relevant.
	X3	S Fork Rose Creek at the pumphouse reservoir	✓	245	E[a]	Actively monitored. Reflects quality of combined flows from North and South Forks Rose Creek. Any input to diversion expected from tailings area that would require this station serve as reference?
	X10	Rose Creek Diversion Channel below weirs		290	R	Actively monitored (monthly). Provides long record of WQ upstream of major mine loads from tailings area and treatment plant discharge, but future status depends on selected closure option.
	X10A	Rose Creek just upstream of counfluence with X13/X5		1	E	Not actively monitored. Short-term purpose served and no longer relevant.
	X10B	Rose Creek just upstream of counfluence with X13/X5		1	E	Not actively monitored. Short-term purpose served and no longer relevant.
	ROSESTVREC	Rose Creek downstream of Stevens Recorder		2	E	Not actively monitored. Short-term purpose served and no longer relevant.
Rose Creek Downstream of Mine	X14	Rose Cr downstream of the diversion channel	✓	437	R	Actively monitored. Reflects all combined inputs from Faro site and is also the main water quality "compliance point" for the site. Should also be considered a "perimeter" monitoring station.
	R2	Rose Creek just d/s X14	✓	17	E	Monitored twice per year, but samples collected more frequently just u/s at X14. Reflects near-field mine influence. Benthic invertebrate community health monitoring station.
	R3	Rose Creek between R2 and R4	✓	16	R	Monitored twice per year. Reflects conditions in Rose Creek midway between mine and Anvil Creek confluence. Benthic invertebrate community health monitoring station.
	R4	Rose Creek upstream of Anvil Creek	✓	30	R	Monitored twice per year. Reflects conditions in lower Rose Creek. Benthic invertebrate community health monitoring station.
Anvil Creek	R5	Anvil Creek downstream of Rose Creek	✓	32	E?	Monitored twice per year. Reflects combined flows of Rose and Anvil Creeks. Benthic invertebrate community health monitoring station.
	R6	Anvil Creek upstream of Rose Creek	✓	29	R	Monitored twice per year. Reference station. Benthic invertebrate community health monitoring station.
	R11	Mouth of Anvil Creek		5	R (as A1)	Actively monitored (2/year). Provides receiving water quality information at a location that is important for Selkirk First Nations people, who use the Pelly River. A1 is better station name than R11.
	Anvil Cr	Anvil Cr above Pelly R	✓	0	E	No data in database. Probably same or similar location to A1 and R11. Need to consolidate for long-term monitoring as Station A1.
	A1	Anvil Creek upstream of Pelly River		0	A (from R11)	No data in database. Probably same or similar location to Anvil Cr and R11. Need to consolidate for long-term monitoring as A1.
Pelly River	P1	Pelly River upstream of Vangorda site		0	A	New reference station.
	P2	Pelly River d/s of Vangorda site		0	A	New station to assess influence of Vangorda site on Pelly River.
	P3	Pelly River u/s of Anvil Creek		0	A	New station to act as reference for Faro inputs
	P4	Pelly River d/s of Anvil Creek		0	A	New station to assess influence of Faro site on Pelly River.
Vangorda Creek	V1	Vangorda Creek, u/s mine and Blind Cr. Rd.	✓	87	R	Reflects background water quality. Benthic invertebrate community health monitoring station.
	V2	Grum Creek upstream of confluence with Vangorda Creek	✓	142	E[a]	Reflects influence on Grum Creek of Grum waste rock dumps.
	V27	Vangorda Creek, just upstr. of Shrimp	✓	55	R	Reflects combined influence of Grum and Vangorda sites on Vangorda Creek. "compliance point" and should thus be considered a "perimeter" monitoring station as well as an aquatic environment. Also a benthic invertebrate community health monitoring station.
	VGMAIN	Main fork Vangorda Creek (upstream West Fork)	✓	101	R	Reflects all mine inputs to main stem Vangorda Creek upstream of West Fork confluence.
	V26	Little Creek between pit and dumps flowing into Dixon Creek		5	E	Not monitored since 1995.
	V20	Vangorda pit, SE interceptor ditch d/s of V26	✓	29	E	Actively monitored. Reflects what? Typically dry in summer.
	V4	Shrimp Creek, u/s Vangorda Creek confluence	✓	48	R	Reflects any input from Vangorda rock dump via Shrimp Creek.
	VR	West Fork of Vangorda Creek u/s Haul Road		0	A	New reference station for West Fork Vangorda Creek.
	V17A	Tribuary to West Fork Vangorda Creek (Ore Transfer Pad)	✓	36	E	Reflects any ARD input from Ore Transfer Pad. Input captured at V6A.
	V6A	AEX Creek	✓	108	R	Reflects input to West Fork Vangorda Creek from Ore Transfer Pad and other local runoff.
	V5	West Fork of Vangorda Creek at gravel pit	✓	177	R	Reflects any mine influence on West Fork Vangorda Creek u/s of confluence with Main Fork.
	V8	Lower Vangorda Creek at the footbridge	✓	234	R	Reflects combined influence of Grum and Vangorda via main and west branches Vangorda Creek. Also near Faro townsite.
	VXX	Main Fork Vangorda Creek calculated at 67% of V8		37	E	Not actively monitored. Short-term purpose served and no longer relevant.
	VGGR	Vangorda Creek at Grum turn off		1	E	Not actively monitored. Short-term purpose served and no longer relevant.

[a] Eliminate or sample as part of source area monitoring program

A - Add

R - Retain

E - Eliminate

Stations tentatively recommended for inclusion in LTMP. Monitoring at other stations could be discounted during IMP unless required by licence.

next scheduled renewal of the water licence (February 2009), which will approximately correspond with the conclusion of IAEMP.

3.5 Water Quality Parameters

3.5.1 Chemistry

Parameters considered to be of particular concern are those that typically exceed Canadian Water Quality Guidelines (CWQGs) (*i.e.,* in ≥ 25% of recent samples), or are predicted to exceed in the future, at stations downstream of the mine sites. If natural background levels of such parameters also exceed CWQG, then it is more relevant to use background concentrations as a benchmark for evaluating mine influence on water quality than the CWQG. Background (reference station) data for the Faro site have been sparse or associated with inadequate analytical method detection limits (MDLs) for many substances for which a CWQG exists (e.g., arsenic, cadmium, chromium, mercury, selenium, silver, thallium; Minnow 2007). This was identified as a key data gap by Minnow (2007) and efforts are underway to collect additional reference data and ensure adequate MDLs are achieved for samples collected at all surface water stations. These data will be reported at the conclusion of the IAEMP, such that the information presented below, including recommendations for monitoring under the LTMP, can be updated.

Samples recently collected from mine-exposed monitoring stations (2004-2006) sometimes contained elevated levels of aluminum, ammonia, copper, iron, lead and zinc relative to reference (background) stations (Minnow 2007); however, concentrations were usually less than the CWQGs in both reference and exposure areas, suggesting these substances are not currently adversely affecting surface water environments downstream of the mines. Low aqueous concentrations of ammonia, arsenic, chromium, mercury, molybdenum, nickel, selenium, and thallium also suggest that these substances do not currently pose a risk to aquatic biota downstream of the Faro complex (water-borne exposures). However, arsenic, along with lead, manganese and zinc, has been elevated in sediments collected downstream of the mine sites, suggesting these substances should continue to be monitored in water samples in the future to track potential changes in concentration. These conclusions will be revisited at the conclusion of the IAEMP based on data collected in the meantime (Minnow 2007).

Of parameters lacking a CWQG, sulphate, hardness, conductivity, manganese, magnesium, calcium, strontium, sodium, and uranium have been the parameters most often elevated (≥20% of samples) in Rose and Vangorda Creeks relative to background (upstream reference) stations (Minnow 2007). These parameters can be considered current indicators

of mine influence on surface water quality downstream of the Faro complex (i.e., "mine indicator parameters"). Strong statistical correlations were evident among almost all the mine-indicator parameters (except uranium), suggesting that measurement of one provides a good indication of the relative concentration of the others (Minnow 2007). Therefore, it is suggested that only a sub-set of these parameters needs to be measured and reported as part of the LTMP for surface water. It is recommended that sulphate (the most consistently elevated parameter in mine-exposed water samples), hardness (a measure of both calcium and magnesium concentrations), conductivity (which reflects the combined contributions of all major ions), manganese (which is also elevated in mine-exposed sediments) and uranium (which didn't strongly correlate with some other mine-indicator parameters; Minnow 2007) continue to be monitored as part of the LTMP.

Ammonia has also been elevated in samples collected downstream of the mine sites, but concentrations have been well below the CWQG (for un-ionized ammonia; Minnow 2007). The source of ammonia is likely blasting residues (ammonium nitrate fuel oil explosives) remaining on waste rock and possibly some contribution from oxidation of cyanide, which was formerly used in the mill floatation circuit for metal separation. As ammonia concentrations are not presently at levels of concern and are expected to decline rather than increase, ammonia is not recommended as a long-term monitoring parameter.

Recognizing the acid generating potential of tailings and waste rock stored at the Faro complex (GLL 2002), predictions of future surface water quality were developed for various scenarios related to mine closure, ranging from no intervention to treatment of all source flows (data from SRK presented by Senes 2006). Of the parameters evaluated, cadmium, copper, iron, lead and zinc can be considered most likely to exceed CWQG in the future (Tables 3.2 and 3.3). Source area concentrations should be re-evaluated during the IAEMP to determine if there are any other substances that may be of concern in the future. In particular, boron, beryllium, chromium, mercury, molybdenum, selenium, antimony, tin, thallium, uranium and vanadium concentrations should be evaluated, since CWQG and/or alternative aquatic toxicity benchmarks are available for these substances to serve as the basis for comparison. Predictions should be developed for any substances that have the potential to exceed such benchmarks in surface waters in the future.

Therefore, the parameters presently recommended for inclusion in the LTMP are arsenic, cadmium, conductivity, copper, hardness, iron, lead, manganese, sulphate, uranium, and zinc. This recommendation should be re-visited at the conclusion of the IAEMP, based on an evaluation of data collected since March 2007, as such data will reflect improved MDLs, increased sampling frequencies at some stations, and more reference stations. It is

Table 3.2: Future concentrations predicted by SRK (in Senes 2006) for different Faro Mine complex closure scenarios [d].

Parameter	Units	Water Quality Criteria[e]	No Intervention				Remediation				Treat All Flows	
			Future 1 [f]		Future 2 [g]		Future 2 [g]		Future 3 [h]		Future 3 [h]	
			Rose	Vangorda	Rose	Vangorda	Rose	Vangorda	Rose	Vangorda	Rose	Vangorda
Aluminum	mg/L	0.1[a]	3.08	0.36	23.3	7.36	0.09	0.08	0.43	0.08	0.07	0.08
Arsenic	mg/L	0.005	0.039	0.017	0.726	0.017	0.004	0.005	0.022	0.005	0.003	0.004
Cadmium	mg/L	0.000047[b]	0.0224	0.0300	0.2220	0.1900	0.0029	0.0030	0.0070	0.0040	0.0028	0.0030
Cobalt	mg/L	0.004[c]	0.0284	0.0900	0.3058	0.5370	0.0033	0.0030	0.0083	0.0060	0.0030	0.0030
Copper	mg/L	0.003[b]	0.873	0.221	7.69	3.88	0.019	0.004	0.133	0.019	0.005	0.016
Iron	mg/L	0.3	48.0	5.7	371	67.7	1.0	0.2	4.9	0.4	0.3	0.2
Lead	mg/L	0.004[b]	0.012	0.023	0.075	0.069	0.141	0.015	0.015	0.015	0.014	0.015
Manganese	mg/L	1.27[b,c]	1.15	8.13	23.65	58.48	0.06	0.03	0.68	0.28	0.03	0.03
Nickel	mg/L	0.110[b]	0.027	0.134	0.242	0.514	0.014	0.016	0.017	0.019	0.014	0.016
Silver	mg/L	0.0001	0.0015	0.0010	0.0100	0.0010	0.0001	0.0003	0.0002	0.0003	0.0001	0.0002
Sulphate	mg/L	50[c]	184	293	1,280	955	151	14.3	486	17.8	1,160	727
Zinc	mg/L	0.03	15.7	24.040	165	158	0.445	0.052	4.92	0.727	0.042	0.040

[a] for pH >6.5

[b] based on hardness of 150 mg/L

[c] BCMOE guideline, 30-day average concentration

[d] Each value for Rose Creek is the maximum concentration predicted for any month at either X2 or X14 under each scenario. Each value for Vangorda Creek is the maximum predicted concentration for any month at either V27 or V8 under each scenario.

[e] Canadian water quality guideline unless indicated otherwise (footnote c)

[f] Future 1 - no treatment of metal releases

[g] Future 2 - partial collection of metal releases (surface runoff and groundwater)

[h] Future 3 - maximum possible metal releases

Table 3.3: Factors (rounded to whole numbers) by which predicted receiving water concentrations are expected to exceed water quality criteria. Shading indicates predicted concentrations will be more than 10 times higher than the respective criterion.

Parameter	Units	Water Quality Criteria[d]	No Intervention				Remediation				Treat All Flows	
			Future 1 [e]		Future 2 [f]		Future 2 [f]		Future 3 [g]		Future 3 [g]	
			Rose	Vangorda	Rose	Vangorda	Rose	Vangorda	Rose	Vangorda	Rose	Vangorda
Aluminum	mg/L	0.1[a]	31	4	233	74	1	1	4	1	1	1
Arsenic	mg/L	0.005	8	3	145	3	1	1	4	1	1	1
Cadmium	mg/L	0.000047[b]	477	638	4723	4043	62	64	149	85	60	64
Cobalt	mg/L	0.004[c]	7	23	76	134	1	1	2	2	1	1
Copper	mg/L	0.003[b]	291	74	2562	1293	6	1	44	6	2	5
Iron	mg/L	0.3	160	19	1238	226	3	1	16	1	1	1
Lead	mg/L	0.004[b]	3	6	19	17	35	4	4	4	4	4
Manganese	mg/L	1.27[b,c]	1	4	11	27	0	0	0	0	0	0
Nickel	mg/L	0.110[b]	0	1	2	5	0	0	0	0	0	0
Silver	mg/L	0.0001	15	10	100	10	1	3	2	3	1	2
Sulphate	mg/L	50[c]	4	6	26	19	3	0	10	0	23	15
Zinc	mg/L	0.03	524	801	5487	5267	15	2	164	24	1	1

[a] for pH >6.5

[b] based on hardness of 150 mg/L

[c] BCMOE guideline, 30-day average concentration

[d] Canadian water quality guideline unless indicated otherwise (footnote c)

[e] Future 1 - no treatment of metal releases

[f] Future 2 - partial collection of metal releases (surface runoff and groundwater)

[g] Future 3 - maximum possible metal releases

anticipated that water quality predictions may be updated based on the same data and based on evolving plans for mine closure, and that these may also influence final selection of water quality monitoring parameters.

3.5.2 Flow

Seasonal and annual discharges (flows) vary widely in the creeks downstream of the Faro complex in response to weather (frozen versus flowing) and precipitation events (SRK 2006). This affects the concentrations of mine-related contaminants, which also show wide variation within and among years at any given station. Measurement of flows will be particularly important at perimeter stations (where contaminants leave the mine sites) since they can be used, along with synoptically measured contaminant concentrations, to calculate and track contaminant loadings to surface waters downstream of the mines. However, in aquatic receiving environments, concentrations are more relevant than loads in terms of evaluating potential effects on aquatic biota. Since surface water concentrations will be part of routine monitoring, there is limited need for flow monitoring at surface water stations over the long-term. In the short-term, flow monitoring is important for characterization of seasonal and annual variability, which is, in turn, used to estimate future water quality under different flow scenarios. Limited long-term flow monitoring will be required to track any changes in flow regimes that may occur over time as a result of climate change. For example, a trend toward reduction in flow due to reduced annual precipitation may cause both loadings and receiving environment concentrations to differ from predictions. Continuous flow monitoring is currently being undertaken at Rose Creek station X14 (a station to be included in the future perimeter monitoring program), as well as at Vangorda Creek station V8 (a surface water station). It would be reasonable to continue to monitor flow at these locations to identify general trends over time for the two systems. Future flow monitoring is not recommended as part of the LTMP for other surface water stations, unless required to satisfy other components of the LTMP (e.g., source area and/or perimeter monitoring).

3.6 Sampling Frequency

Water quality monitoring at surface water stations has been conducted at varying frequencies, ranging from monthly to once annually, and not always at a consistent frequency over time. In order to determine what minimum frequency would be adequate at each station, key locations have to have been sampled often enough to fully characterize the variability of conditions at that station within and among years. Therefore, monthly sampling frequencies are strongly recommended for surface water quality stations during the IAEMP (Table 3.4). The data will be used to develop a model of seasonal water quality variance

Table 3.4: Summary of recommended changes to surface water sampling frequencies at Faro during IMP.

Water Body	Database Station ID	Station Description	License Require-ment	Frequency Stipulated in Licence	Recommended Frequency	Historical Monitoring (start, frequency)
Faro Creek Area	FC	Faro Creek above diversion channel	-	-	Monthly	88 to '96, 0-15 times per year
	FAROCR	Faro Cr. Diversion u/s confluence with North Fork Rose Cr.	✓	Monthly	Monthly	Since '93, 2 - 3 times per year
North Fork Rose Creek	R7	N Fork of Rose Creek above Faro Ck Diversion	✓	Monthly	Monthly	Since '89, 2 - 18 times per year (93,94 missing)
	R8	N Fork of Rose Creek 900 m below Faro Ck Div.	✓	Monthly	Monthly	Since '92, 3 - 17 times per year (93, 94 missing)
	NF2	North Fork Rose Creek Site 2 d/s of Haul Road	✓	Spring / Fall	Monthly	Since '89, 1 - 3 times per year (92-94 missing)
	X2	N Fork of Rose Creek u/s of mine access road	✓	Monthly	Monthly	Since '87, 10 - 22 times per year
Guardhouse Creek and North Wall Interceptor	W10	Upper Guardhouse Ck u/s of NW Dump	✓	Spring / Fall	Monthly	Since '95, 1 - 2 times per year
South Fork Rose Creek and Tailings Diversion	Grum Corner/GCULV	Grum Culvert-Ross River resident usage	✓	Monthly	Monthly	Since '03, 3-11 times per year
	K8	Ross River resident usage	✓	Monthly	Monthly	Since '03, 3 - 11 times per year
	R1	Rose Creek upstream of Pumphouse Pond	✓	Winter / Summer	Monthly	96, '98, '00, '04 - '06, 2 - 7 times per year
	X10	Rose Creek Diversion Channel below weirs			Monthly	Since '87, 3 - 42 times per year
Rose Creek Downstream of Mine	X14	Rose Creek downstream of the diversion channel	✓	Weekly when discharging	Monthly	Since '75, 0-37 times per year
	R3	Rose Creek between R2 and R4	✓	Winter / Summer	Monthly	96, '98, '00, '04 - '06, 2 - 6 times per year
	R4	Rose Creek upstream of Anvil Creek	✓	Winter / Summer	Monthly	Since '90, 1 - 6 times per year (intermitent)
Anvil Creek	R6	Anvil Creek upstream of Rose Creek	✓	Winter / Summer	Monthly	Since '90, 1 - 6 times per year (intermitent)
	A1 (Anvil Creek)	Anvil Creek upstream of Pelly River	✓		Monthly	Since '04 as R11
Pelly River	P1	Pelly River upstream of Vangorda site			Monthly	no data (new)
	P2	Pelly River d/s of Vangorda site			Monthly	no data (new)
	P3	Pelly River u/s of Anvil Creek			Monthly	no data (new)
	P4	Pelly River d/s of Anvil Creek			Monthly	no data (new)
Vangorda Creek	V1	Vangorda Creek, u/s mine and Blind Cr. Rd.	✓	Quarterly	Monthly	Since '88, 1 - 10 times per year
	V27	Vangorda Creek, just upstr. of Shrimp	✓	Spring / Summer / Fall	Monthly	Since '91, 2 - 10 times per year
	V4	Shrimp Creek, u/s Vangorda Creek confluence	✓	Spring / Summer / Fall	Monthly	Since '88, 1 - 10 times per year ('90, '92, '93 missing)
	VR	West Fork of Vangorda Creek u/s Haul Road			Monthly	no data (new)
	V6A	AEX Creek	✓	Quarterly	Monthly	Since '89, 1 - 17 times per year
	V5	West Fork of Vangorda Creek at gravel pit	✓	Monthly	Monthly	Since '88, 1 - 26 times per year
	V8	Lower Vangorda Creek at the footbridge	✓	Monthly	Monthly	Since '88, 1 - 28 times per year

based on recent monthly data and comparison to historical data (during IAEMP). Seasonal variance will also be compared to year-to-year and spatial variance to determine the monitoring frequency necessary to adequately characterize conditions at each station. The minimum sampling frequency and recommended timing of sampling will be identified for each station by showing that the resulting data will be adequate to reflect a similar mean and range as found for the greater sampling frequency. This information will be used recommend water sampling frequencies for the LTMP.

3.7 Data Analysis and Reporting

Water quality data should be analyzed by comparing concentrations in mine-exposed areas to both background concentrations (background benchmarks; Minnow 2007) and CWQG (or site-specific water quality objectives [SSWQO], if any are developed for the Faro complex). Background benchmarks computed by Minnow (2007) should be updated at the conclusion of the IAEMP by incorporating all new reference station data. Concentrations of the recommended parameters (Section 3.5) measured in water samples collected at mine-exposed stations should be compared to the updated background benchmarks, as well as CWQG (or SSWQO), taking into account both the frequency and magnitude of samples exceeding these values at each station. This analysis will be used to re-evaluate the magnitude and spatial extent of mine-related influence on water quality to make a final selection of water quality monitoring station locations, monitoring parameters and sampling frequency for the LTMP.

As described in Sections 2.2 and 8.0, water data should be presented in annual water quality reports and in the comprehensive study reports to be completed every 5 years.

3.8 Summary

Existing water quality data are inadequate to determine the optimum design for long-term water quality monitoring data at the Faro complex. Additional data should be collected in 2007-2009 (IAEMP) to collect the data necessary to rationalize a streamlined and effective long-term monitoring progam (LTMP). Changes to the water quality monitoring that are recommended for the IAEMP include:

- eliminate surface water monitoring stations that are not required by licence and do not meet specified criteria;
- increase the number of reference stations to develop or update background benchmarks;

- increase sampling frequencies to monthly to generate enough data to permit characterization of seasonal variability and allow the optimum frequency and timing of water sample collection for the LTMP to be determined;
- evaluate the potential for concentrations of antimony, boron, beryllium, chromium, mercury, molybdenum, selenium, tin, thallium, uranium, or vanadium to exceed Canadian water quality guidelines (CWQG), or alternative toxicity-based benchmarks, in surface waters in the future; and
- ensure laboratory method detection limits are sufficiently low to permit meaningful comparisons to CWQG.

The data will be evaluated at the conclusion of the IAEMP to determine the monitoring stations, parameters and sampling frequencies that should be incorporated into the LTMP.

4.0 SEDIMENT MONITORING

4.1 Current Conditions

Sediment quality sampling has been conducted in the Rose-Anvil and Vangorda Creek systems since as early as 1973 and 1991, respectively, and the results were recently summarized by Minnow (2007). Some study-to-study variability has occurred in terms of precise sampling station locations, laboratory equipment/techniques as well as the metal parameters reported. However, in general, the sediment chemistry results were reasonably comparable among studies. Typically fine-grained sediment samples were collected in triplicate from streambed deposits using a trowel or shovel, then placed into glass jars, refrigerated and shipped to a preferred laboratory for analysis of metal content. Metals analyses were usually performed on the fraction of sediment samples that passed through a 100 mesh sieve (0.15 mm). Therefore, the results reflect a standardized size fraction of sediment particles, but do not necessarily correspond to bulk sediment concentrations.

Studies showed that metal concentrations associated with fine sediments were significantly elevated in Rose Creek relative to background benchmarks (e.g., arsenic, cobalt, copper, iron, lead, manganese, mercury, nickel zinc) with elevations of some metals such as manganese, lead, and zinc levels extending further downstream into Anvil Creek (i.e., Stations A4 and A3; Minnow 2007). Arsenic, lead, and zinc were observed at concentrations above Canadian Sediment Quality Guideline (CSQG) Probable Effect Levels (PEL), suggesting some potential to adversely affect aquatic life, although such concentrations pertain to the fine fraction of sediments only and would thus overestimate whole sediment concentrations. These three metals, plus manganese, which was also elevated in downstream sediments, can be considered the mostly strongly indicative of Faro mine influence on sediment chemistry (i.e., “mine indicators”). There was no evidence of substantial tailings remnants in the channels of Rose or Anvil Creeks associated with a winter (over-ice) tailings spill which occurred in 1975, although deposits are still evident in the floodplain. Sediment metal concentrations in North Fork Rose Creek were also significantly higher at mine-influenced station R8 relative to the upstream reference station R7, although sediment metal levels at R8 were within reference benchmarks levels suggesting only a minor mine-effect. Although temporal comparison of the Rose-Anvil historical sediment chemistry data may have been confounded by differences in laboratory equipment/techniques from study to study, the data suggested that sediment metal concentrations in the Rose-Anvil system have decreased slightly over the period from 1973 to 2006.

In the Vangorda Creek system, sediment metal concentrations were significantly elevated at Station V27 the nearest downstream station to the Grum and Vangorda mines. Statistical evaluation of the historical data identified that the key indicators of mine influence on sediment chemistry were arsenic, lead, and zinc, which were the only metals observed at concentrations above CSQG PEL. Sediment chemistry differed between West Fork/lower Vangorda Creek versus upper Vangorda Creek, possibly reflecting natural variability in the various drainages or other upstream mine influences on the West Fork (roads, waste rock drainage). High natural variability in sediment chemistry was also observed among reference areas in the Rose-Anvil system. In lower Vangorda Creek (V8), sediment metal concentrations were intermediate between the West Fork and upper Vangorda Creek watercourses. Sediment lead and zinc concentrations, likely originating from upper Vangorda Creek, were elevated relative to reference, whereas calcium and strontium, likely originating from the West Fork, were also elevated. Of these, only sediment lead concentrations exceeded the PEL at V8. Temporal comparison of Vangorda sediment data suggested substantially lower metal concentrations at the near-field (V27) location in 2005, whereas metal concentrations at the West Fork and lower Vangorda showed slower temporal decreases.

4.2 Considerations for Future Monitoring

Mine-related metals accumulate in bedload sediments when metals transported in the water column adsorb onto fine particulate materials and eventually settle to the bottom (Ongley 1996, McKay et al. 2001, DiToro et al. 2005). This is more apt to occur in slow-flowing or still aquatic environments, particularly those with substantial concentrations of suspended particles, than in fast-flowing environments. At Faro, aquatic receiving environments are typically moderate to swiftly flowing, with low concentrations of total suspended solids (<5 mg/L) except during high flow events (e.g., heavy melt and/or rain events such as spring freshet conditions) when flow conditions are particularly conducive to scour rather deposition. Therefore, accumulation of fine particles in bedload sediments is limited. As a result, the substrates of aquatic receiving environments near the Faro complex are generally coarse (sand, gravel, rocks) with limited, patchy deposits of finer particulates (e.g., fine sand, silt, clay). Consequently, benthic invertebrate communities are probably primarily exposed to mine-related substances via water than sediment-detrital pathways.

Even within deposits of finer particulates, there are large spatial variations in particle size distributions, ranging from pebble-granular to silt dominance (Hoos and Holman 1973, Godin and Osler 1985). As noted above, to control for differences in particle sizes among samples, sediment analyses conducted after 1973 measured the metal content in only the fine fraction

(<0.15 mm) of each sediment sample. Even though samples of sediment downstream of the mines showed elevated concentrations of mine-related substances (arsenic, lead, manganese, zinc) the effect of such deposits on the ecology of the erosional habitats of the Rose/Anvil, Vangorda and Pelly River systems depends on the following:

1) Are sediments with elevated metal concentrations in the <0.15mm fraction toxic to biota?

2) What are the metal concentrations in bulk sediments?

3) What proportion of depositional sediments is typically comprised of the <0.15 mm fraction?

4) If depositional sediments are found to be toxic (e.g., through toxicity testing described below), what proportion of the total substrate area do the depositional patches represent and/or are such depositional areas critical for sustaining life-cycles of valued resources (e.g., fish)?

If the sediments are found to be non-toxic, then the LTMP will not recommend inclusion of sediment monitoring. That is because the information to be gained in the LTMP would not be commensurate with the added cost of sample collection, sample and data analysis, and data reporting. The potential need for collection of sediment samples should be re-evaluated in the future if effluent loadings substantially increase, and or flow regimes change (less flow), such that increased metal deposition becomes a concern.

If the sediments prove to be toxic, it would be appropriate to initiate a study to determine how representative such substrate is as a proportion of the total substrate area downstream of mines and/or with respect to critical habitat requirements of biota (e.g., resident fish spawning, rearing, nursery or feeding). If toxic sediments are found to be widely distributed and/or important for sustainability of fisheries, sediment monitoring should be continued in the LTMP and specific requirements will be outlined at the conclusion of the IAEMP.

If sediment deposits containing elevated metals are not toxic or are not large enough or important enough to affect the sustainability of fisheries, then the costs associated with repeated future monitoring of sediments are not likely justifiable. Therefore, it is recommended that additional study be undertaken during the IAEMP to address the questions listed above. Details of such monitoring are outlined in Sections 4.3 to 4.6.

4.3 Sampling Locations

It is recommended that sediment samples be collected in areas previously shown to contain elevated metal concentrations (e.g., R2, V27 to represent "worst-case" conditions). It is recommended that three samples be collected in each exposure area (geographically separated to represent different stations rather than replicates within stations), plus at two reference areas, for a total of 12 samples. Replication within areas will assist in characterizing spatial variability.

4.4 Sampling Methods

It is generally desirable to collect sediment samples from a standardized depth, with analyses typically focused on the top sediment layers (e.g., 1-3 cm) to reflect recent conditions rather than historical deposits (ESG 1999). This usually necessitates the use of a corer or grab sampler (e.g., Ponar or Ekman; Environment Canada 1994). Such devices assist in preserving the natural integrity of the sample (and thus chemical composition), although some level of disruption is unavoidable (Environment Canada 1994). At Faro, previous studies have involved collection of fine-grained sediment samples using a trowel or shovel, perhaps because corers and grab samplers have proven to be ineffective for collection of (the relatively coarse) sediments present in the Rose/Anvil and Vangorda systems. However, this method likely results in the loss of some of the fine sediment as the sample is collected (i.e., due to downstream drift). Therefore, potential use of core or grab samplers should be investigated in the IAEMP. If it is found that samples cannot be consistently collected using one of these devices, trowels should again be used.

Ideally, the collected sample at a station should be homogenized and then divided such that a portion is allocated for chemical analyses and the other portion is used for laboratory toxicity testing (described below). Toxicity tests will determine if the observed concentrations are toxic and potentially having localized impacts. The subsample collected for chemical analysis should be further divided to allow for chemical characterization of both the whole (bulk) sediment and the <0.15mm fraction. However, the large volume of sample required for all the analyses precludes collection solely via retention of the surface layer of core samples (i.e., too many core samples would need to be collected). Therefore, alternative methods are described in Section 4.5 in association with the various analyses to be conducted.

Polyethylene jars (or strong polyethylene bags) should be used for storing and shipping samples (no air headspace); glass should be avoided due to the potential for breakage during transport (Environment Canada 1994). Samples should be stored at around 4°C after collection, to minimize on-going chemical changes (Environment Canada 1994).

4.5 Sediment Quality Parameters

As noted in Section 4.4, sediment samples collected during the IAEMP will be used for chemical analyses and toxicity testing. The analyses should include particle size distribution (whole sediment) and total organic carbon (TOC) and metal content (separate analyses of the whole sediment and the <0.15mm fraction). Metals to be analyzed should include arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc. Samples to be analyzed for metal content should be collected by coring, if possible based on sediment texture, to achieve precise standardization of sample depth among stations and thus facilitate comparisons among stations and relative to sediment quality guidelines. If substrate characteristics preclude the use of a corer, samples to be chemically analyzed should be collected using a grab (e.g., Ponar or Ekman) from which the top 3 cm should be retained for analyses. Multiple grabs may be required to provide sufficient sample volume, in which case the surface layers from all grabs should be homogenized prior to allocation among sample containers (e.g., typically separate containers for analysis of TOC and metals versus particle size). Samples to be collected for toxicity tests should also be taken using a grab sampler, if possible. If neither corers nor grab samplers can be effectively deployed, samples should be collected using a trowel. Once the best sampling method has been determined, the same method should be used at all stations.

Toxicity testing should be performed on whole sediment samples and conducted as soon possible after collection to minimize chemical changes (e.g., metal speciation) that can occur between sampe collection and analysis (Environment Canada 1994). Environment Canada has established sediment toxicity test methods for two genera of benthic invertebrates: *Hyallela azteca* and *Chironomus riparius/tentans* (Environment Canada 1997a,b). These species tend to prefer slow-flowing or stagnant water with soft substrate and sufficient algae or decaying vegetation to provide food (Environment Canada 1997a,b). Therefore, it is not surprising that they have not been reported in benthic samples collected at Faro (Minnow 2007). However, all three species, particularly *Hyallela azteca* and *Chironomus riparius* are tolerant of a wide range of substrate particle sizes and sediment TOC content (Environment Canada 1997a,b) and thus could likely withstand exposure to the relatively coarse sediments at Faro. Of the three species, *Hyallela* appears to be slightly more sensitive (ESG 1999; Environment Canada 1997a) and is thus is recommended for the toxicity testing described above.

4.6 Sample Timing/Schedule

Samples should be collected in the late summer when water flows are apt to be low, enhancing accessibility to pools where fine sediments may accumulate (i.e., by wading). This timing is consistent with the proposed collection of benthic invertebrates. Samples should be collected in the first or second year of the IAEMP if possible, to allow for follow up activities in the subsequent year, if required (i.e., possible characterization of the ecological importance of fine sediment deposits if samples prove to be toxic).

4.7 Data Analysis and Reporting

Sediment chemistry measured at mine-exposed areas should be compared to background benchmarks and Canadian Sediment Quality Guidelines for both whole (bulk) and fine (<0.15mm) sediment samples. Toxicity test data will show if metal concentrations observed in the fine and bulk sediment samples are toxic. If toxic, comparison of toxicity test results to sediment chemistry for different samples may identify causal relationships. All data should be presented in the interpretive report to be completed at the conclusion of the IAEMP along with recommendations regarding potential future sediment sampling in the LTMP.

4.8 Summary

The substrates of aquatic receiving environments near the Faro complex are generally coarse (sand, gravel, rocks) with limited, patchy deposits of finer particulates (e.g., fine sand, silt, clay). To date, sediment chemistry has usually involved analysis of metal content in the fine fraction (<0.15mm) of sediment sample collected from fine-particle deposits. While elevated metals (e.g., arsenic, lead, zinc) have been observed in fines at stations downstream of the Faro and Vangorda sites, it is not known: a) what proportion of whole (bulk) sediments the fines represent, b) what concentrations of metals are present in whole sediment samples, c) what proportion of total substrate area the deposits of fine sediments represent, nor d) if the sediments showing elevated metal concentrations are toxic to biota. Therefore, additional sediment characterization is recommended as part of the IAEMP, including analysis of particle size, metal content, and toxicity of whole sediments along with analysis of metal content in the fine fraction (0.15mm). Sediment samples should be collected for such analyses in the first year of the IAEMP to allow for possible follow-up activities in the second year, if required (e.g., possible characterization of the ecological importance of fine sediment deposits, if such deposits are found to be toxic in laboratory testing). The results of sediment characterization completed during the IAEMP will determine if sediment analyses should be continued as part of the LTMP, and, if continued, what type of analyses should be included.

5.0 BENTHIC INVERTEBRATE COMMUNITY MONITORING

5.1 Current Conditions

Numerous benthic invertebrate surveys have been conducted in the Rose/Anvil watershed during the past three decades (Minnow 2007). From 1991 on, benthic invertebrate population monitoring has been conducted annually at standardized station locations (alternating between Rose and Vangorda Creeks) as per the requirements of the Water Licence. Artificial substrates were used for the majority of studies, providing some consistency across much of the data set, although sample/data analysis varied in terms of factors such as numbers of replicate samples and levels of taxonomic identifications (Minnow 2007).

Many historical studies concluded that the Faro site has impacted benthic invertebrate communities as far downstream as the Anvil Creek confluence (Minnow 2007). Detailed analysis of data from even years between 2000 and 2006 confirmed that benthic invertebrate communities downstream of the Faro site (e.g., R2-R4) were somewhat different from upstream reference communities (e.g., R6, R7, R1; Minnow 2007). However, such differences were not those typically associated with effluent impacts. For example, higher percentages of mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera; collectively referred to as EPT), which are often considered sensitive to pollution, were present downstream of the Faro site than at reference areas. Temporal changes appear to have played as large a role as relative station location in structuring benthic communities in Rose Creek, at least in recent years (Minnow 2007).

Detailed analysis of data from 2001, 2003 and 2005 surveys at the Grum/Vangorda site also revealed significant differences in benthic community composition between the reference station V1 and the exposure station V27, which are located in Vangorda Creek immediately upstream and downstream of the site, respectively. However, the nature of such differences may be attributable to habitat differences (e.g., stream order, water velocity) rather than mine-related effects, based on a higher proportion of EPT taxa at near-field exposure station V27 than at reference station V1. Highest numbers of taxa were found at stations V5 and V8 in West Vangorda Creek compared to V1 and V27, and some differences in community composition were also evident between these two groups of stations, although the difference did not appear to be mine-related. These and previous surveys have shown that mean benthic invertebrate abundance and taxon richness varies considerably among both stations and years.

Overall, mine-related influences on benthic invertebrate communities, if any, appear to be minor at the present time.

5.2 Considerations for Future Monitoring

Benthic invertebrates are excellent biomonitors for assessing potential effects of the chemical condition of water and sediment on the health of the aquatic system. Specific advantages of benthic invertebrate community monitoring include (Barbour et al. 1999, Feltmate and Fraser 1999):

- Macroinvertebrate assemblages are good indicators of localized conditions. Because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particularly well-suited for assessing site-specific impacts (upstream-downstream studies).
- Macroinvertebrates integrate the effects of short-term environmental variations. Most species have a complex life cycle of approximately one year or more. Sensitive life stages will respond quickly to stress; the overall community will respond more slowly.
- Macroinvertebrate surveys measure the community level of organization and provide numerous useful endpoints.
- Degraded conditions can often be detected by an experienced biologist with only a cursory examination of the benthic macroinvertebrate assemblage. Macro-invertebrates are relatively easy to identify to family; many taxa can be identified to lower taxonomic levels with ease.
- Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects.
- Sampling is relatively easy, requires few people and inexpensive gear, and has minimal detrimental effect on the resident biota.
- Benthic macroinvertebrates serve as a primary food source for fish, including many recreationally and commercially important species.
- Benthic macroinvertebrates are abundant in most streams. Many small streams (1st and 2nd order), which naturally support a diverse macroinvertebrate fauna, only support a limited fish fauna.

Consequently, benthic invertebrate community assessment allows for the tracking of potential effects or improvements among areas and over time through assessment of community structure and taxa specific indices. For these reasons, the assessment of benthic invertebrate communities health downstream of the Faro complex will be an important component of the LTMP.

Several studies were conducted in the mid-1990s to evaluate the best approaches for assessing mine-related impacts on benthic invertebrate communities in Canada (summarized by ESG 1999). Conclusions included those listed below:

- Rapid bioassessment procedures (e.g., Barbour et al. 1999) were not recommended because they typically employ low-rigour sampling methodologies (e.g., sampling areas of undefined size such as by kick-sweep methodology which precludes density estimates, coarse mesh for retaining organisms, field identifications to coarse taxonomic levels, and minimal within-area replication). Rapid bioassessment procedures are generally too insensitive to be useful in most routine monitoring (Taylor 1997).
- Taxonomic identifications should be done to lowest practical level (ESG 1999, Beak 1999, Taylor 1997).
- Artificial substrates are generally unnecessary in shallow streams and rivers with cobble or gravel substrate since it is easy to obtain natural substrates in such habitats (Golder 1995, ESG 1999).
- The use of hypothesis testing procedures (analysis of variance) is preferred for establishing the likelihood that an effect has occurred (ESG 1999).
- A variety of endpoints should be used to describe community health and used together in a weight of evidence approach to conclude if mine-related effects are occurring (ESG 1999).

These and other points are considered in more detail in the following sections of the report in the context of recommendations for long-term monitoring at the Faro complex.

5.3 Sampling Methods

Benthic invertebrate community monitoring at Faro has predominantly employed the use of artificial substrates. There are both advantages and disadvantages associated with this type of approach relative to the use of natural substrates (Cairns 1982, Golder 1995, ESG 1999):

5.3.1 Advantages of Artificial Substrates:

- Artificial substrates allow sample collection in locations that are typically difficult to sample effectively (e.g., bedrock, boulder, or shifting substrates; deep or high velocity water).
- As a "passive" sample collection device, artificial substrates permit standardized sampling by eliminating subjectivity in sample collection technique. Direct sampling of natural substrate requires similar effort and degree of efficiency for the collection of each sample. Use of artificial substrates requires standardization of setting and retrieval; however, natural colonization provides the actual sampling mechanism.
- Confounding effects of habitat differences are minimized by providing a standardized microhabitat. (But a corresponding and potentially significant disadvantage is that microhabitat standardization may promote selectivity for specific organisms if the artificial substrate provides a different microhabitat than that naturally available at a site as noted under “Disadvantages”, below). This could be advantageous if a study is designed to isolate water quality effects from substrate and other microhabitat effects. Where habitat quality is a limiting factor, artificial substrates could be used to discriminate between physical and chemical effects and assess a site's potential to support aquatic life on the basis of water quality alone.
- Sampling variability is decreased due to a reduction in microhabitat patchiness, improving the potential for spatial and temporal similarity among samples.

5.3.2 Disadvantages of Artificial Substrates:

- Samples may not be fully representative of the benthic assemblage at a station if the artificial substrate offers different microhabitats than those available in the natural substrate. Artificial substrates often selectively sample certain taxa (e.g., those that happen to drift during the substrate deployment period), misrepresenting relative abundances of these taxa in the natural substrate. Artificial substrate samples would thus indicate colonization potential rather than the resident community structure. Most artificial substrates, by design, select for the Scraper and Filterer components of the benthic assemblages or for Collectors if accumulation of debris has occured in/on the substrates.
- They reflect short-term conditions rather than integrate long-term conditions.

- Sampler loss or perturbation commonly occurs due to sedimentation, extremely high or low flows, or vandalism during the relatively long (at least several weeks) exposure period required for colonization.
- Depending on the configuration of the artificial substrate used, transport and storage can be difficult. The number of artificial substrate samplers required for sample collection increases such inconvenience.
- Two trips (one to set and one to retrieve) are required for each artificial substrate sample; only one trip is necessary for direct sampling of the natural substrate. Artificial substrates require a long (6- to 8-week average) exposure period for colonization.

5.3.3 Proposed Approach for Monitoring at Faro

Although past benthic community assessments have primarily used artificial substrates and have been conducted with a high level of consistency from year to year, current opinion in the Canadian scientific community indicates a preference for natural substrate surveys. For example, current technical guidance for national monitoring programs stipulates that artificial substrates should be used only in situations where it has been shown that suitable natural substrates are not present or other viable alternatives are unavailable (Environment Canada 2002). Also, as noted above, artificial substrates are generally considered unnecessary in shallow streams and rivers with cobble or gravel substrate since it is easy to obtain samples of resident communities in such habitats (Golder 1995, ESG 1999). However, no studies have been conducted to date to compare the relative utility of artificial substrates versus natural substrate sampling for benthic community assessment at Faro. To determine the best approach for the LTMP, it is recommended that samples be collected using both approaches as part of the IAEMP. This should involve sampling of natural substrates using an appropriate samping device (e.g., Hess, or Surber) at the same time that artificial substrates are retrieved as part of the on-going monitoring under the site Water Licence. Detailed methods for sample collection are outlined in Appendix B, Section B.3.0; these should be used as the basis for developing SOPs for the LTMP (Section 7.1). Details regarding recommended sampling locations and timing for the IAEMP are presented in the following sections.

5.4 Sampling Design (Locations)

Bowman and Somers (2005) recently expanded a “decision key” previously developed by Green (1979) for selecting the appropriate sampling design in environmental studies. A

before-after control-impact (BACI) design (Green 1979, Bernstein and Zalinski 1983, Smith et al. 1983, Stewart-Oaten et al. 1986, Underwood 1991, 1992, 1994, Underwood and Chapman 2003) is generally considered to be the optimal sampling design for situations where an impact has yet to occur, the general location of future impact is known, and one or more appropriate control (reference) areas can be found (Bowman and Somers 2005). In this design, the impacted sites (I) are compared with unaffected control sites (C) both before (B) and after (A) the impact has occurred. If an impact has already occurred (i.e., a "before" sample cannot be taken), but its location is known and a suitable reference area is available, a control-impact (CI) design can be followed. If control (C) and impacted (I) sites differ with regard to the environmental variable, the inference is that this difference is because of the human intervention. Clearly, this inference is valid only if control and impacted sites are identical in the absence of the impact source, an assumption that cannot be tested, because the "before" measurement is missing (Osenberg and Schmitt 1996). This issue is minimized in CI designs through selection of reference areas with habitat characteristics similar to the area(s) of suspected impact (e.g., gradient, substrate type, distance to source, depth, flow velocity), provided such habitats are available.

Alternative designs may be preferable when the criteria for a BACI, BA, or CI design, cannot be met. For example, a reference condition approach (RCA; Rosenburg et al. 1998, Reynoldson et al. 2005) can be used when the location or timing of an impact is not known (Bowman and Somers 2005). RCA involves characterization of a large number of reference areas and thus has the potential to better characterize the range of natural variability for a given habitat type. There are currently several programs in development across Canada (Rosenburg et al. 1998, Reynoldson et al. 1997, 2005; Sylvestre et al. 2005; Sarrazin-Delay et al. 2006), including the Yukon (Branton et al. 2006, Bailey et al. 2007), that are based on RCA, but these generally provide a broad-based assessment of locations across wide geographic areas and questions remain as to the suitability of such an approach for assessment of site-specific impacts within a regulatory framework (Minnow and Martin 2007).

Other sampling designs may be employed at sites where suitable reference areas are not available (Environment Canada 2002, Bowman and Somers 2005), but this limitation is not applicable at the Faro complex where there are numerous local streams that remain uninfluenced by mine-related activities; consequently such designs are not currently being contemplated for the LTMP at Faro.

Based on the above, it is recommended that benthic invertebrate sampling follow a CI design that compares community characteristics in mine-exposed areas to those in reference areas. Given that current impacts at Faro appear to be limited, but may increase in the future in

response to increased ARD and metal loadings, temporal comparisons will also be appropriate. The combination of spatial and temporal comparisons performed in consecutive studies will largely fit the criteria of the optimal BACI design described above, thus providing statistical robustness. For the IAEMP, sampling methods will include both artificial and natural substrate sample collection (Section 5.3), and a decision will be made regarding the preferred approach for the LTMP based on analysis of the data.

Recognizing that there are initiatives within the Yukon to assess regional samples following RCA (Branton et al. 2006, Bailey et al. 2007, Yukon Placer Aquatic Health Working Group 2007), it would be of interest to investigate the comparability of results using the two sampling designs (CI versus RCA) and the different sampling methods discussed above (artificial substrate versus natural substrate sampling). Therefore, it is recommended that investigators involved in the RCA program be invited to also collect samples during the IAEMP. All benthic invertebrate samples collected according to the different methodologies should be collected on similar dates and at the same locations to ensure direct comparability of results.

Since benthic invertebrate survey results will be used to measure the biological response to changes in chemical conditions downstream of the mines, benthic sampling stations should correspond with those used for water quality monitoring. This will allow for correlation of chemistry results with measures of benthic community structure. Stations that have been monitored for benthic invertebrate community health assessment under the current site Water License are R1 – R7, V1, V27, V5 and V8, which are also monitored for water quality. Therefore, these stations should continue to be sampled to assess benthic community health during the IAEMP. The utility of all station locations will be re-evaluated at the conclusion of the IAEMP.

Multiple stations will need to be sampled within each area to measure within-area variability and allow for statistical comparisons to be made among areas. In past studies at Faro, three stations (three artificial substrates) have typically been sampled per area. The optimum number of stations depends on the alpha (type I error) and beta (type II error) values used in statistical comparisons, the variability existing among stations, and the effect size one wishes to detect. The guidance for federal programs at mines operating under the MMER stipulates that alpha and beta levels should be equal and a minimum of 0.1 and that an effect of ±2 reference area standard deviations should be detectable (Environment Canada 2002). This necessitates a minimum of five stations per area. Therefore, a minimum of five artificial and five natural substrate sample stations should be targeted in each area during the IAEMP. The stations/substrates should be spaced sufficiently far apart (e.g, 3 bankfull widths) to be

considered stations within areas, rather than replicate samples within stations (Environment Canada 2002).

Generally, the cost efficiency of benthic invertebrate monitoring programs is dramatically improved by using samplers with small sample area and increasing the number of replicates per area (Taylor 1997). To maximize total sampling area, while also minimizing the time associated with sample collection and processing, it is recommended that three samples be collected at each station and combined to form a single composite sample for that station. With five stations per area, a total of 15 samples will be collected per area. This approach makes each sample more representative of conditions at each station relative to a single sample per station, while also reducing inter-station variability and the total number of samples to be analyzed.

The IAEMP benthic survey results will be evaluated prior to making recommendations regarding the number and location of stations that should be sampled in the LTMP.

As noted above, the success of sampling designs relying on spatial comparisons (reference versus impacted areas) is predicated on habitat comparability among areas. That is, the natural variability of habitat characteristics should be minimized among stations within and among areas so such differences do not mask or confound the detection of mine-related differences in benthic communities. It is not clear if the reference areas currently used in benthic community assessments represent optimal locations from this standpoint. Habitat descriptions reported in past studies are incomplete and/or contradictory for some locations. Combining information from various studies, it is apparent that there are substantial differences in characteristics such as channel width, gradient, stream morphology, and substrate type among areas (Table 5.1; photos in Appendix C). Therefore, another key component of the IAEMP will be the assessment of existing and potential reference areas.

Evaluation of candidate reference areas should include assessment of habitat features (e.g., depth, width, substrate type, gradient, flow velocity, distance to source, channel morphology, in-stream and riparian vegetation) at locations in the Rose and Vangorda watersheds upstream of any mine disturbances, as well as locations on other nearby watersheds possessing similar geology to that underlying the Faro complex. This should be done at the same time as benthic community sampling described for the IAEMP. Recognizing that exposure areas in the Rose/Anvil and Vangorda watershesds possess a range of habitat characteristics, a similar range of reference habitats will be sought. The goal will be to ensure that there are at least two comparable reference areas for every exposure area, while also trying to minimize the variability among exposure habitats sampled so as to minimize the total number of reference areas required (e.g., if suitably comparable habitat for sampling

Table 5.1: Habitat characteristics for surface water stations at Faro Mine Complex, Yukon.

Site	Station Type	Watershed	Station	Wetted Width (m)	Channel Width (m)	Mean Depth (m)	Velocity (m/s)	Discharge (m3/s)	Gradient (%)	Morphology			Substrate				Bank Cover / Overhead Canopy (%)	Instream Cover	References
										% Riffle	% Run	% Pool	% Boulder	% Cobble	% Gravel	% Fines (<2mm)			
Faro	Minimal Exposure	Rose Creek - South	**R1u/s**		7.1				3.5	80	0	20	70	20	10	0	boulder		Harder, 1991b
		Rose Creek - South	**R1**	4	4	0.3	1.5	0.671 (0.048 - 2.2)	1.5	65	25	10	70	20	5	5	10	boulders	Harder, 1991b, Burns, 1989b, Harder, 1993a, WMEC, 2005, GLL, 2002, Robertson, 1996
		Rose Creek - North	**R8**		7			0.96 (0.078 - 3.2)	1.4	20	20	60	40	30	10	20			Harder, 1991b, Harder, 1993a
	Exposure	Rose Creek	**R2**	8	14	0.6	0.8	2.31 (1.51 - 3.1)	0.5	30	40	30	0	30	50	20	undercut bank	woody debris.	Harder, 1991b, Burns, 1989b, WMEC, 2005
		Rose Creek	**R3**		7.8 (3.1 - 15)	0.3		4.28 (3.1 - 6.528)	1	30	40	20	0	0	80	20	undercut bank	debris	Harder, 1991b, Burns, 1989b
		Rose Creek	**R4**	16	20	0.3	>1	3.1 (0.26 - 11)	1.5	60	25	15	25	30	40	5	20	boulder pools	Harder, 1991b, Burns, 1991a, Burns, 1989b, Harder, 1993a, WMEC, 2005
		Anvil Creek	**R5**	8	35	0.18		5.37 (0.9 - 8.42)	1.5	70	20	10	10	60	10	20		cobble	Harder 1991b, Burns, 1991a
		Anvil Creek	**A4**	6.3	60	0.25			1	40	30	30	0	60	30	10	present	cobble	Harder, 1991b
		Anvil Creek	**A3**		60				0.7	40	30	30	0	60	30	10			Harder, 1991b
		Anvil Creek	**A2**	6.5 (2.7 - 10.2)	80	0.2			1.5	30	60	10	0	40	40	20		present	Harder, 1991b
		Anvil Creek	**A1/R11**		80			8.85 (0.72 - 30)	1.9	30	50	20	0	40	40	20			Harder 1991b, Harder 1993a
Vangorda	Minimal Exposure	Vangorda Creek - West	**V5**					0.22											GLL, 2002, Robertson, 1996
	Exposure	Vangorda Creek	**V27**		4			0.33	3.4				90		10	0			Harder, 1987, GLL, 2002, Robertson, 1996
		Vangorda Creek	**V8**	3.3	6	0.4	1.5	1.1 (0.75 - 2.13)	2.5	80	0	20	50	20	15	15	20	boulders, woody debris	Harder, 1992b, Harder 1987, Montreal, 1976, WMEC, 2005, GLL, 2002, Robertson, 1996
Reference		Blind Creek	**B1**	14	15.5	0.5	0.4	5.45 (4.5 - 6.45)	1.5	0	100	0	0	60	40	0	10	woody debirs	Harder, 1991c, WMEC, 2005
		Blind Creek	**B3**	3.8		0.3			0.5	20	40	40	0	0	90	10	Present	present	Harder, 1991c
		Blind Creek	**B4**	3.6		0.15			1	50	0	50	0	60	30	10	boulder	present	Harder, 1991c
		Blind Creek	**B5**	7.3		0.2			2	0	10	90	10	70	20	0	Present	cobble	Harder, 1991c
		Blind Creek Tributary	**BT1**	5.5		0.3			1-2	50	30	20	50	40	0	10	Present		Harder, 1991c
		Blind Creek	**B6**	7.4		0.3			1	30	20	30	0	60	30	10	Present	cobble	Harder, 1991c
		Anvil Creek	**R6**	14	15	0.4	1.5	3.04 (0.26 - 11)	1.5	60	20	20	55	20	10	15	<5	boulders	Harder, 1991b, Burns, 1991a, Harder, 1993a, WMEC, 2005
		Rose Creek - North	**R7**		12			0.96 (0.693 - 1.164)	2	30	40	20	10	60	10	20			Harder, 1991b, Burns, 1991a, GLL, 2002, Robertson, 1996
		Rose Creek - North	**R7u/s**		9	0.3			1.5	30	40	30	50	40	10	0	present	cobble	Harder, 1991b
		Rose Creek - North	**N6**		5.6	0.15			2.5	40	40	20					Present	cobble	Harder, 1991b
		Anvil Creek Tributary	**AT1**		5.25	0.2			1	10	10	80					present	present	Harder, 1991b
		Rose Creek South Tributary	**ST1**		1.8	0.25			3	90	0	10					present	boulder	Harder, 1991b
		Vangorda Creek	**V1**		8			0.23	4	90	0	10	70		10	20			Harder, 1987, GLL, 2002, Robertson, 1996
		Shrimp Creek	**V4**					0.082											GLL, 2002, Robertson, 1996

** bracketed values represent the range from which the mean value was calculated

could be found at all exposure areas, then only two reference areas would be required overall, although this is an unlikely example).

At the conclusion of the IAEMP, the data will be reviewed to identify the recommended reference and exposure areas for long-term monitoring.

5.5 Monitoring Endpoints

Ideally, the metrics selected to describe benthic invertebrate communities will be those that provide the most useful information and provide the greatest sensitivity with lowest cost (Taylor and Bailey 1977). Based on extensive reviews of the literature, organism density (or abundance if sampling methods do not allow for expression of abundance based on unit area or volume) and species richness were among the metrics recommended for federal monitoring programs under the federal MMER based on a long history of use and the conclusion that they are reasonably descriptive (ESG 1999). However, these metrics alone are often inadequate to detect mine-related effects, since more tolerant taxa may replace sensitive taxa such that an impacted area may still support similar numbers of individuals and taxa (ESG 1999). Therefore, other community descriptors and/or key indicator taxa also need to be assessed.

A similarity index (e.g., Bray-Curtis; Environment Canada 2002) is recommended because it summarizes the overall differences in composition, and requires no preconceived assumptions about the nature of the impact (Taylor 1997, ESG 1999). The Bray-Curtis index takes into account the abundance of each taxon at each station compared to the median abundance computed for the reference area(s) and identifies the relative “distance” of each station from the hypothetical median reference station. The distance co-efficient reaches a maximum value of 1 for areas that are entirely different and a minimum value of 0 for areas that are identical to the hypothetical median reference benthic invertebrate community.

An evenness index (e.g., Simpson’s; Environment Canada 2002) should also be included as a measure of how well individuals are distributed among the total number of sampled taxa. Simpson’s evenness values range from 0 to 1, with low evenness values indicating benthic communities dominated by few taxa, suggesting an impaired biological community.

The suite of metrics recommended above (organism density, number of taxa, the Bray-Curtis index and Simpson’s evenness index) is the same as that presently required for operating mines within Canada conducting environmental monitoring under the MMER (Environment Canada 2002). This indicates that these metrics have gained a level of acceptance among the Canadian scientific community.

Community structure can also be assessed by using a multivariate technique known as correspondence analysis (CA). CA is used to calculate synthetic axes, which can be thought of as new variables summarizing variation in the relative abundance of benthic taxa. When depicted in two-dimensional plots, taxa that tend to co-occur will have similar CA axis scores and will plot together, while those that rarely co-occur plot farther apart. Similarly, stations sharing many taxa plot closest to one another, while those with little in common plot farther apart. The greatest variation among either taxa or stations is explained by the first axis, with other axes accounting for progressively less variation. Therefore, this type of multivariate analysis differs from the metrics discussed above by describing not only which stations have distinct benthic communities but also how these benthic communities differ among stations (*i.e.*, which particular taxa differ). Therefore, it is recommended that an ordination technique such as CA also be used to describe benthic invertebrate communities at Faro.

Past studies at Faro have also reported proportions of dominant taxa (e.g., Burns 2000-2006), an approach that is considered reliable for assessing metal-related effects on benthic invertebrate communities (Taylor and Bailey 1997). It is recommended that the proportions of dominant taxa (e.g., two or three dominant orders, families or genera) also be compared among areas in future studies (IAEMP and LTMP).

5.6 Sample Timing/Schedule

For the IAEMP, it is recommended that benthic invertebrate samples be collected in late summer to be consistent with the timing of previous surveys. Artificial substrates have typically been retrieved at the end of August, which is the recommended timing for collection of parallel samples of resident benthic communities (and any samples that might be collected following RCA methodologies if researchers involved in the Yukon RCA initiatives elect to participate). Although the details regarding sampling design and methods for the LTMP will not be decided until the conclusion of the IAEMP, it is presently expected that samples collected for the LTMP will also be taken in late summer.

Benthic invertebrate data collection for the IAEMP will take place over 2-3 years, with samples being collected during the first two years according to the regularly scheduled monitoring for the Faro versus Grum/Vangorda sites (i.e., one site/year for two sequential years). Also, as noted in Section 5.4, habitat information will need to be collected at exposure areas and candidate reference areas in these years, or in a third year (depending on resource allocation relative to the overall schedule for closure plan finalization). This will complete the information collection associated with the IAEMP and the results of this monitoring will be considered in formuating recommendations for the LTMP.

5.7 Data Analysis and Reporting

While previous studies at Faro have sometimes pooled replicate sample data within areas, it is recommended that future studies report separate values for each station to allow for statistical comparisons among areas using analysis of variance (ANOVA).

The interpretive report should describe sampling methods, supporting field measurements (e.g., water temperature, pH, dissolved oxygen, conductivity), and laboratory processing of samples. Reported data should include the raw taxon abundances observed at each station, plus the values for each metric recommended in Section 5.5 (at each station), as well as the mean, sample size (n), standard deviation, standard error, and 95% confidence interval of each endpoint for each area. Reported ANOVA results should include statistical significance (p) values and power achieved, clearly indicating how the data were handled with respect to ANOVA assumptions related to normality and homogeneity of variance. The results of post-hoc comparisons should also be reported in the case of comparisons involving more than two areas.

5.8 Summary

Benthic invertebrates are good, community-level integrators of localized conditions over time, they are important components of aquatic food webs and there are standardized methods for their collection and evaluation. Therefore, benthic invertebrate community monitoring will be an important component of the LTMP. To date, benthic community assessments at the Faro and Vangorda sites have relied on deployment of artificial substrates, which have the advantage of controlling for natural differences in substrate among exposed and reference areas, but may bias collections toward organisms that happen to drift from upstream and colonize on the substrates over the short (typically 6-week) period they are deployed. The latter point may also partially explain why high year-to-year variability has been observed in previous benthic community assessments at Faro.

To determine the best long-term approach for benthic community monitoring, it is recommended that the IAEMP include parallel sampling of resident benthic communities at the same time that artificial substrates are retrieved in fulfillment of monitoring requirements at the Faro and Vangorda sites under the Water License. This would involve sample collection at each of the two sites in alternate years. A control-impact sampling design will be followed, in which community characteristics at exposure areas will be statistically compared to those at reference areas. This will necessitate field reconnaissance and exploratory sampling during the IAEMP to identify additional reference areas possessing similar habitat characteristics to the mine-exposed areas. In addition, the number of replicate

samples collected per area will be increased from three to five to improve statistical power, and the samples will be taken sufficiently far apart to be considered stations within areas, rather than replicate samples within stations. Statistical comparisons will be made for a variety of community metrics such as density, number of taxa, Bray-Curtis similarity index, Simpson's evenness index, and proportions of dominant taxa. Recommendations for the LTMP will be made on the basis of IAEMP results.

6.0 MONITORING OF FISH

6.1 Current Conditions

Fish communities in the Rose/Anvil and Vangorda systems are comprised of arctic grayling, Chinook salmon, slimy sculpin, round whitefish, burbot, and longnose sucker, with slimy sculpin being most widely distributed and abundant species and longnose sucker being only rarely observed (Minnow 2007). Differences in sampling designs and methods over the years have precluded definitive conclusions regarding changes in fish community composition over time, but conditions may have slightly improved in recent years based on observations of Chinook salmon in upper Rose Creek in 2004 and 2005 (e.g., near stations R1 and R2, respectively), where none had been previously reported. Adult Chinook salmon were observed spawning in Anvil Creek in 2005 (Station A4; ACG et al. 2006) and the presence of fertilized salmon eggs in the stomach of an arctic grayling male captured at South Fork Rose Creek in 2005 (Station R1; WMEC 2005) suggested salmon may have also spawned in this area.

6.2 Considerations for Future Monitoring

Monitoring of fish is justifiable for numerous reasons (Barbour et al. 1999):

- Fish are good indicators of long-term (several years) effects and broad habitat conditions because they are relatively long-lived and mobile (Karr et al. 1986).
- Fish assemblages generally include a range of species that represent a variety of trophic levels (omnivores, herbivores, insectivores, planktivores, piscivores). They tend to integrate effects of lower trophic levels; thus, fish assemblage structure is reflective of integrated environmental health.
- Fish are at the top of the aquatic food web and are consumed by humans, making them important for assessing contamination.
- Fish are relatively easy to collect and identify to the species level. Most specimens can be sorted and identified in the field by experienced fisheries professionals, and subsequently released unharmed.
- Environmental requirements of many fish are comparatively well known. Life history information is extensive for many species, and information on fish distributions may also be available.

- Aquatic life uses (water quality standards) are typically characterized in terms of fisheries (coldwater, coolwater, warmwater, sport, forage). Monitoring fish provides direct evaluation of "fishability" and "fish propagation", which emphasizes the importance of fish to sport, subsistence, and commercial fishermen.
- Fish account for a large proportion of the endangered vertebrate species and subspecies (Warren and Burr 1994).

Monitoring of fish may include assessment of fish community composition, population health, tissue pathology, biochemical (biomarker) responses, and/or contaminant concentrations in tissues (EVS 1999). In the hierarchy of biological organization from the molecular to the ecosystem level, physiological processes affecting cellular and subcellular structure and function are generally the earliest responses to environmental stress (EVS 1999). However, ecological relevance of sub-organism-level responses is more difficult to relate to community sustainability than direct measures or indicators of population or community health. As noted above (Section 6.1) previous monitoring of fish at Faro has focused on relative fish abundance and community composition among areas and it is recommended that such monitoring continue in the LTMP. However, quantitative community surveys can be technically challenging and costly to implement due to the level of sample replication (e.g., multiple closed stations per area) necessary to make statistical comparisons. Therefore, it is recommended that a semi-quantitative assessment of community composition be combined with a detailed assessment of a sentinel fish population (as outlined by Environment Canada 2002), to evaluate potential mine-related impacts on fish at the Faro complex.

6.3 Sampling Approaches

6.3.1 Community Composition

Improvements or degradation in fish community composition should be tracked at key locations near the Faro complex over time. The proposed approach is similar to that employed in recent years at the Faro complex (WMEC 2004, 2005), with modifications (habitat permitting) that would allow for more definitive conclusions to be made about relative community status among sampling areas and over time. Specifically, monitoring areas should be enclosed using barrier nets, located a set distance apart (e.g. 20-50 m), and spanning the entire width of the creek/river to define each sampling area. Fish communities within each enclosed area should be sampled by backpack electrofisher using a multiple pass (i.e., K-pass) removal method to yield population estimates for dominant species (e.g., slimy sculpin and grayling) using Moran-Zippin methods (methods in Appendix B, Section B4.1).

As previous surveys of fish and benthic invertebrates have indicated little or no mine-related impact in the receiving waters downstream of the Faro and Vangorda mine sites, it is recommended that samples be collected at only one area downstream of each mine, located as close as possible to each mines site, yet downstream of all mine-related discharges, and where sculpin have been previously observed (the specific relevance of sculpin is discussed in Section 6.3.2). For the Faro site, this would be in the vicinity or slightly downstream of Station R2. At the Vangorda site, sampling would occur in the vicinity of Station V8, since fish have not been found at areas closer to the mine site.

It is recommended that fish communities also be sampled in at least two reference areas to characterize the natural variability of unimpacted regional populations. Candidate sampling areas being considered include North Fork Rose Creek upstream of Station R7, Anvil Creek upstream of R4, and/or Blind Creek, although other, more suitable areas may be identified through exploratory sampling in the IAEMP. The selected sampling areas should have habitat characteristics that are as similar as possible to each other with respect to gradient, water velocity, depth, aquatic and riparian vegetation, and substrate type. If results indicate that adequate information can be achieved with fewer reference areas, the sampling design should be modified accordingly in future surveys (LTMP).

Generally, the preferred sampling season for fish communities is mid to late summer, when stream and river flows are moderate to low, and less variable than during other seasons. Although some fish species are capable of extensive migration, fish populations and individual fish tend to remain in the same area during summer (Funk 1957, Gerking 1959, Cairns and Kaesler 1971). Also, fish sampling will be most cost-effective in late summer, when it can be coordinated benthic invertebrate sample collection.

6.3.2 Sentinel Species Population Health

Subject to verification of adequate population densities, it is recommended that population health assessments be conducted at the Faro complex using slimy sculpin (*Cottus cognatus*) as a sentinel for the broader fish community. The advantages of this species are that they are ubiquitously distributed in the Rose/Anvil and Vangorda watersheds, are relatively abundant (Minnow 2007), and have small home range and are therefore reflective of localized conditions (Gray et al. 2004, Brasfield 2007). Slimy sculpin reach sexual maturity at approximately 3 years of age and have a life span of approximately 10 years (Coker et al. 2001, Scott and Crossman 1998) so they respond relatively quickly to changes in environmental conditions than the populations of other longer-lived species. Like arctic grayling and young burbot, slimy sculpin feed on immature aquatic insects such as mayflies (Ephemeroptera), caddisflies (Trichoptera), true flies (Diptera), stoneflies (Plecoptera) and

dragonflies (Odonata; Scott and Crossman 1998, WMEC 2005). Sculpin are also preyed upon by large burbot and grayling (Scott and Crossman 1998, WMEC 2005). Therefore, they are an integral component of the food web in surface waters near the Faro mine.

Slimy sculpin should be collected from the same areas recommended for fish community assessment (e.g., R2, V8, and three reference areas; Section 6.3.1). The sampling and assessment of sculpin should follow technical guidance developed for Environmental Effects Monitoring (EEM) at Canadian mines (EVS 1999, Environment Canada 2002, 2005). The preferred sampling season would be late summer, when it could be coordinated with fish community assessment and benthic invertebrate sample collection. However, sculpin are unlikely to have re-invested in post-spawning gonad recrudescence (re-development) by this time (Brasfield 2007), which would hamper efforts to use relative gonad sizes among areas as an indicator of mine-related effects on reproduction[3]. An alternative approach would be the collection and assessment of sculpin using non-lethal (catch-release) sampling techniques[4], but this approach is most viable if large numbers of sculpin (e.g., 100+), including YOY, can be obtained in each area with a reasonable fishing effort (e.g., up to 4 days per area). YOY may not be sufficiently large nor readily catchable (among rocky substrates) near Faro in late summer to support a meaningful non-lethal design. Alternatively, spring sampling may be hampered by higher flows and turbidity associated with freshet.

Therefore, it is recommended that the Interim Monitoring Program include reconnaissance-level sampling of slimy sculpin to determine the optimal timing (pre- versus post-freshet in spring and in late summer) and sampling design (lethal versus non-lethal). The Interim Monitoring Program should also include investigation of suitable sampling areas based on the habitat considerations mentioned above. The sampling design for the Long-Term Monitoring Program will be developed based on the results of such reconnaissance (reported at the conclusion of the IAEMP). Methods that may be applied for lethal or non-lethal survey designs are presented in Appendix B, Section B4.0.

[3] In an EEM-type survey, fish are sacrificed for measurement of age, body size, liver size, and gonad size. These measurements are compared among areas as indicators of relative survival, growth and reproductive success. See Appendix B, Section B4.2.3.

[4] In a non-lethal design, length-frequency distributions are compared among areas to indicate relative survival and growth among areas. Data interpretation is enhanced by sacrificing some fish for analysis of age. If both young-of-the-year and adults can be captured at the same time with the same collection method (e.g., seine nets), relative proportions of YOY can be compared among areas as an indicator of reproductive success. See Appendix B, Section B4.2.2.

National monitoring programs at operating mines are typically required to investigate the health of two sentinel fish species (Environment Canada 2002). However, most other species present in the vicinity of the Faro site are either not available in sufficient abundance (e.g., round whitefish, burbot, longnose sucker), or at appropriate life stages (e.g., Chinook salmon are predominantly juvenile) to justify population health assessments for two species. Although it might be possible to collect Arctic grayling in sufficient numbers for a lethal survey (e.g., 20 males and 20 females; Environment Canada 2002), removal of such numbers from each area is likely to adversely affect the population, and it is unlikely that sufficient numbers (100+) could be obtained in each area within a reasonable fishing effort (e.g., one week) to satisfy a non-lethal sampling design. Therefore, it is recommended that assessment of fish populations d/s of Faro complex focus on combined assessment of fish community composition (Section 6.3.1) and sculpin population health (above).

6.3.3 Tissue Concentrations

Mining activities have had only very minor influences on tissue metal concentrations of fish collected in the Rose-Anvil and Vangorda Creek systems, with no clear temporal trends suggested by the available data (Minnow 2007). Concentrations of cadmium, copper, manganese and zinc were well below human and wildlife consumption benchmarks since the late 1970s in both the Rose-Anvil and Vangorda Creek systems. Although arsenic, lead and mercury tissue metal levels have occasionally exceeded respective consumption benchmark levels (most notably in 1992 and 1997), similar concentrations observed in reference samples and widely variable survey-to-survey tissue concentrations suggested that tissue metal levels may be higher naturally and/or that differing analytical laboratory techniques among studies may have contributed to the apparently high values.

Consequently, fish tissue monitoring is not recommended as part of the LTMP, unless a substantial increase in aqueous metal concentrations is observed downstream of the mines in response to increased mine-related loadings. A specific trigger should be developed as part of the LTMP.

6.4 Summary

Fish tend to occupy the upper trophic levels of aquatic ecosystems and are often their most visible and valued components. Both population and community-level assessment can be used as indicators of longer-term exposure conditions (e.g., over years). Therefore, changes in fish community composition and relative species abundance should be tracked at key near-field locations near the Faro complex (R2 and V8) over time and compared to the communities at two or more reference areas possessing similar habitat characteristics. The

recommended methods for fish community characterization are similar to those used in previous surveys with modifications to allow for greater standardization of fishing effort and quantification of results. In brief, block-netting should be used, if possible, to enclose sampling areas, with Moran-Zippan methods used to estimate relative species abundances.

In addition, fish health will be assessed using a sentinel species approach (Environment Canada 2002) that targets collection of slimy sculpin. Fishing collection during the IAEMP will focus on determining the appropriate seasonal timing (pre- or post-freshet in spring versus fall) and sampling design (lethal or non-lethals survey) for the LTMP.

7.0 QUALITY MANAGEMENT PLAN

A number of formal procedures, outlined herein, must be implemented to assure the quality of the LTMP at Faro Such procedures include the establishment of organization and reporting channels, standard operating procedures, requirements for training, data quality and quantity objectives, and a protocol for data quality assessment.

7.1 General Responsibilities, Controls and Reporting Channels

Consistency is an important component of a quality management program. To minimize field and laboratory error and to maintain consistency in data collected in the LTMP standardized sampling and analytical methods should be implemented. To facilitate this, Standard Operating Procedures (SOPs) should be developed and maintained once the components of the LTMP are finalized (at the conclusion of the IAEMP). SOPs can be developed from methods presented in Appendices A and B. Once SOPs are established, any future modifications for water sampling should be reported in the Annual Water Quality Reports (Section 8.1), while modifications to other components should be reported in the comprehensive study reports. Any short-term changes to the specified methods must be documented in the field or laboratory notes and recorded in the database. In addition to the basic considerations of sampling technique, procedure control includes guidance on the use of standard procedures for cleaning sampling equipment before and after use and proper sample labelling. Detailed notes must be made in the field so that any discrepancy may be traced. All samples, related field observations and field data must be recorded in the database with relevant sample information recorded on the chains of custody. If samples have to be shipped by air or ground, proper procedures must be strictly adhered to (more details regarding sample handling are presented in subsequent sections).

7.2 Training, Health and Safety Requirements

All staff and consultants involved in the LTMP must be appropriately experienced and trained for their respective responsibilities (e.g., sample collection and handling; analyses; data entry; reporting etc.). Everyone involved in field and/or laboratory components should comply with applicable Health and Safety Policies.

7.3 Overview and Definitions for Data Quality Assurance

Although the general intent and process for data quality assurance (DQA) has become increasingly standardized, the terminology and definitions used in controlling and describing the quality of environmental data varies among geographical locations, regulatory agencies,

accreditation bodies, and practitioners. For the purpose of the monitoring conducted at the Faro complex, the terminology and processes relating to data quality are defined below.

Quality Assurance (QA) is a set of operating principles that, if strictly followed, will produce data with a quality that is defined and satisfies the intended use of the data. Included in QA are **quality control (QC)** and **quality assessment**. Quality control involves special actions providing some measure of data quality. These measures are for the purpose of identifying means to control the errors and variability associated with performance of sampling, analysis and reporting such that the data are appropriately accurate and precise to serve the purpose for which the data are being collected. Furthermore, it is desired that performance elements be controlled such that the variability observed in the data can be assumed to reflect real spatial or temporal variability. QC in an environmental monitoring program typically includes such elements as laboratory method detection limits for chemical analyses, collection and analysis of field and laboratory replicate samples, field and laboratory blank analysis, recovery of known additions (spikes), analysis of standard reference materials, etc.

Data quality objectives (DQOs) represent the performance expectations for QC elements. DQOs have been developed for the environmental monitoring program at Faro (Section 7.5). These should be periodically reviewed and updated based on the results of data quality assessments conducted over time.

Data quality assessment (DQA) is the process of comparing actual field and laboratory performance to the DQOs to determine the overall quality of the data. The goal of data quality assessment is to identify any significant issues with the data (e.g., performance outside of accepted boundaries or data entry errors) and to take action in a timely and efficient manner to address errors and concerns. This will ensure that the data are associated with a defined level of quality and thus enhance the defensibility of the data in the context of its ultimate use.

Data validation is the additional process of applying preliminary statistical analyses to the data to identify any data points that fall outside expected limits (i.e., flagged data). Flagged data trigger additional assessment, and possibly re-sampling, to determine whether the result is valid or is the result of error or upset condition. All data must undergo data quality assessment and validation *prior* to use in statistical analysis and interpretation respecting the environmental conditions at the Faro complex. This rigorous level of QA provides added confidence in the overall interpretation and conclusions of the program by ensuring that all data are defensible.

7.4 Laboratory Selection

Laboratories vary in their ability to consistently achieve specific DQOs, to follow up on any identified data issues, to produce clear and concise reports in formats that facilitate ready transfer of information to project databases, and in the costs charged for analyses. Therefore, it will be appropriate to do a thorough evaluation of candidate laboratories to select a preferred and back-up laboratory for each type of sample to be analyzed at the Faro complex in the LTMP. In all cases, candidate laboratories should be provided with relevant project DQOs, approximate annual sample quantities, requirements for data and QC reporting, and be invited to bid on the work. The laboratory should identify their capabilities with respect to relevant experience, available instrumentation, client service, QA/QC performance and reporting, and analytical costs. The laboratory should also identify if any of the requested analyses must be sub-contracted out to another location, whether it is a facility in the same or a different company.

Laboratory evaluation and selection should be done as part of the IAEMP such that the selected laboratories can be identified and utilized for the LTMP. Once selected, all site personnel and contractors should be required to submit all samples to the identified laboratories to ensure consistency in data quality and reporting and also minimize costs (based on availing themselves of the negotiated pricing for Faro).

Since personnel, equipment and pricing change over time, the selected laboratories should be periodically re-evaluated (e.g., every 2-3 years for water samples and in advance of each study cycle for other sample types) by comparison to other laboratories following the process described above.

7.5 Data Quality Objectives and Quality Control

Data quality objectives are statements of desired sensitivity, precision and accuracy in order to permit a defined level of confidence in drawing conclusions from the data of the entire monitoring program. Data quality objectives established for the Faro complex serve as criteria for data acceptability. These objectives consider the intended use of the data and the technical feasibility of collecting data of such quality.

Assurance of adequate data quality is only possible when specific data uses and data quality objectives have been defined. Data quality objectives may pertain to factors such as sensitivity, precision, accuracy, comparability, compatibility, representativeness and completeness. Data quality objectives have been developed for the sensitivity, precision and accuracy of chemical and biological measurements in the LTMP. These data quality

objectives include negligible contaminant levels in all blank samples, acceptable variability between field and laboratory duplicate duplicate samples, efficient recovery of matrix spike amounts and minimal bias in analytical estimates for certified reference materials. Each type of quality control sample is explained in more detail below.

The quantity of data retrieved in the LTMP must be sufficient to address the objectives of the program. The number of samples collected in each component of the program consists of the samples required for routine monitoring and the samples required for quality control (QC).

7.5.1 Water Samples

Quality control (QC) samples relating to analysis of surface water samples are taken in the field and in the laboratory. General guidelines for the type of quality control samples required to track and minimize the effects of bias and imprecision in the sampling effort are outlined below. The number of field QC samples should correspond to a minimum of 10% of the total number of samples taken in the sampling period the QC samples are intended to represent. The same rule applies to the laboratory QC samples. Quality control samples are integral to a quality assurance program, and recommendations for their use should be strictly adhered to. Types of QC samples that will be used in the LTMP at Faro include:

Field (Bottle) Blanks: A field blank is a sample of distilled/de-ionized water that is placed in a bottle identical to those used for all samples at a randomly selected sampling location. The field blank allows assessment of the potential contamination of the sample by the bottle itself, preservatives, dust and sample handling.

Field Duplicates: A field duplicate is a randomly selected sample that is taken at the same time and location as a regular field sample (i.e., side by side). The samples are prepared and analyzed in an identical manner. The data from field duplicate samples reflect the natural spatial and/or temporal variability, as well as the variability associated with sample collection and handling methods.

Laboratory Blanks: A laboratory blank is a randomly selected laboratory analysis vial that is filled with distilled water and/or appropriate laboratory reagent(s) and then analyzed as a regular sample. The laboratory blank is similar to the field (bottle) blank and allows an assessment of the potential contribution of the analysis vial, laboratory reagents, or laboratory cross-contamination to analyte concentrations. This type of QC sample is prepared, analyzed, and reported by the analytical laboratory.

Laboratory Duplicates: A laboratory duplicate is a sample that has been submitted for analysis and is randomly split in the laboratory into two (or more) sub samples that are analyzed independently. The laboratory duplicate sample results reflect the variability introduced during laboratory sample handling and analysis. This type of QC sample is prepared, analyzed, and reported by the analytical laboratory.

Matrix Spike Recoveries: A matrix spike involves the addition of a known quantity of chemical (e.g., metal) to an environmental sample (e.g., surface water). The spiked sample is analyzed and the resulting chemical concentration is compared to the results for the unspiked sample to determine the percentage of the spike amount that was recovered in the analysis of the spiked sample. This type of QC sample is prepared, analyzed, and reported by the analytical laboratory.

Certified Reference Materials : A certified reference sample is certified reference material (CRM) having a known concentration of specified parameter(s). The CRM is prepared and analyzed in a manner identical to the field-collected samples. The certified reference material allows an assessment of the analytical accuracy and allows for instrument calibration. This type of QC sample is prepared, analyzed, and reported by the analytical laboratory.

Based on the above, DQOs for water samples have been established, with further explanation provided below:

Method Detection Limits

Method detection limits are the smallest concentration of an analyte that can be measured with a defined certainty of being distinguishable from a blank sample. MDLs vary depending on the analyte, sample matrix, analytical method and instrumentation used. Analytical method detection limits should be at least as low at the water quality guidelines to which the data will be compared. To the extent possible, target MDLs should be set at $1/10^{th}$ the applicable guideline or lower (McQuaker 1999).

Blanks

DQOs were established for field and laboratory blank samples (Table 7.1). Field blanks provide an indication of potential contamination from the sample container or preservatives as well as any other material that may have been introduced during sample handling. Laboratory blanks provide an indication of potential contamination of glassware, equipment, and reagents. The desired performance for field and laboratory blank samples is stipulated in Table 7.1.

Table 7.1: Data quality objectives for Faro surface water samples.

		Aquatic Criteria				Field Performance	Laboratory Performance Criteria					
Measurements	Units	Canadian Water Quality Guideline (for protection of FW aquatic life)[a]	British Columbia (freshwater)[b]	Ontario Provincial Water Quality Objective[c]	Canadian Drinking Water Quality Guideline	Field Duplicates (relative percent difference)	Minimum Method Detection Limit	Preferred Method Detection Limit	Blank Samples	Laboratory Precision (relative percent difference) Concentration in Sample >10x MDL	Laboratory Precision (relative percent difference) Concentration in Sample <10x MDL	Laboratory Accuracy (sample spike recovery)
Micellaneous Parameters												
alkalinity	mg/L			no decreases more than 25% of natural concentration		20%	1	1	2x MDL	10%	20%	80-120%
ammonia - N	"	0.44[d]		0.25[d]		20%	0.05	0.02	2x MDL	10%	20%	80-120%
chloride	"				250[k]	20%	1	0.05	2x MDL	10%	20%	80-120%
conductivity	uS					20%			2x MDL	10%	20%	80-120%
cyanide, WAD	mg/L	0.005 (free)	0.01	0.005 (free)	0.2	20%	0.005	0.001	2x MDL	10%	20%	80-120%
dissolved solids, total (TDS)	"				500[k]	20%	10	10	2x MDL	10%	20%	80-120%
fluoride	"	0.120			1.5	20%	0.1	0.01	2x MDL	10%	20%	80-120%
hardness	"					20%	-		2x MDL	10%	20%	80-120%
mercury, total	ug/L	0.026[e]	0.004-0.02[m]	0.2 (filtered)	0.001	20%	0.001	0.0005	2x MDL	10%	20%	80-120%
nitrate - N	mg/L	13	40	narrative	10	20%	0.1	0.03	2x MDL	10%	20%	80-120%
nitrite - N	"	0.06	0.02	0.06	3.2	20%	0.02	0.005	2x MDL	10%	20%	80-120%
organic carbon, dissolved (DOC)	"					20%	1	0.1	2x MDL	10%	20%	80-120%
organic carbon, total (TOC)	"					20%	1	0.1	2x MDL	10%	20%	80-120%
pH	pH units	6.5-9.0	6.5 - 9.0	6.5-8.5	6.5-8.5	20%	0.01	0.01	2x MDL	10%	20%	80-120%
phosphorus, total	mg/L			0.01-0.03, depending on lake versus river[o]		20%	0.003	0.002	2x MDL	10%	20%	80-120%
sulphate	"		50		500[k]	20%	1	0.2	2x MDL	10%	20%	80-120%
suspended solids, total (TSS)	"	narrative	narrative			20%	2	1	2x MDL	10%	20%	80-120%
Metals						20%						
aluminum	mg/L	0.005 - 0.100[f]	0.05	0.015 - 0.075[o]	0.1	20%	0.005	0.001	2x MDL	10%	20%	80-120%
antimony	"			0.02[o]	0.006	20%	0.005	0.001	2x MDL	10%	20%	80-120%
arsenic	"	0.005	0.005	0.005[o]	0.005 proposed	20%	0.001	0.0005	2x MDL	10%	20%	80-120%
barium	"				1.0	20%	0.01	0.001	2x MDL	10%	20%	80-120%
beryllium	"			0.011 - 1.1		20%	0.001	0.001	2x MDL	10%	20%	80-120%
bismuth						20%	0.002	0.001	2x MDL	10%	20%	80-120%
boron	"		1.2	0.2[o]	5.000	20%	0.05	0.001	2x MDL	10%	20%	80-120%
cadmium	"	0.000017 or more depending on hardness[g]		0.0001 - 0.0005[o]	0.005	20%	0.00001	0.000005	2x MDL	10%	20%	80-120%
calcium	"					20%	0.5	0.05	2x MDL	10%	20%	80-120%
chromium	"	0.001 (for trivalent form), 0.0089 (for hexavelent form)		0.001 (for trivalent form), 0.0089 (for hexavelent form)	0.05	20%	0.001	0.0002	2x MDL	10%	20%	80-120%
cobalt	"		0.004	0.0009		20%	0.0009	0.00005	2x MDL	10%	20%	80-120%
copper	"	0.002-0.004[h]	0.002-0.008[l]	0.001-0.005[o]	1.0[k]	20%	0.001	0.0001	2x MDL	10%	20%	80-120%
iron	"	0.300		0.300	0.3[k]	20%	0.05	0.005	2x MDL	10%	20%	80-120%
lead	"	0.001 - 0.007[i]	0.005-0.011[l]	0.001 - 0.005[o]	0.010	20%	0.001	0.0002	2x MDL	10%	20%	80-120%
magnesium	"					20%	0.5	0.05	2x MDL	10%	20%	80-120%
manganese	"		0.8 - 1.48[l]		0.05[k]	20%	0.002	0.0005	2x MDL	10%	20%	80-120%
molybdenum	"	0.073	1	0.04[o]		20%	0.001	0.001	2x MDL	10%	20%	80-120%
nickel	"	0.025 - 0.150[j]		0.025		20%	0.002	0.001	2x MDL	10%	20%	80-120%
potassium	"					20%	0.5	0.05	2x MDL	10%	20%	80-120%
selenium	"	0.001	0.002	0.100	0.01	20%	0.001	0.0002	2x MDL	10%	20%	80-120%
silver	"	0.0001	0.00005/0.0015[n]	0.0001		20%	0.00005	0.00001	2x MDL	10%	20%	80-120%
sodium	"				200[k]	20%	0.5	0.05	2x MDL	10%	20%	80-120%
strontium	"					20%	0.002	0.001	2x MDL	10%	20%	80-120%
thallium	"	0.0008		0.0003[o]		20%	0.0003	0.00005	2x MDL	10%	20%	80-120%
tin	"					20%	0.001	0.001	2x MDL	10%	20%	80-120%
titanium	"					20%	0.005	0.005	2x MDL	10%	20%	80-120%
uranium	"			0.005[o]	0.02	20%	0.005	0.0001	2x MDL	10%	20%	80-120%
vanadium	"			0.006[o]		20%	0.006	0.001	2x MDL	10%	20%	80-120%
zinc	"	0.030	0.0075-0.090[j]	0.02[o]	5.0	20%	0.005	0.0005	2x MDL	10%	20%	80-120%
zirconium	"			0.004		20%	0.004	0.001	2x MDL	10%	20%	80-120%

[a] CCME (Canadian Council of Ministers of the Environment). 1999. Canadian Environmental Quality Guidelines. 1999 (plus updates), Canadian Council of Ministers of the Environment, Winnipeg

[b] BCMOE (British Columbia Ministry of Environment). 2006. British Columbia Approved Water Quality Guidelines (Criteria), 2006 Edition. Updated August 2006. For parameters with both maximum and 30-day average values, the 30-d average is shown.

[c] OMOE (Ontario Ministry of Environment and Energy). 1994. Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of the Environment and Energy (Ontario), July 1994

[d] based on conservative assumption of pH 8.5 and temperature of 15C to achieve un-ionized ammonia of <0.02 mg/L

[e] Inorganic mercury

[f] 0.1 mg/L at pH ≥ 6.5; [Ca^{2+}] ≥ 4 mg/L; DOC ≥ 2 mg/L

[g] CWQG for cadmium = $10^{\{0.86[\log(\text{hardness})] - 3.2\}}$ in ug/L

[h] 0.002 at [$CaCO_3$] = 0-120 mg/L, 0.003 at [$CaCO_3$] = 120-180 mg/L, 0.004 at [$CaCO_3$] > 180 mg/L

[i] 0.001 at [$CaCO_3$] = 0-60 mg/L, 0.002 at [$CaCO_3$] = 60-120 mg/L, 0.004 at [$CaCO_3$] = 120-180 mg/L, 0.007 at [$CaCO_3$] > 180 mg/L

[j] 0.025 at [$CaCO_3$] = 0-60 mg/L, 0.065 at [$CaCO_3$] = 60-120 mg/L, 0.110 at [$CaCO_3$] = 120-180 mg/L, 0.150 at [$CaCO_3$] > 180 mg/L

[k] aesthetic objective

[l] for hardnesses ranging between 50 and 200 mg/L, respectively

[m] depending on proportion present as MeHg

[n] hardnesses of ≤100 mg/L and >100 mg/L, respectively

[o] interim objective

Precision

Precision is a measure of how closely replicate samples agree with one another. Precision can be expressed in various ways: as the standard deviation, relative standard deviation (RSD), or the relative percent difference (RPD) of replicate results. In the evaluation of environmental samples, the standard deviation is rarely used, because the magnitude of analyte concentration in samples usually influences the magnitude of standard deviation among samples and thus makes setting of a single data quality objective (DQO) inappropriate. Therefore, either the RSD or RPD method is preferred, because each expresses the variability among replicates relative to the arithmetic mean of the replicate results. In the case of very few replicates, RPD seems to be most frequently applied, since it is slightly simpler to calculate and is "nearly as efficient as the standard deviation because the two measures differ by a constant (1.128s = R for duplicates and 1.693s = MEAN R for triplicates" (APHA, 1995)). In the majority of environmental programs, including SRWM and In-Basin programs, assessment of precision is based on replicates of two (duplicates); therefore, it is recommended that RPD be used to estimate precision as follows:

Relative Percent Difference (RPD) of Duplicate Analyses

%RPD = 100 x ABS(A-B)/MEAN(A,B) (1) after Csuros (1997)

where: A is the result of the first analysis of a sample,

B is the result of the second analysis of a sample,

ABS (A-B) is the absolute value of the difference between duplicate results,

MEAN (A,B) is the arithmetic mean of duplicates A and B.

If, in the future, three or more replicate analyses become routinely incorporated in the LTMP, all results should be expressed as RSD, according to the following:

Relative Standard Deviation (RSD) of Multiple Replicates

%RSD = 100 x s/ MEAN (replicates) (2) after Csuros (1997)

where: s is the standard deviation, and

MEAN (replicates) is the arithmetic mean of all replicate results.

It should be recognized that duplicate analyses conducted on samples containing concentrations of parameters approaching the MDL will tend to show less precision than samples containing concentrations more than five or ten times the MDL.

Accuracy

Accuracy is the degree to which a measured value agrees with the "true" (expected) value. Accuracy is generally expressed as percentage recovery (%R) of a known amount. For certified reference materials, the total analyte concentration in a sample matrix is known and therefore the percent recovery is calculated as shown in formula 3, below. For spiked samples, the spike amount is known and compared to the difference in total analyte concentration measured in spiked and unspiked samples (formula 4).

%R = 100 x measured value /known value (3) after Csuros (1997)

$\%R = 100(X_s - X_u)/K$ (4) after USEPA (in Patnaik, 1997)

where X_s = measured amount in the spiked sample,

X_u = measured amount in the unspiked sample, and

K = known spike amount.

The measured amount in an unspiked sample may be the result of a single analysis or the average of duplicate analyses.

7.5.2 Sediment

The DQOs for sediment samples are shown in Table 7.2. The types of samples to be collected and analyzed for assessment of sediment data quality are similar to those specified for water, with the exception that field blanks will not be required. As for water quality sampling, the number of field and laboratory QC samples should correspond to a minimum of 10% of the total number of samples taken/analyzed in the period the QC samples are intended to represent. The same rule applies to the laboratory QC samples. The DQOs should be reviewed with the analytical laboratory well in advance of sample collection and submission to ensure the requirements are understood and achievable.

7.5.3 Benthic Invertebrate Community Assessment

Minimum requirements for benthic invertebrate data quality assurance are (Beak 1999, Environment Canada 2002, Glozier et al. 2002):

- documentation of study design and objectives;
- documentation of data quality objectives and performance;
- documented standard operating procedures for field and laboratory work;

Table 7.2: Data quality objectives for Faro sediment samples.

Measurements	Units (dry weight)	Sediment Criteria				Field Precision (Duplicates)	Laboratory Performance				
		Canadian Freshwater		Ontario Sediment			Target Method Dectection Limit	Analytical Precision (Relative Percent Difference)		Analytical Accuracy	
								Concentration in Sample		Spike Recovery	CRM[g]
		ISQG[b]	PEL[c]	LEL[e]	SEL[f]			>10x MDL	<10x MDL		
Miscellaneous Parameters											
total organic carbon (TOC)	mg/kg			10,000	100,000	30%	500	20%	30%	20%	20%
particle size	%					30%	0.1	20%	30%	20%	20%
total Kjeldahl nitrogen (TKN)	mg/kg			550	4,800	30%	10	20%	30%	20%	20%
total phosphorus	"			600	2,000	30%	2	20%	30%	20%	20%
methyl mercury	"					30%	0.05	20%	30%	20%	20%
total mercury	"	0.17	0.486	0.2	2	30%	0.05	20%	30%	20%	20%
Metals											
aluminum	mg/kg					30%	10.0	20%	30%	20%	20%
antimony	"					30%	0.2	20%	30%	20%	20%
arsenic	"	5.9	17	6	33	30%	0.5	20%	30%	20%	20%
barium	"					30%	1	20%	30%	20%	20%
beryllium	"					30%	0.2	20%	30%	20%	20%
bismuth	"					30%	1	20%	30%	20%	20%
boron	"					30%	2.0	20%	30%	20%	20%
cadmium	"	0.6	3.5	0.6	10	30%	0.1	20%	30%	20%	20%
chromium	"	37.3	90	26	110	30%	1	20%	30%	20%	20%
cobalt	"					30%	1	20%	30%	20%	20%
copper	"	35.7	197	16	110	30%	1	20%	30%	20%	20%
iron	"			20,000	40,000	30%	20	20%	30%	20%	20%
lead	"	35	91.3	31	250	30%	1	20%	30%	20%	20%
manganese	"			460	1,100	30%	1	20%	30%	20%	20%
molybdenum	"					30%	0.5	20%	30%	20%	20%
nickel	"			16	75	30%	0.5	20%	30%	20%	20%
selenium	"					30%	1.0	20%	30%	20%	20%
silver	"					30%	0.1	20%	30%	20%	20%
strontium	"					30%	0.5	20%	30%	20%	20%
thallium	"					30%	0.2	20%	30%	20%	20%
tin	"					30%	1	20%	30%	20%	20%
titanium	"					30%	1	20%	30%	20%	20%
uranium	"					30%	0.1	20%	30%	20%	20%
vanadium	"					30%	1.0	20%	30%	20%	20%
zinc	"	123	315	120	820	30%	1.0	20%	30%	20%	20%

[a] Canadian Environmental Quality Guildelines 2003, http://www.ccme.ca/assets/pdf/update3.2_cover_e.pdf

[b] interim sediment quality guideline

[c] probable effect level

[d] Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, 1993

[e] lethal effect level

[f] severe effect level

[g] CRM (Certified Reference Material); note that for sediment, the recommended digestion is not the same as that used to certify CRMs. Thus, the laboratory must establish mean analyte concentrations (minimum 5 replicates) against which results will be compared for accuracy.

[h] boron is run as a separate analyte on request only (additional cost)

- use of appropriately qualified and trained personnel for sample collection;
- use of a qualified laboratory for benthic invertebrate sorting and taxonomic identifications;
- an average of 95% recovery of invertebrates from samples with no samples having less than 90% recovery;
- calculation of the error associated with any subsampling techniques by examining a minimum of 10% of samples to verify that sub-sampling accuracy and precision are within 20%;
- archiving of sorted invertebrates and bench sheets until the study report has been completed and undergone any external technical review; and
- compilation of a voucher (reference) collection.

7.5.4 Fish

Minimum requirements for assurance of fish data quality are:

- documentation of study design and objectives;
- documented standard operating procedures for field and laboratory work;
- use of appropriately qualified and trained personnel for sample collection;
- use of a qualified laboratory for analysis of fish ages; and
- send approximately 10% of age structures to a separate laboratory for third-party verification.

7.6 Data Quality Assessment

In order to assess whether the overall quality of the LTMP is assured, formal data quality assessment (DQA) procedures must be utilized. The overall objective of a quality assurance program is to control measurement errors to acceptable levels and to ensure, therefore, that the data are useful and of known quality. DQA will involve evaluation of the requirements discussed in Section 7.5, with guidance on how to do so presented below.

7.6.1 Water Quality Data

It would be unrealistic to expect that the DQA processes described below can be implemented immediately. A schedule should be developed to allow for the coordination and phasing in of the various requirements.

For water monitoring, DQA should be undertaken monthly on an informal basis and annually on a more formal basis. The informal monthly assessment will be geared to pinpointing and correcting errors, while the annual assessment will involve formal quality assurance reporting (see Section 8.1). The detailed processes for detecting data quality anomalies will depend on the capabilities of the database utilized for long-term information storage and management. Formal reporting will be based on a direct comparison of QC sample results with the objectives specified in Table 7.1. Data quality assessment reports prepared during this formal assessment will include the QC data (including the results of blanks and the precision and accuracy achieved) and a memorandum summarizing the significant findings. Formal quality assurance reporting will also include an assessment of the implications of not having met specific data quality objectives, if applicable, and recommendations for improvement. Formal quality assurance reports must be reviewed by the person responsible for managing/coordinating the environmental monitoring program, then filed as part of the long-term quality assurance record of the monitoring program and included with the Annual Reports (Section 8.1). This will provide data users with a consistent record of data quality and can be used to determine the cause of any inconsistencies.

7.6.2 Sediment

The DQA for sediment should follow a similar process to that described for water data, including evaluation of the MDLs, field precision, and analytical precision and accuracy relative to the DQOs established for the program. The information should be documented in all integrated study reports that include sediment quality monitoring.

7.6.3 Biological Data

The quality of the biological data will be evaluated on the basis of the information listed in Section 7.5.3 and 7.5.4. The information should be documented in all integrated study reports that include the corresponding biological components (e.g., benthic invertebrates and fish data).

8.0 REPORTING

A report will be prepared at the conclusion of the IAEMP to outline the methods used for sample collection and analysis and for data data analysis, as well as to present and integrate the IAEMP findings. The report will also recommend the approach and methods for the long-term aquatic ecosystem monitoring at the Faro complex (within the LTMP).

It is expected that two types of reports will be recommended for documenting the results of the LTMP. These include Annual Water Quality Reports and Comprehensive Aquatic ecosystem Study Reports related to aquatic ecosystem monitoring. The contents of each type of report are described in the following sections.

8.1 Annual Water Quality Reports

The objective of the Annual Water Quality Report is to track concentrations over time (seasonal trends), to allow for management of the treatment and discharge condition, at an interval more frequent than the five-year comprehensive study cycle. Annual reports will demonstrate to stakeholders that the program is being competently implemented through the description of methods, presentation of data and quality assurance assessment. The report will present the surface water quality monitoring results obtained over the previous year and will include the following information:

- locations and dates monitored;
- samples collected at each station and methods employed;
- data quality assessment methods and results;
- explanation of outliers;
- results for surface water monitoring;
- tables that compare measured concentrations against applicable benchmarks (CWQG or background concentrations);
- graphs to show changes in the concentrations of key parameters over time;
- description(s) of any additional water quality monitoring planned or implemented; and
- recommendations for potential changes to the program and rationale.

Although the requirements of source area and perimeter monitoring for the LTMP have yet to be developed, such monitoring results should also be included in the annual water quality

report. The report should present the data in a clear and concise manner, with detailed data presented in appendices as required. A template should be developed in the first year of preparation to establish the format to be followed for subsequent annual reports. The potential need for an alternate format for reporting to First Nations should also be determined at that time and developed, if required.

8.2 Comprehensive Study Reports

The Comprehensive Aquatic ecosystem Study Reports will summarize the water quality data collected since the previous study was completed (likely every 5 to 10 years as discussed in Section 2.2), highlighting any significant issues or finding reported in the Annual Water Quality Reports (Section 8.1). In addition, the results of other types of monitoring (sediment, benthic invertebrate and/or fish) conducted since the previous study will be presented and discussed. Specifically, the reports will include the following information:

- descriptions of the methods used in each component of the program;
- review of quality control procedures and data quality assessment;
- presentation of the results of all monitoring components;
- integration of the results of water and sediment chemistry with the biological community (fish and benthos) to identify and evaluate relationships;
- assessment of spatial and temporal changes in the receiving environment;
- assessment of the conditions in the receiving environment relative to predicted changes; and
- recommendations for any changes to subsequent monitoring cycles.

9.0 SUMMARY AND IMPLEMENTATION SCHEDULE

9.1 Overall Framework

The goal of the long-term monitoring program (LTMP) is to track environmental conditions within and around the Faro complex over time, to assess the conditions relative to predictions, and to verify that remediation and treatment options implemented at the site are having the desired effect. It has been estimated that peaks in metal loadings from the tailings area will occur at various times over the next 300+ years (SRK 2005), so monitoring will be long-term and associated with considerable cumulative cost. Therefore, it will be important for the program to measure only what is necessary and relevant at any given time and to adapt to changes as they occur (e.g., potentially worsening water quality associated with acidification and metal leaching from waste rock and tailings). The initial scope of the LTMP should be commensurate with the relatively limited magnitude and spatial extent of mine-related effects that are currently evident (Minnow 2007). The frequency of monitoring must be sufficient to provide early warning of changes, particularly degradation, so that appropriate responses can be made (e.g., changes to monitoring, mitigation, or remediation). Similarly, reductions in the scope or frequency of monitoring should be considered in response to improving conditions.

The overall long-term monitoring program (LTMP) at Faro, Yukon, will be comprised of three sub-programs, each with its own sub-objectives. The aquatic ecosystem monitoring program, which is described in this document, will assess the chemical and biological condition of the aquatic environments receiving mine drainage. A perimeter monitoring program will also be developed to measure the concentrations and loadings of mine-related substances at the perimeter of the Faro and Vangorda sites where contaminants are released from the mine sites (source areas) to the natural environment (downstream surface waters). The objective of the third sub-program, the source area monitoring program, will be to track source conditions relative to predictions and monitor the performance of any treatment systems and/or mitigation. This will include assessment of contaminant concentrations and movements within/from waste rock, pits, seeps, groundwater, surface water conduits, and the Faro tailings basin. The approach and framework for the aquatic ecosystem monitoring program presented in this document can be a template for developing the approach and framework for the other two sub-programs.

9.2 Aquatic Ecosystem Monitoring Sub-Program

The aquatic ecosystem monitoring sub-program of the LTMP will integrate biological and chemical information for a weight of evidence approach, including the following components:

- water chemistry,
- hydrology,
- (possibly) sediment chemistry,
- benthic invertebrate community monitoring, and
- fish community and population assessment.

However, before the details of the LTMP can be fully developed for most of the components, several additional, one-time studies will be required to fill critical data gaps. It is proposed that these be addressed through the implementation of an Interim Aquatic Ecosystem Monitoring Program (IAEMP) in 2007-2009. Results of the IAEMP will be reported at its conclusion and incorporated into the rationale for the LTMP components. The proposed schedule will ensure that the technical information required for developing the LTMP will be largely complete when the existing site Water Licence expires (February 28, 2009). Consequently, the goal will be to replace the monitoring stipulated by the current Water Licence with the new LTMP.

9.3 Interim Aquatic Ecosystem Monitoring Program (IAEMP)

The interim monitoring program will involve collection of additional information/data over the next two to three years, while monitoring requirements stipulated in the Water Licence for the Faro complex continue to be fulfilled. Since biological monitoring under the Water Licence is scheduled to be conducted at the two mine sites in alternate years, it is recommended that data collection for the IAEMP be structured accordingly (i.e., Vangorda site in 2007 and at the Faro site in 2008). Depending on the findings, it is anticipated that all the necessary data may be available by the end of 2008, such that a final report, with recommendations for the LTMP can be completed in early 2009, roughly corresponding to the expiry of the existing Water Licence. The components of the IAEMP are described below.

9.3.1 Surface Water Quality

Existing water quality data are inadequate to determine the optimum design for long-term water quality monitoring data at the Faro complex. Additional studies should be conducted in 2007-2009 (IAEMP) to collect the data necessary to rationalize a streamlined and effective

long-term monitoring progam (LTMP). Changes to the water quality monitoring that are recommended for the IAEMP include:

- eliminate surface water monitoring stations that are not required by licence and do not meet specified criteria (listed in the report);
- increase the number of reference stations to develop or update background benchmarks;
- increase sampling frequencies to monthly to generate enough data to permit characterization of seasonal variability and allow the optimum frequency and timing of water sample collection for the LTMP to be determined;
- evaluate the potential for concentrations of antimony, boron, beryllium, chromium, mercury, molybdenum, selenium, tin, thallium, uranium, or vanadium to exceed Canadian water quality guidelines (CWQG), or alternative toxicity-based benchmarks, in surface waters in the future; and
- ensure laboratory method detection limits are sufficiently low to permit meaningful comparisons to CWQG.

The data will be evaluated at the conclusion of the IAEMP to determine the monitoring stations, parameters and sampling frequencies that should be incorporated into the LTMP.

9.3.2 Sediment Quality

The substrates of aquatic receiving environments near the Faro complex are generally coarse (sand, gravel, rocks) with limited, patchy deposits of finer particulates (e.g., fine sand, silt, clay). To date, sediment chemistry has usually involved analysis of metal content in the fine fraction (<0.15mm) of sediment sample collected from fine-particle deposits. While elevated metals (e.g., arsenic, lead, zinc) have been observed in fines at stations downstream of the Faro and Vangorda sites, it is not known: a) what proportion of whole (bulk) sediments the fines represent, b) what concentrations of metals are present in whole sediment samples, c) what proportion of total substrate area do the deposits of fine sediments represent, nor d) if the sediments showing elevated metal concentrations are toxic to biota. Therefore, additional sediment characterization is recommended as part of the IAEMP, including analysis of particle size, metal content, and toxicity of whole sediments along with analysis of metal content in the fine fraction (0.15mm). Sediment samples should be collected for such analyses in the first year of the IAEMP to allow for possible follow-up activities in the second year, if required (e.g., possible characterization of the ecological importance of fine sediment deposits, if such deposits are found to be toxic in laboratory

testing). The results of sediment characterization completed during the IAEMP will determine if sediment analyses should be continued as part of the LTMP, and, if continued, what type of analyses should be included.

9.3.3 Benthic Invertebrate Communities

Benthic invertebrates are good, community-level integrators of localized conditions over time, they are important components of aquatic food webs and there are standardized methods for their collection and evaluation. Therefore, benthic invertebrate community monitoring will be an important component of the LTMP. To date, benthic community assessments at the Faro and Vangorda sites have relied on deployment of artificial substrates, which have the advantage of controlling for natural differences in substrate among exposed and reference areas, but may bias collections toward organisms that happen to drift from upstream and colonize on the substrates over the short (typically 6-week) period they are deployed. The latter point may also partially explain why high year-to-year variability has been observed in previous benthic community assessments at Faro.

To determine the best long-term approach for benthic community monitoring, it is recommended that the IAEMP include parallel sampling of resident benthic communities at the same time that artificial substrates are retrieved in fulfillment of monitoring requirements at the Faro and Vangorda sites under the Water License. This would involve sample collection at each of the two sites in alternate years. A control-impact sampling design will be followed, in which community characteristics at exposure areas will be statistically compared to those at reference areas. This will necessitate field reconnaissance and exploratory sampling during the IAEMP to identify additional reference areas possessing similar habitat characteristics to the mine-exposed areas. In addition, the number of replicate samples collected per area will be increased from three to five to improve statistical power, and the samples will be taken sufficiently far apart to be considered stations within areas, rather than replicate samples within stations. Statistical comparisons will be made for a variety of community metrics such as density, number of taxa, Bray-Curtis similarity index, Simpson's evenness index, and proportions of dominant taxa. Recommendations for the LTMP will be made on the basis of IAEMP results.

9.3.4 Fish

Fish tend to occupy the upper trophic levels of aquatic ecosystems and are often their most visible and valued components. Both population and community-level assessment can be used as indicators of longer-term exposure conditions (e.g., over years). Therefore, changes in fish community composition and relative species abundance should be tracked at

key near-field locations near the Faro complex (R2 and V8) over time and compared to the communities at two or more reference areas possessing similar habitat characteristics. The recommended methods for fish community characterization are similar to those used in previous surveys with modifications to allow for greater standardization of fishing effort and quantification of results. In brief, block-netting should be used, if possible, to enclose sampling areas, with Moran-Zippin methods used to estimate relative species abundances.

In addition, fish health will be assessed using a sentinel species approach similar to that required for federal environmental monitoring programs, which will target collection of slimy sculpin. Fish collection during the IAEMP will focus on determining the appropriate seasonal timing (pre- or post-freshet in spring versus fall) and sampling design (lethal or non-lethal survey) for the LTMP.

9.3.5 Triggers for Change

Future increase or decreases in the scope and/or frequency of aquatic ecosystem monitoring, including surface water, should be triggered by temporal changes in loadings of key contaminants at stations around the perimeter of the Faro complex. It will be important that the selected stations capture all significant contaminant sources. Trigger values should be based on the change in loading predicted to result in a measurable change in downstream water quality for a given parameter. Specific follow-up actions should be identified so that stakeholders understand how the program will change as environmental conditions change. The loadings-based numeric triggers should be developed during the IAEMP so they can be agreed upon and implemented as part of the LTMP.

9.4 Long Term Monitoring of Aquatic Ecosystems

Details of the aquatic ecosystem monitoring sub-program of the LTMP will be finalized based on data collected during the IAEMP. It is anticipated that the frequency of biological monitoring and reporting will be reduced to a 5-year cycle, although surface water quality data should continue to be assessed and reported annually. The costs associated with additional data collection over the short-term (e.g., two to three years for the IAEMP) are expected to be greatly offset by savings realized by the implementation of a streamlined, scientifically defensible monitoring program over the longer term (e.g, hundreds of years for the LTMP). Both the scope and frequency of long-term monitoring should evolve in response to program findings. A rigorous quality assurance plan has been outlined to ensure all monitoring data will reliably serve the project objectives.

10.0 REFERENCES

ACG, LES, and WMEC (Access Consulting Group, Laberge Environmental Services, and White Mountain Environmental Consulting). 2006. Pelly River Aquatic Effects Assessment – 2005. Prepared for the Selkirk First Nation.

APHA (American Public Health Association). 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edition. Prepared and published jointly by the American Public Health Association, American Water Works Association and Water Environment Federation. APHA, Washington DC.

Bahls, L.L. 1993. *Periphyton bioassessment methods for Montana streams.* Montana Water Quality Bureau, Department of Health and Environmental Science, Helena, Montana.

Bailey, J., T.B. Reynoldson, and R.C. Bailey. 2006. Reference Condition Approach Bioassessment of Yukon River Basin Placer Mining Streams Sampled in 2006. Draft. February 2007.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Beak International Inc. 1999. Quality Assurance Program of Assessing Mine-Related Effects Using Benthic Invertebrate Communities. Prepared for Aquatic Effects Technology Evaluation (AETE) Program, Canada Centre for Mining and Energy Technology (CANMET), Ottawa, Ontario. February 1999.

Bernstein B. B. and Zalinski J. 1983. An optimum sampling design and power tests for environmental biologists. J. Environ. Manag. 16: 335-343.

Bowman, M.F. and K.M. Somers. 2005. Considerations when Using the Reference Condition Approach for Bioassessment of Freshwater Ecosystems. Water Qual. Res. J. Canada 40(3): 347-360.

Branton, M.A., Manson, M.M., and Galbraith, R.V. 2006. Application of the Canadian Aquatic Biomonitoring Network and reference condition approach to Canada's Pacific Wild Salmon Policy. Can. Manuscr. Rep. Fish. Aquat. Sci. 2770: v + 29p.

Brasfield, S. 2007. Investigating and interpreting reduced reproductive performance in fish inhabiting streams adjacent to agricultural operations. PhD Thesis, University of New Brunswick, Saint John, NB.

Burns, B.E. 2000. Biological Monitoring Program at Vangorda Creek, Faro, Y.T. 1999. Laberge Environmental Services. Prepared for Deloitte & Touche Inc.

Burns, B.E. 2001. Biological Monitoring Program at Rose and Anvil Creek, Faro, Y.T. 2000. Laberge Environmental Services. Prepared for Deloitte & Touche Inc.

Burns, B.E. 2002a. Biological Monitoring Program at Vangorda Creek, Faro, Y.T. 2001. Laberge Environmental Services. Prepared for Deloitte & Touche Inc.

Burns, B.E. 2002b. Biological Monitoring Program at Rose and Anvil Creek, Faro, Y.T. 2002. Laberge Environmental Services. Prepared for Deloitte & Touche Inc.

Burns, B.E. 2003. Biological Monitoring Program at Vangorda Creek, Faro, Y.T. 2003. Laberge Environmental Services. Prepared for Deloitte & Touche Inc.

Burns, B.E. 2004. Biological Monitoring Program at Rose and Anvil Creek, Faro, Y.T. 2004. Laberge Environmental Services. Prepared for Deloitte & Touche Inc. December 2004.

Burns, B.E. 2005 Biological Monitoring Program at Vangorda Creek, Faro, Y.T. 2005. Laberge Environmental Services. Prepared for Deloitte & Touche Inc. November 2005.

Burns, B.E. 2006. Biological Monitoring Program at Rose and Anvil Creek, Faro, Y.T. 2006. Laberge Environmental Services. Prepared for Deloitte & Touche Inc.

Cairns, J., Jr. 1982. *Artificial substrates.* Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

Cairns, J., Jr. and R.L. Kaesler. 1971. Cluster analysis of fish in a portion of the Upper Potomac River. *Transactions of the American Fisheries Society* 100:750-756.

Campbell, P.G. 1995. Interactions between trace metals and aquatic organisms: A critique of the free-ion activity model. In Tessier A, Turner DR, eds, *Metal Speciation and Bioavailability in Aquatic Systems.* John Wiley, New York, NY, USA, pp 42–102.

Coker, G.A., C.B. Portt, and C.K. Minns. 2001. Morphological and Ecological Characteristics of Canadian Freshwater Fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2554. Fisheries and Oceans Canada.

Csuros, M. 1997. Environmental Sampling and Analysis: Lab Manual. Lewis Publishers, Boca Raton.

Deaver, E. and J.H. Rodgers. 1996. Measuring bioavailable copper using anodic stripping voltammetry. Environ. Toxicol. Chem. 15:1925-1930.

DiToro, D.M., J.A. McGrath, D.J. Hansen, W.J. Berry, P.R. Paquin, R. Mathew, K.B. Wu, and R. Santore. 2005. Predicting sediment metal toxicity using a sediment biotic ligand model: methodology and initial application. Environ. Toxicol. Chem. 24:2410-2427.

Environment Canada. 1994. Guidance Document on Collection and Preparation of Sediments for Physicochemical Characterization and Biological Testing. Report EPS 1/RM/29. December 1994.

Environment Canada. 1997a. Biological Test Method: Test for Survival and Growth in Sediment Using the Freshwater Amphipod *Hyallel azteca*. EPS 1/RM/33. December 1997.

Environment Canada. 1997b. Biological Test Method: Test for Survival and Growth in Sediment Using the Larvae of Freshwater Midges (*Chironomus tentans* or *Chironomus riparius*). EPS 1/RM/32. December 1997.

Environment Canada. 2002. Metal Mining Guidance Document for Aquatic Environmental Effects Monitoring. Environment Canada Report EEM/2002/1. June 2002.

Environment Canada. 2005. Further Guidance for Non-Lethal Sampling. January 2005.

ESG International Inc. 1999. Aquatic Effects Technology Evaluation (AETE) Program Synthesis Report of Selected Technologies for Cost-Effective Environmental Monitoring of Mine Effluent Impacts in Canada (AETE Synthesis Report). Prepared for Canada Centre for Mining and Energy Technology, Ottawa, Ontario. March, 1999.

EVS Environmental Consultants. 1997. Technical Evaluation: Water Quality and Biological Effects. Prepared for Canada Centre for Mining and Energy Technology (CANMET) and Mining Association of Canada (MAC) for the Aquatic Effects Technology Evaluation (AETE) Program. May, 1997.

EVS Environmental Consultants, Ecological Services for Planning Ltd., and Jacques Whitford Environment Ltd. 1997. Field Evaluation of Aquatic Effects Monitoring: 1997 Study Design. Prepared for CANMET, Ottawa, Ontario. January 1997.

EVS Environmental Consultants. 1999. Technical Evaluation of Fish Methods in Environmental Monitoring for the Mining Industry in Canada: Final. Prepared for Aquatic Effects Technology Evaluation (AETE) Program, Canada Centre for Mining and Energy Technology (CANMET), Ottawa, Ontario. February 1999.

Feltmate, B.W., and B.G. Fraser. 1999. Determining Metal Related Impacts Utilizing Benthic Macroinvertebrate Population Level Fitness Parameters: Discussion Paper. Prepared for Canada Centre for Mining and Energy Technology (CANMET) and Mining Association of Canada (MAC) for the Aquatic Effects Technology Evaluation (AETE) Program. February 1999.

Funk, J.L. 1957. Movement of stream fishes in Missouri. *Transactions of the American Fisheries Society* 85:39-57.

Gerking, S.D. 1959. The restricted movement of fish populations. *Biological Review* 34:221-242.

Glozier, N.E., J.M. Culp, and D. Halliwell. 2002. Revised Guidance for Sample Sorting and Subsampling Protocols for EEM Benthic Invertebrate Community Surveys. Environment Canada.

Godin, B., and T. Osler. 1985. Environmental Quality of Rose Creek as Affected by Discharges from the Cyprus Anvil Mine, Yukon Territory (1983). Environment Canada, Environmental Protection Service. Regional Program Report No. 85-12.

Golder Associates Ltd. 1995. Review of Artificial Substrates for Benthos Sample Collection. Sponsored by the Canada Centre for Mineral Technology (CANMET) and the Mining Association of Canada on Behalf of the Aquatic Effects Technology Evaluation (AETE) Program. Project 2.1.1. June 1005.

Gray, M.A., R.A. Cunjak, and K.R. Munkittrick. 2004. Site fidelity of slimy sculpin (Cottus cognatus): insights from stable carbon and nitrogen analysis. Can. J. Fish. Aquat. Sci. 61:1717-1722.

Hall, G. 1998. Cost-Effective Protocols for the Collection, Filtration and Preservation of Surface Waters for Detection of Metals and Metalloids at ppb (ug l^{-1}) and ppt (ng l^{-1}) levels. Phase I: Evaluation of Bottle Type, Bottle Cleaning, Filter and Preservation Technique. Submitted to Aquatic Effects Technology Evaluation Program. April 1998.

Hoos, R.A.W., and W.N. Holman. 1973. A Preliminary Assessment of the Effects of Anvil Mine on the Environmental Quality of Rose Creek, Yukon. October 1973.

Horowitz, A.J., K.R. Lum, J.R. Garbarino, G.E.M. Hall, C. Lemieux, and C.R. Demas. 1996. Problems associated with using filtration to define dissolved trace element concentrations in natural water samples. Environ. Sci. Technol. 30:954-963.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. *Assessing biological integrity in running waters: A method and its rationale.* Special publication 5. Illinois Natural History Survey.

McKay, D., S. Sharpe, T. Cahill, T. Gouin, I. Cousins, and L. Toose. 2001. Assessing the Environmental Persistence of a Variety of Chemical Substances Including Metals. Prepared for Environment Canada. November 2001. CEMC Report No. 200104.

McQuaker, N.R. 1999. Technical Evaluation on Sample Collection, Handling, Analysis and Interpretation for Trace Level Contamination in Water. Edited by C. Dumaresq, Environment Canada. Prepared for Natural Resources Canada, Canada Centre for Mineral and Energy Technology, Ottawa, Ontario. January 1999.

Minnow Environmental Inc. and I.D. Martin Biological Consulting. 2007. Comparison of Benthic Invertebrate Community Surveys at Ontario Mines Using Control-Impact Designs Versus the Reference Condition Approach. Report Prepared for: Williams Operating Corporation, Golden Giant Mine, and Red Lake Gold Mines. February 2007.

Minnow Environmental Inc. 2007. Ecological Impact Assessment, Faro Mine, Yukon. Prepared for Faro Mine Closure Office, Whitehorse, Yukon. May 2007.

Ongley, E.D. 1996. Control of water pollution from agriculture - FAO irrigation and drainage paper 55. Chapter 2: Pollution by Sediments. Food and Agriculture Organization of the United Nations, Rome, 1996.

Osenberg, C. W., and R. J. Schmitt. 1996. Detecting ecological impacts caused by human activities. Pages 3-16 in C. W. Osenberg and R. J. Schmitt, editors. Detecting ecological impacts; concepts and applications in coastal habitats. Academic Press, San Diego, California, USA.Patnaik, P. 1997. Handbook of Environmental Analysis: Chemical Pollutants in Air, Water, Soil, and Solid Wastes. Lewis Publishers, Boca Raton.

Prothro, M. 1993. Technical Memorandum Regarding Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria. U.S. Environmental Protection Agency. October 1, 1993. 40CFR§131.36(b)(1). Available at: http://www.epa.gov/waterscience/library/wqcriteria/metalsinterpret.pdf

Reynoldson, T. B., Norris, R.H., Resh, V.H., Day, K.E. and Rosenberg, D.M. 1997. The reference condition approach: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrate. J. North Am. Benthol. Soc. 16:833-852.

Reynoldson, T.B., C.I. Brereton, W. Keller, and C. Sarrazin-Delay. 2005. Development of a Northern Ontario Benthic Invertebrate Reference Condition Approach (RCA) Biomonitoring Network to Meet Metal Mining Environmental Effects Monitoring Requirements (DRAFT). January 2005.

Rosenburg, D.M., T.B. Reynoldson, P.F. Reece, and V.H. Resh. 1998. Design of a Regional Biomonitoring Program for the Fraser River Basin. FRAP Report No. DOE FRAP 1998-32.

Sarrazin-Delay, C.L., M.F. Bowman, W. Keller, and K.M. Somers. 2006. Summary of the Model-Building Results for the Northern Ontario Benthic Invertebrate RCA Biomonitoring Initiative: 2003-2006.

Scott, W.B. and E.J. Crossman. 1998. Freshwater Fishes of Canada. Galt House Publications, Oakville, Ontario.

Senes Consultants Limited. 2006. Anvil Range Mine Tier 2 Ecological and Human Health Risk Assessment of Remediation Scenarios. Prepared for Deloitte and Touche Inc., Interim Receiver of Anvil Range Mining Corporation. April 2006.

Smith, E.P., D.R. Orvos, and J. Cairns, Jr. 1993. Impact assessment using the before-afterontrol-impact (BACI) model: concerns and comments. Canadian Journal of Fisheries and Aquatic Sciences 50:627-637.

SRK Consulting Engineers and Scientists. 2004. Water Quality Estimates for Anvil Range Waste Rock (Draft). Prepared for Deloitte and Touche Inc. November 2004.

SRK Consulting Engineers and Scientists. 2005. Project Memorandum: Faro Tailings Source Term Calculations. From John Chapman. Dated June 14, 2005.

SRK Consulting Engineers and Scientists. 2006. Anvil Range Mining Complex: Site Water and Load Balance (Draft). 2005/06 Task 19C. Prepared for Deloitte and Touche on Behalf of the Faro Mine Closure Planning Office. September 2006.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "psuedoreplication" in time? Ecology 67:929-940.

Sylvestre. S., Fluegel M. and Tuominen T. 2005. Benthic invertebrate assessment of streams in the Georgia Basin using the Reference Condition Approach: Expansion of the Fraser River invertebrate monitoring program 1998-2002. Environment Canada, Vancouver, B.C., 194 p.

Taylor, B.R. 1997. Optimization of Field and Laboratory Methods for Benthic Invertebrate Monitoring: Final Report. Prepared for Canada Centre for Mineral and Energy Technology, Ottawa, Ontario. January 1997.

Taylor, B.R., and R.C. Bailey. 1997. Technical Evaluation for Benthic Invertebrate Data Analysis and Interpretation: Final Report. Prepared for Canada Centre for Mineral and Energy Technology, Ottawa, Ontario. June 1997.

Underwood, A. J. 1991. Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. Australian Journal of Marine and Freshwater Research 42:569-587.

Underwood, A. J. 1992. Beyond BACI: The detection of environmental impacts on populations in the real, but variable, world. Journal of Experimental Marine Biology and Ecology 161:145-178.

Underwood, A. J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4:3-15.

Underwood, A. J., and M. G. Chapman. 2003. Power, precaution, Type II error and sampling design in assessment of environmental impacts. Journal of Experimental Marine Biology and Ecology 296:49-70.

Warren, M.L., Jr., and B.M. Burr. 1994. Status of freshwater fishes of the US: Overview of an imperiled fauna. Fisheries 19(1):6-18.

WMEC (White Mountain Environmental Consulting). 2004. Aquatic Life Sampling and Testing Program for the Anvil Range Mine Site, Rose and Vangorda Creek Watersheds, Faro, Yukon. Prepared for Deloitte and Touche Inc. October 2004

WMEC (White Mountain Environmental Consulting). 2005. Aquatic Life Sampling and Testing Program for the Anvil Range Mine Site, Rose and Vangorda Creek Watersheds, Faro, Yukon. Prepared for Deloitte and Touche Inc. December 2005.

Yukon Placer Aquatic Health Working Group. 2007. Yukon Placer Mining Industry Aquatic Health Monitoring Protocol. January 2007.

APPENDIX A

STANDARD OPERATING PROCEDURES FOR FIELD MEASUREMENTS

A1.0 PH MEASUREMENT

pH is the logarithm of the reciprocal of the hydrogen ion concentration. Most surface waters in Canada have pH values between 6 and 9. Waters with pH below 7 are acidic, while those with pH above 7 are alkaline. pH is considered to be a master variable controlling the chemical form (speciation) of metals and nutrients in aquatic systems. Low pH will generally result in metals being present in their ionic form, which are most available to aquatic organisms. The combination of the direct effects of high hydrogen ion concentrations (low pH) and the indirect effects of increased ionic metal can reduce biodiversity. The instrument (meter) method of measuring pH is usually most appropriate.

A1.1 Procedure

A wide variety of pH meters and multimeters with pH probes are currently in use. Refer to the operation manual of your meter for detailed operating instructions.

Direct measurement of pH can be done in the field. Prior to any use, the meter must be calibrated using a minimum of two pH calibration standards. Operators will follow manufacturer's instructions for proper calibration, use, storage and maintenance of the specific meter. Calibration of the pH meter should be verified at least daily. The meter must be re-calibrated or replaced if the meter readings do not meet project objectives for minimum detectable differences, precision, and accuracy. The two standards chosen for calibration should bracket the pH of the water being monitored. The exact calibration procedure for each pH meter may vary slightly from the procedure outlined here and is outlined in the meter-specific operation manual. To calibrate, press the <CAL> "calibration" key and place the standards in plastic or glass bottles. Set the temperature of the pH standards (if required) and immerse the probe into the standard, stir gently and press the <RUN/ENTER> key. When in calibration mode, most new meters will recognize the pH of the buffer solution and automatically calibrate. Allow the reading to stabilize. Many newer meters have an icon indicating that a stable reading has been reached. Once the reading has stabilized remove the probe and rinse with distilled water. Pat the probe dry with a paper towel and immerse the probe into the second standard. Record the calibration process in the meter calibration log book, including the % slope.

To record pH in the field, simply place the probe in the water or in a water sample and turn the meter on. Stir the sample and allow the reading to reach equilibrium. In soft waters this may take a long time (>2 minutes). Record the pH on the appropriate data

sheet. Corresponding depth should be recorded for all pH measurements according to the calibrated probe line when producing a profile. If the water is deeper than the probe line, pH can be read directly from the water samples collected at depth (e.g., with beta bottle or Kemerer).

When the pH probe is not in use, the end should be immersed in potassium chloride (KCl, generally 4 M).

A1.2 Records

Accurate field books must be kept, including all instances of pH meter calibration. All data collected should be recorded in the dedicated field notebook and/or on the supporting data field sheets.

A1.3 Maintenance

In general, the only maintenance required for the pH meter is battery replacement and probe cleaning. All maintenance should be conducted in accordance with the manufacturer's instructions.

A2.0 CONDUCTIVITY MEASUREMENT

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability will depend upon the type and concentration of ions present in the sample and on the temperature of the solution on which the measurement is made. Conductivity provides insight into the total concentration of ions (e.g., high metal concentrations) and also into the chemical behaviour of metal ions in solution (i.e., a higher proportion of metals will be in ionic form in a solution of high ionic strength). It also provides insight into the biological uptake of metals ions (i.e., ion balance issues can become challenging at high ionic strength). Conductivity is measured with a calibrated conductivity meter.

A2.1 Procedure

A variety of conductivity meters and multimeters with conductivity probes are currently in use. The units in which conductivity is expressed may vary among meters and may be expressed as μS/cm, μmhos/cm, or simply as cm^{-1}. Refer to the operations manual of your meter for detailed operating instructions.

Conductivity measurements can be taken by direct measurement in the field. Prior to use, the meter must be calibrated and/or verified using a calibration standard. Operators will follow manufacturer's instructions for proper calibration, use, storage and maintenance of the specific meter. When sampling is conducted over many days, the conductivity meter should be calibrated or verified at least daily. The exact calibration procedure for each conductivity meter is outlined in the meter-specific operation manual and may vary slightly from the procedure outlined here. To calibrate, press the <CAL> ("calibration") key and place enough standard in a small container to allow for a reading. Immerse the conductivity measuring cell (probe) in the control standard solution and press <RUN/ENTER>. Most new meters have an icon indicating that a stable reading has been reached. Once the reading has stabilized remove the probe, rinse with distilled water and pat dry with a paper towel. Record the calibration results in the meter calibration log book, including the determined cell constants relative to the accepted range.

Following calibration, conductivity measurements can be taken in the field. To record conductivity in the field, simply place the probe in the water or in a water sample and turn the meter on. Stir the sample and allow the reading to reach equilibrium. Record the temperature (switch MODE to TEMPERATURE and read the meter when reading stabilizes) and the conductivity (switch MODE to appropriate conductivity scale for on-

scale meter readings) on the appropriate data field sheet. Corresponding depth should be recorded for all conductivity measurements according to the calibrated probe line when producing a depth profile. If the water is deeper than the probe line, conductivity can be read directly from water samples collected at depth (e.g., with beta bottle or Kemerer).

Some conductivity probes may require wet storage. If this is the case, store in a dilute solution of potassium chloride (KCl). Each conductivity cell constant is recorded in the meters log book. Should, at any point, the cell reach conductivity values more than ±5.0% of the original cell constant, cleaning may be necessary. Cleaning should be conducted by submersing the cell in HCl foam cleaning solution. If the % error in conductivity is still greater than ±5% then the probe should be sent in for evaluation or replacement. Any cleaning or replacement of the probe is to be noted in the meter log book.

If properly calibrated, interferences are minimal. This method is applicable to surface water, groundwater and wastewater with specific conductance values greater than 0.5 μS. The minimum detectable conductivity obtainable with this method is generally 0.2 μS.

A2.2 Records

Accurate field books must be kept, noting all instances of conductivity meter calibration. All data collected should be recorded in the dedicated field notebook and/or in the supporting data field sheets.

A2.3 Maintenance

In general, the only maintenance required for the conductivity meter is battery replacement and probe cleaning. All maintenance will be conducted in accordance with the manufacturer's instructions.

A3.0 DISSOLVED OXYGEN MEASUREMENT

Measurement of the dissolved oxygen in water provides information on the chemical and biological status of a waterbody. Oxygen is a requirement of aerobic life and low levels of dissolved oxygen can indicate low biodiversity. In addition, oxygen is the ultimate electron donor; therefore its presence indicates an oxidizing environment. Thus, most metals and nutrients will be present in their most oxidized state in water with high concentrations of dissolved oxygen.

Dissolved oxygen is measured with a calibrated dissolved oxygen (DO) meter. A variety of DO meters and multimeters with DO probes are currently in use. Most meters automatically measure and compensate for temperature and can be adjusted for salinity. Probes are typically composed of two electrodes (a gold cathode and a lead anode) in an electrolyte solution behind a Clark-type membrane. Probes are usually equipped with a thermistor. This method is applicable to surface waters and waste waters with dissolved oxygen concentrations greater than 0.1 mg/L.

A3.1 Procedure

A variety of DO meters and multimeters with DO electrodes are currently in use. The units in which dissolved oxygen is usually expressed are mg/L and % saturations. Refer to the operations manual of your meter for detailed operating instructions.

Dissolved oxygen measurements can be taken by direct measurement in the field. Prior to any use, the meter must be calibrated with saturated water or a standard. Operators will follow manufacturer's instruction for proper calibration, use, storage and maintenance of the specific meter. Calibration of the DO meter must be conducted at least daily. Each time the meter is turned off, it may be necessary to re-calibrate before taking measurements. The meter must be re-calibrated or the membrane replaced if the meter readings do not meet project objectives for minimum detectable differences, precision, and accuracy. The exact calibration procedure for each DO meter may vary slightly from the procedure outlined below and is outlined in the meter-specific operation manual. Typical procedures for calibrating a digital (e.g., YSI Model 85, WTW Oxi) DO meter are outlined here. The calibration is performed in water vapour-saturated air usually within a supplied calibration vessel. Turn the meter on and set the measuring mode to read mg/L or % saturation. Wait for the dissolved oxygen and temperature readings to stabilize (usually 15 minutes is required). Press the <CAL> "calibration" key until the oxygen calibration mode appears and then press <RUN/ENTER>. Certain DO meters will require the operator to know and enter the approximate altitude of the region

in which the meter is being used. When the measured value is stable, the instrument displays the value of the relative slope and the sensor evaluation. Record the calibration process in the meter calibration log book, including the determined slope and sensor evaluation.

Following calibration, DO measurements can be taken in the field.

A3.1.1 Determination of DO Concentration

Stream DO measurements should be taken just below the surface of the water. In lakes, DO should be measured at depth intervals within the water column to obtain a DO profile. In order to take the measurements within the water column, an extended cable should be attached to the DO probe. It is important to ensure that the probe is not inserted into the mud when obtaining the DO measurement.

1. Place the probe into the water column and gently move it in a circular motion, while remaining at the same depth.
2. Adjust salinity control if necessary.
3. Read dissolved oxygen, while continuing to gently move the probe.
4. The instrument should be left on between measurements to avoid the necessity of re-calibrating the probe.
5. Repeat Steps 1-4 for subsequent measurements.

The probe should be stored in calibration solution and must be kept moist at all times. Record the DO on the appropriate data field sheet. Corresponding depth and temperature should be recorded for all DO measurements according to the calibrated probe line when producing a profile. If the water is deeper than the probe line, DO can be read directly from water samples collected at depth (e.g., with beta bottle or Kemerer).

A3.2 Records

Accurate field records must be kept, noting all instances of DO meter calibration. All data collected should be recorded in the dedicated field notebook and/or in the supporting data field sheets.

A3.3 Maintenance

The membrane should be replaced under any of the following conditions:

1. Deposit on the transparent surface near the gold cathode (also remove smudge by wiping with lab wipe and flushing with potassium chloride (KCl)).
2. Probe has dried out and crystals have formed under the membrane (also flush the crystals out).
3. Large bubble(s) inside of membrane.
4. If erratic operation is observed or a calibration is not stable.
5. If holes or wrinkles are present in membrane.
6. If gold cathode is discoloured (also remove tarnish by vigorously wiping with a soft cloth or immerse for one minute in 25% acetic acid and rinse thoroughly with distilled de-ionized water).

If the gold cathode turns silver, return to the manufacturer for refinishing. To replace the membrane, disconnect the probe and remove the membrane (or membrane head in the case of some newer models). Rinse the electrode and polish away any impurities on the electrode. Rinse the electrode and immerse it in a cleaning solution for one to three minutes. Rinse the electrode several times and shake to remove all water drops. Fill the sensor headspace with electrolyte solution and replace the membrane, avoiding the introduction of air bubbles. In many newer models, entire membrane head units can simply be interchanged.

Replace the batteries when the LCD display a “low battery” icon.

A4.0 TEMPERATURE MEASUREMENT

Temperature is a useful measure of the thermal status of a water body. Temperature can influence the distribution of species, the rate of chemical reactions, the rate of biochemical reactions and the metabolic rate of organisms. Most temperate lakes have thermal gradients with depth in certain seasons (particularly summer and winter) and a thermocline that corresponds to the mixing depth.

A4.1 Procedure

The measurement of temperature usually requires no additional equipment, since most field meters (and all conductivity and dissolved oxygen meters) are equipped with a thermistor. Therefore, temperature measurement simply involves recording the temperature while taking the conductivity and/or dissolved oxygen readings. A standard glass thermometer should be brought into the field to verify the accuracy of the thermistors.

A4.2 Records

Accurate field books must be kept, noting all instances of meter verification. All data collected should be recorded in the dedicated field notebook and/or in the supporting data field sheets.

A4.3 Maintenance

Temperature measurements are taken using conductivity and dissolved oxygen meters. All maintenance will be conducted in accordance with manufacturer's instructions. No additional maintenance is required for the temperature thermistors.

APPENDIX B

STANDARD OPERATING PROCEDURES FOR SAMPLING

APPENDIX B: SAMPLING METHODS

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B1.0 WATER SAMPLING

B1.1 Preparation and Materials

Prior to departure for sampling, all field equipment should be checked for functionality and cleanliness. All equipment, calibration standards, sampling gear and sample bottles should be assembled in clean, dry containers. The analytical laboratory chosen to analyze the samples will supply the appropriate sample containers for the collection of water. The laboratory should ensure that sample bottles are clean prior to delivery, although it should be noted that some laboratory practices such as adding a concentrated charge of acid (e.g., ≥ 8M HNO_3) may result in contamination (Hall 1998). High density polyethylene (HDPE) bottles are recommended as they require minimal pre-cleaning (e.g., distilled water or weak HNO3 solution; Hall 1998). Interestingly, the purchase of pre-cleaned (by the manufacturer/supplier) HDPE bottles was discouraged based on the potential for increased contaminantion, particularly of zinc (Hall 1998). Polypropylene (PP) bottles generally require cleaning if aluminum concentrations are of interest (Hall 1998). The use of teflon (FEP) bottles is not recommended.

Sample bottles should be ordered from the laboratory one week before the field trip or earlier if bottles need to be shipped ahead of time to the site.

Sample bottles will be labeled using a permanent marker, with labels appearing on the jars (not the lids). All sample bottles should be transported in large sealed coolers to prevent damage and reduce the risk of contamination. Several extra bottles should be included as a reserve in case of sample contamination, loss or breakage.

Preparation and materials must also include provision for quality control samples (e.g., blanks, field replicates). The number of field quality control samples taken must correspond to a minimum of 10% of the total number of samples taken during the sampling program.

The field crew must be experienced in the operation and safety requirements for all sampling gear, meters, equipment (e.g., boats) and reagents used in the water quality assessment. This should include having reviewed the study design and applicable standard operating procedures.

B1.2 Sample Collection

Water sampling in different aquatic environments involves different sampling techniques. Whenever sediment or benthic samples are also taken at a site, water samples should

always be taken first to avoid contamination. Samples should only be collected if it can be done safely.

The same protocol for rinsing of sample bottles must be followed in all sampling environments. If sample bottles have not been pre-cleaned and pre-preserved by the laboratory, then they must be rinsed three times with either de-ionized water or sample water prior to collecting the sample. The exceptions to this are when a sample is to be analyzed for suspended sediments, for contaminants likely associated with the suspended solids, or for oil and grease. In these cases, the bottles should not be rinsed with sample water as suspended particles or grease-like materials are retained on the interior surface of each bottle with each rinsing.

Wherever practical, samples should be collected away from rather than near shore. If the water body has no or slow flow such that the collector can wade in, then the sample can be collected at a depth that does not pose a threat to the safety of the sample collector. When conditions, such as a strong flow or thin ice, dictate that the sample be taken from shore (e.g., stream bank), deviations from the standard protocol should be accurately documented in a field notebook.

B1.2.1 Wading to Sample Collection Point

Obtain labelled bottles and wade to the sampling point. In creeks/rivers, wade in downstream from the point at which the samples will be collected, and then wade upstream to the sample site. Continue to stand perpendicular to the flow and face upstream to collect the sample. This minimizes sediment disturbance in the vicinity of the sample point.

If rinsing is required as described above, then proceed from step (a), otherwise start at step (e).

a) Grasp the bottle well below the neck. Plunge it beneath the surface in front of you to a depth of 20 cm (if possible) with the opening facing directly up, then remove the lid underwater and let the bottle fill with water. This avoids collection of surface materials in the container.

b) Once the bottle is full, replace the lid underwater, remove the bottle from the water and shake it vigorously.

c) Remove the lid and reach back towards shore to pour the water out.

d) Repeat steps (a) through (c) twice more before collecting the sample.

e) Grasp the bottle well below the neck. Plunge it beneath the surface in front of you to a depth of 20 cm (if possible) with the opening facing directly up, then remove the lid underwater and let the bottle fill with water.

f) Once the bottle is full, replace the cap underwater and remove the bottle from the water. Samples should be filled to the very top to minimize air space.

B1.2.2 Sampling from a Stream Bank

a) Be careful not to disturb sediments or debris along the shoreline and avoid sampling any disturbed areas by sampling upstream of where you are. As a safety precaution, the second person must remain nearby while the first is collecting the samples.

b) If sample containers do not contain preservatives and the samples are not being collected for analysis of suspended solids or oil/grease, rinse three times as described in Section B1.2.1 a) to d).

c) Hold the bottle well below the neck.

d) Reach out upstream (arm length only) and plunge the bottle beneath the surface in front of you to a depth of 20 cm (if possible) with the opening facing directly up, then remove the lid underwater and let the bottle fill with water.

e) When the bottle is full, replace the cap underwater and remove the bottle from the water.

B1.2.3 Sample Collection from a Boat

Surface Grab Samples

Once the sampling station is reached, anchor the boat and wait until it settles with the bow facing into the current, if applicable, before collecting the sample. Collect the samples as follows:

a) The person at the bow should always collect the samples because the bow is the anchor point and the boat will drift so that the bow is facing the current or wind direction. This precaution reduces the potential for contamination from the boat and/or motor.

b) Obtain a labeled sample bottle. If sample containers do not contain preservatives and the samples are not being collected for analysis of suspended solids or oil/grease, rinse three times as described in Section B1.2.1 a) to d).

c) Ensure that the person in the stern is providing counterbalance. Reach out an arm length from the boat to take the sample.

d) Plunge the bottle under the surface to a depth of approximately 20 cm and move it slowly towards the direction the boat is facing.

e) Once full, recap the bottle underwater and remove it from the water. Repeat procedure for the next sample.

Deep Grab Samples

Water samples may be collected from a specific depth using a Van Dorn or similar sampler (e.g. Beta Bottle) using the following protocol.

a) Ensure the sample bottle is clean.

b) Open the sampler by raising the end seals.

c) Set the trip mechanism.

d) Lower the sampler to the desired depth.

e) Send the messenger down to “trip” the mechanism that closes the end seals.

f) Raise the sampler to the surface.

g) Transfer the water from the bottle to a labelled sample container via the drain valve if collecting water samples for analyses. If sample containers do not contain preservatives and the samples are not being collected for analysis of suspended solids or oil/grease, rinse three times as described in Section B1.2.1 a) to d) before retaining the sample for laboratory analysis.

h) If only field measurements (e.g., pH, temperature, DO, conductivity) are being taken, then the probe of the water quality meter can be inserted directly into the sampler after removing one of the end seals.

B1.3 Field Filtration

If it is necessary to collect samples for analysis of dissolved metals, samples should be filtered and preserved in the field, rather than later at the analytical laboratory. This will minimize chemical reactions potentially affecting chemical speciation that can occur in the sample prior to filtration.

An assessment of field filtration units concluded that a Millipore Sterivex syringe with a Durapore membrane was superior to 11 other filtration systems in terms of overall

performance and ease of use (Hall 1998). A Gelman (now Pall) Acrodisc syringe filter with Supor membrane Gelman system also resulted in good performance but showed higher retention (filtration) of colloidal forms of some metals. The Millex LS 5 um syringe prefilter was recommended for samples high in particulate matter (Hall 1998). It was noted that nylon membranes should be avoided as they are slow and may show inferior performance.

B1.4 Supporting Information

Field measurements to be taken at all water sampling stations include pH, conductivity, dissolved oxygen (mg/L and % saturation) and temperature. These parameters should be measured in the field using appropriate meters and methods (See Appendix A). Given the wide variety of meters currently available (including single and multipurpose meters), operators should follow manufacturer's instructions for proper calibration, use, storage and maintenance.

All field measurements must be recorded, along with relevant site observations, on field sheets. Information recorded should include: station location and number, time and date of collection, sampler's name, general conditions (baseflow, freshet, during or following significant rain event or drought, etc.), water depth, type of sampler used (if applicable), any modifications to standard sampling methods required during sampling, and details pertaining to any unusual events which occurred during sampling (e.g., possible sample contamination, equipment failure, etc.). If meter failure occurs and no back-up meters are available, water samples should be collected and subjected as quickly as possible to laboratory analysis of pH and conductivity. A back-up measurement for dissolved oxygen can be obtained in the field using a Winkler Kit, which provides a rough measurement of dissolved oxygen concentration ($\pm$ 1 mg/L). Litmus paper should also be available as back-up for pH measurements, as well as a hand-held thermometer, in the event of meter failure.

B1.5 Sample Handling and Submission

From the time of collection to chemical analysis, all water samples should be maintained at or near 4°C in coolers or in a refrigerator. Samples should not be allowed to freeze. All samples should be submitted to the analytical laboratory (or laboratories) for chemical analysis within the required holding times for parameters to be analyzed.

All samples must be submitted to the appropriate laboratory for analysis according to the following schedules:

1. On the next business day following return from the field program; or
2. From the site before returning from the field program, if necessary, based on the maximum allowable holding times for samples.

The project manager should confirm the holding times for all sample analyses prior to going into the field and inform the field crew of sample submission schedules.

A Chain of Custody Record must accompany all samples being submitted in order to ensure that the laboratory receives all samples, that the required analyses are completed, and to facilitate efficient sample tracking. Most analytical laboratories will provide a Chain of Custody Record for samples submitted to their laboratory for chemical analyses. After completing the Chain of Custody Record, a copy should be retained and the original form should be submitted to the lab with the samples. A copy of the data quality objectives and any other necessary laboratory quality control procedures should also be provided to the lab with the samples.

B2.0 SEDIMENT SAMPLING

The analytical laboratory chosen to analyze the samples should supply appropriate sample containers for the type of analyses to be performed. Glass should usually be avoided (unless required for specific analysis such as low-level mercury) to minimize risk of breakage and associated loss of samples (PET or HDPE are generally adequate). Containers should have a wide enough mouth to facilitate transfer of sediment into the container.

Prior to departure for sampling, all field equipment should be checked for functionality and cleanliness. All equipment, calibration standards, sampling gear and sample jars should be assembled in clean, dry containers. Sample bags or jars should be labelled using a permanent marker prior to the field campaign, if possible, or immediately prior to collecting samples. All sample jars should be transported in large sealed coolers to prevent damage and reduce the risk of contamination. Extra jars should be included as a reserve in case the need arises for additional or replacement samples in the field.

The number of field quality control samples taken must correspond to a minimum of 10% of the total number of samples taken during the sampling program.

B2.1 Sample Collection

Sediment samples will generally be collected using one of two methods, either by grab sampling or core sampling. Core sampling is conducted when isolating a specific surficial sediment layer is critical to the study objectives or if specific depth intervals need to be sampled. Grab sampling is conducted in all other cases and is almost always used for the collection of samples for total organic carbon and particle size analyses which demand large sample volumes. Techniques for each method are outlined below.

B2.1.1 Core Samples

Core samples should be taken using a Kajak-Brinkhurst (K-B) or hand corer. The K-B corer consists of an upper head assembly including a trigger mechanism, plunger, and thread-in for the core tube metal sleeve. Outer metal sleeves are available in several lengths. The trigger mechanism includes a spring that provides tension on the trigger arm, keeping the plunger up until released by a messenger. Spare springs should be carried in case of damage or corrosion.

Core tubes are held in the outer metal sleeve using nose pieces. Core catchers may also be used to retain samples consisting of sand and/or clay that are not easily retained within the core tube. However, these devices may disrupt the upper layers of the sediment. Additional weights are also available to increase the penetration of the core tube into the sediment. In most soft sediments, these are not necessary.

In preparing the K-B corer for use, the steel outer sleeve is securely threaded into the head piece to ensure an airtight fit. A clean core tube is then slipped into the sleeve and secured with either the nose piece or with duct tape. The upper end of the plunger rod is inserted into the trigger mechanism and the corer lowered towards the bottom at a controlled rate. The K-B corer is lowered through the sediment-water interface using either wire or rope connected through the head piece. A messenger is attached to the wire prior to the final drop into the sediment. Care should be taken to avoid using overly large messengers, as they could damage the triggering mechanism. Tension should be kept on the line at all times to ensure that the sampler remains vertical.

A hand corer can be operated in a similar manner to the K-B corer, except it is pushed into the sediment by hand, rather than being lowered by a wire or rope.

In very soft sediments, care should be taken to ensure that the corer is not over inserted into the bottom. Once the sampler is dropped into the bottom, the messenger is released. When the messenger releases the plunger mechanism, the sampler can be retrieved smoothly, avoiding jerks, twisting and tilting. This will help minimize the loss of material from the bottom of the core and disturbance of the upper loose layers of the sediment. The sampler should then be pulled to the surface, capped with the extruder, after which the core sleeve is removed and the corer lifted off the inner core tube. An upper core cap should then be attached and secured with duct tape, avoiding any entrapment of air.

The sample should be visually inspected to ensure that the sampler was not over-inserted into the sediment. Evidence of over-insertion may include the presence of sediment all the way to the top of the core and murky overlying water. A successful core will have an intact sediment-water interface with no sign of channeling or sample washout, will be of the desired depth, and will exhibit no evidence that the core sampler was inserted on an angle or tilted on retrieval (i.e., loss of sediment). If the collected core sample fails any of these visual criteria then the sample should be discarded and sampling should be repeated at the same location. Rejected samples should be discarded in such a manner as to avoid contaminating subsequent samples. The

sampler should be washed free of particulates with site water and rinsed three times prior to the collection of each sample to prevent the contamination of the new sample.

Core Extrusion and Subsampling

Core extrusion can be conducted using a pressurized tank or manually. The pressurized tank method is recommended as it provides better control over the extrusion, resulting in increased accuracy in the incremental slices. A five-gallon soda-pop syrup canister tank (Challenger VI; Spartanburg Steel Products Inc.) is used to contain the air pressure. Prior to operating the pressurized extruder, check all lines and joints for notable leaks and bleed the lines of all air bubbles. Insert the core tube, ensuring that the bung is flush with the bottom of tube. Measure and record the total length of the core sample. Fill the port with water (to ensure that no air is trapped below the bung). Prior to inserting the core tube, siphon off excess water, making sure to leave 2 cm of water to avoid accidental removal of any of the sediment. With the base plate on a level stable surface, insert the core tube into the port with firm even pressure until the core tube is flush with the bottom of the port. As the tube is inserted, the bung will move up the tube. Once the core tube is fully inserted, fasten the clamps around the tube to stabilize.

Once the core tube has been inserted into the base plate port and secured, the core may be extruded part-way up the tube but not beyond 5 cm past the clamps. To initiate extrusion, gradually open the pressure valve until the bung slowly begins to move. It may be difficult to initiate movement due to the restriction placed on the tube and bung by the base plate clamps. If this occurs, simply undo the clamps and hold the core until the bung has passed at least 5 cm beyond the clamps. Replace the clamps at this point and measure the core length from the bottom of the bung to the surface of the sediment. Using gradual pressure to ensure smooth movement, continue extrusion until the surface sediment is flush with the top of the core tube.

To slice the cores into segments, use the appropriate core measuring extension (collar) and extrude the core to the desired depth. Once this has been done, slide the sectioning (slicing) device quickly between the core tube and the measuring extension. Once the core segment has been separated, remove the extension, and transfer the core segment from the sectioning device to a pre-labeled sample bag, remove air and seal. At this point, record the length of the remaining core from the sediment surface (which should be flush with the top of the core tube) to the bottom of the bung.

A minimum of two cores should be composited for each sample. The composite should be well mixed with a stainless steel or plastic spoon before transferring to the sample

container. Repeat the process outlined above for each core and record the number of cores collected for each sample. Samplers should be thoroughly cleaned between samples, using a brush to remove any material.

B2.1.2 Grab Samples

Grab samplers, sometimes called dredges, have spring-loaded or gravity-activated jaws that "bite" into unconsolidated surficial substrates (sand, silt, mud, etc.). These samplers are lowered on a line or cable from a survey vessel to the bottom, often with the aid of a winch. The effectiveness of grab samplers depends on the type of substrate, the depth of penetration, the angle the device strikes the bottom, the completeness of the closure, the loss of material during retrieval and the "shock wave" and subsequent washout of sample when the grab strikes the sediment surface. All of these factors will vary, depending upon the characteristics of the sampler used.

Two types of grab samplers are recommended for the collection of sediment samples. These are the Ponar or Ekman grab. Both are available in regular (9" x 9") and petite (6" x 6") sizes.

Ponar Grab

The Ponar grab is useful for sampling in lakes, rivers, estuaries and reservoirs with both hard and soft sediment such as clay, hard pan, sand, gravel and muck. The Ponar is somewhat less efficient in softer sediments because its weight can lead to over penetration and the potential loss of fine particles through the screens on the top of the jaws. This situation is often apparent upon retrieval as the screens appear to bulge. Such samples should be discarded. The Ponar may require the use of a boat with winch and cable, particularly when a large number of samples are to be collected in deep waters.

Ponar grab jaws are set by interlocking levers that are held in place by the weight of the sampler. The levers are released when the downward pressure on the rope or cable is removed. The sampler should not be lowered too quickly, particularly when the sampler approaches the bottom. Due to the screens on the jaws, the sampler retards the flow of water; thus, rapid lowering can create a pressure wave that can force sediment away from the area of penetration, resulting in a non-representative sample.

When the samples are retrieved, the sampler should be checked for proper closure. Lodged debris such as stones and pieces of wood may hold the jaws open causing a loss of material. If this occurs, samples should be discarded.

Ekman Grab

The Ekman grab is most usable in soft substrates such as muck and silt and is most effective where there is little current. Since the Ekman is substantially lighter than the Ponar, it is easy to use by hand. The Ekman sampler has a set of spring loaded jaws that are released when a messenger is sent from the surface. The surface of the sample should be checked upon retrieval to ensure that it has not been disturbed. Retrieval of the sampler should be done relatively slowly to prevent washout from the top flaps. If the sediment is sufficiently cohesive, the sampler can be placed in a tray, the two jaws retracted quickly, and the sampler lifted vertically away.

Taking Subsamples from Grabs

Sample removal from the grab should normally include only the surficial 3 cm layer. The grab sample should be placed in a clean plastic receptacle by releasing the sample from the Ponar and very carefully lifting the sampler straight up. Normally, the sample mass will retain its form and the surficial layer of interest may be removed using a plastic or stainless steel spoon or similar utensil for transfer to sample containers (500 mL PET jars). Samples can be taken from the Ekman grab through the top flaps. Two grabs should be taken and the top 3 cm composited in a clean plastic container for each sample. Composites should be well mixed with a stainless steel or plastic spoon before transferring into the sample container. A minimum of 450 mL of sample should be taken from the composite to provide sufficient sediment for analysis. Samplers should be thoroughly cleaned between samples, using a brush to remove any material.

B2.2 Supporting Information

Field observations must be reported on field sheets. Supporting information should include station location, date and time of sampling, field crew members, sampling method, description of sediment including texture and consistency, odour, presence of biota, core length (if applicable), water temperature, pH, dissolved oxygen, and conductivity near the sediment-water interface, general conditions (baseflow, freshet, during or following significant rain event or drought, etc.), any modifications to standard sampling methods required during sampling, and details pertaining to any unusual events which occurred during sampling (e.g., equipment failure, sample site inaccessible, etc.). Redox potential (Eh), if measured, should be done as soon as possible following collection, and the sample must receive minimal disturbance prior to measurement.

B2.3 Sample Handling and Submission

From the time of collection to chemical analysis, all samples should be maintained at or near 4°C in coolers or in a refrigerator. All samples should be submitted to the analytical laboratory (or laboratories) for chemical analysis as soon as possible. A Chain of Custody Record must accompany all samples being submitted in order to ensure that the laboratory receives all samples, that the required analyses are completed, and efficient sample tracking. Most analytical laboratory will provide a Chain of Custody Record for samples submitted to their laboratory for chemical analyses. After completing the Chain of Custody Record, a copy should be retained and the original form should be submitted to the lab with the samples. A copy of the data quality objectives and any other necessary laboratory quality control procedures should also be provided to the lab with the samples.

B3.0 BENTHIC SAMPLE COLLECTION

B3.1 Natural Substrates (Erosional Habitats)

Benthic invertebrates residing in erosional (coarse-substrate) habitats are usually sampled using a Hess or Surber sampler. A Hess sampler is highly efficient because it totally encloses the area to be sampled and therefore does not allow any invertebrates to escape by swimming or crawling away. However, in very low water depths, the water may not pass through the sampling net of a Hess and it may be necessary to use a Surber sampler. A five-minute sampling time for each sample should be sufficient to make sure all invertebrates from the area have been collected.

Samples should be taken by placing the sampler in a representative location at the sampling station and inserting it into the substrate to a depth of approximately 5-10 cm or as deep as substrate density permits. Using your hand or a small implement (garden claw), stir the enclosed area, lifting the disturbed substrate into the flowing water. This will allow benthos to be swept into the mesh bag, and washed free of substrate. Continue agitating the substrate until all the debris and invertebrates to a depth of 10 cm below the bed have been suspended and washed into the mesh. Larger rocks should be rigorously rubbed to remove invertebrates and then removed from the sampler so the finer material can be accessed. Repeat the procedure to obtain the desired number of samples for compositing at each station.

Once the entire sample has been collected, the sampler mesh will contain the (potentially composited) benthic sample. Transfer the sample to the labelled sample jars while holding the mesh and sample jars over a tub or bucket. Be careful to ensure that all invertebrates clinging to the mesh are removed before collecting the next sample.

B3.2 Artificial Substrates

An artificial substrate survey can be an effective alternative to a natural substrate survey due to the elimination of natural variability in substrate type. Several types of artificial substrate are available, including rock-filled baskets, Beak trays, rock-filled trays, and multiplate samplers such as the Hester-Dendy sampler (Golder 1995). Rock-filled baskets are the sampler of choice for most applications because they: 1) closely mimic natural substrata yet 2) permit standardization of sampler area, 3) provide abundant microhabitat for colonization, 4) produce low replicate variability, 5) are reasonably stable in currents, and 6) are easy and inexpensive to build (Golder 1995).

B3.2.1 Deployment

Artificial substrates can be deployed by wading, from a boat, or by SCUBA diving. Artificial substrates should be deployed such that replicates will be located at a consistent depth and a consistent distance above the substrate. This is achieved by tying the substrate to an anchor using a length of rope appropriate for the habitat. A small marker float is then used to mark the location of the sampler. To maintain data comparability, samplers should be placed at similar depths and current velocities in habitats with comparable substrate type. The date and time of sampler deployment should be recorded along with field measures of temperature, dissolved oxygen, conductivity, and pH.

The recommended time for substrate colonization is usually six weeks (USEPA 1990, Golder 1995). The low flow period from late summer to early fall is the best time for deployment (Golder 1995). Samplers should be replicated in each area to allow for robust statistical analysis of data and potential sampler loss (e.g., minimum six samplers per area; Golder 1995).

B3.2.2 Collection

Collection of artificial samplers is more difficult than deployment due to the possibility of losing invertebrates. In cases where the water is flowing, approach must be from downstream. Upon reaching the sampler, a fine-mesh net (e.g., 500 µm sieve bag) should be placed around the sampler, and closed tight before retrieving the sample to the surface for washing, sieving and storage.

Once in the boat or on shore, the sieve bag containing the substrate should be placed in a tub to catch any organisms that could potentially fall out during the process of sample transfer to bottles. The substrate can be placed in a labeled sample bottle of sufficient size to accommodate it, can be dismantled and placed in a sample bottle or can be fully scrubbed and only sample placed in a sample bottle. Regardless of the procedure used, all manipulation must be undertaken in the sieve bag and over a tub whose contents could be poured back into a sieve bag. Small scrub-brushes work best for removing colonized organisms from the substrates. Once the entire sample has been successfully transferred to a sample bottle (including a final rinse and examination of both the sieve bag and tub), place an internal label in the sample bottle, seal it, and place it in a safe place for storage. Repeat the entire sampling procedure for all subsequent samples.

B3.3 Sample Preservation, Handling and Submission

Samples must be preserved within eight hours of collection with buffered formalin solution (saturated with Borax or baking soda). The samples are preserved to a minimum dilution of 10% formalin. Samples should remain in an upright position during transport to the lab to avoid leakage of formalin. Sample shipping should be done by ground transport. A Chain of Custody Record must accompany all samples being submitted in order to ensure that the laboratory receives all samples and understands the analyses to be performed. After completing the Chain of Custody Record, a copy should be retained and the original form should be submitted to the lab with the samples. A copy of the data quality objectives and any other necessary laboratory quality control procedures should also be provided to the lab with the samples.

B3.4 Supporting Information

The careful recording and reporting of field observations will be critical for the proper interpretation of the benthic community data. Field observations must be reported on field sheets. Supporting information should include station location, date and time of sampling, field crew members, sampling method and sieve mesh size(s), wetted channel width and depth, sample depth, substrate texture observations, relative abundance of algae or other vegetation, water temperature, pH, dissolved oxygen, conductivity, general conditions (baseflow, freshet, during or following significant rain event or drought, etc.), any modifications to standard sampling methods required during sampling, and details pertaining to any unusual events which occurred during sampling (e.g., equipment failure, sample site inaccessible, etc.).

B4.0 FISH SAMPLING

B4.1 Preparation and Materials

The first step in conducting the fish survey will be to obtain a license to collect fish for scientific purposes. This license must be obtained from the local provincial or federal department office that is responsible for such licences. A licence request must generally include: target species, size and quantity of fish, waterbody(s) to be sampled, type of gear to be employed, the purpose of the survey, the names of persons doing the fishing, their training, any notable precautions and the proposed timing of the collection. A number of conditions are usually applied at the discretion of department staff.

All equipment, calibration weights, sampling gear and sample bags should be assembled in clean, dry containers. Fish collected at each station should be recorded on field sheets. Each fish should be uniquely identified and all data on that fish will be entered onto the record. Fish or tissue samples that will be transported to the laboratory for analyses should be placed in a container (e.g. Ziploc or whirl-pak bag for most tissues, small bottle/jar for ripe eggs) that has been labeled with a permanent marker.

B4.1 Quantifying Species Abundance in Riverine/Stream Habitat

Monitoring areas should be enclosed using nylon mesh barrier nets, located a set distance apart (e.g. 50 m), and spanning the entire width of the creek/river to define the sampling area. Stream morphology, substrate size, and total area should be similar and documented among sampling areas. Locations with relatively low gradient and/or small to moderate (cobble) substrate size are preferable for placement of upper and lower boundaries to ensure adequate closure of each area.

Fish communities within each enclosed area should be sampled using a battery-powered backpack electrofishing unit operated by a certified technician. An electrofishing team, consisting of the electrofisher operator and a netter should employ a multiple pass (i.e., K-pass) removal method whereby one upstream and downstream pass (i.e., a ‘sweep’) of the enclosed reach is repeated to yield population estimates for dominant species (e.g., slimy sculpin and grayling) using Moran-Zippin methods (Ricker 1975).

At the conclusion of each sweep, total shocking effort (i.e., electrofishing seconds), and electrofisher settings should be recorded and captured fish temporarily placed in an aerated bucket of water dedicated to that sweep. After electrofishing has been completed (i.e., after a consistent decrease in catches through three or more sweeps),

captured fish should be identified, enumerated, examined for external condition and measured for total length and fresh body weight, with separate data records for each sweep. Length should be taken using a standard measuring board (to the nearest 0.5 mm) and body weights recorded to the nearest 0.001 gram using an appropriate field balance (± 1% precision). After processing, all fish should be released to the waters from which they were captured.

At the conclusion of fish processing, the dimensions (length and width) of each enclosed station should be measured with a measuring tape and depth should be measured across several transects using a meter stick. The locations of the upstream and downstream boundaries of each sampling area should be geo-referenced using a global positioning system (GPS). As noted above, fish population (abundance) and biomass estimates (abundance) should be determined using Moran-Zippin methods (Ricker 1975).

B4.2 Sentinel Species (Sculpin) Population Health Evaluation

Slimy sculpin will be sampled for a population health assessment using the approach and methods described by Environment Canada (2002). UTMs will be recorded at the upstream and downstream boundary of each fish sampling reach.

B4.2.1 Sampling Methods

Sampling will be conducted using a battery-powered backpack electrofishing unit, seine nets, or minnow traps depending on the type of survey conducted and habitat conditions.

Two field crew members are necessary to conduct electroshocking. The field crew should review the safety procedures and safety options on the electrofisher prior to its use. One person operates the shocker and the second person works downstream of the operator with a dip net and a holding bucket. The crew should work from downstream to upstream so that disturbed debris and sediment does not interfere with catching fish as the material drifts downstream. Polarized glasses and a brimmed hat should be worn by both crew members to increase the ability to see fish in the water and to view underwater obstacles. During fish collection, the operator walks slowly through the water with the unit on their back, making sure both the cathode and anode are in the water. With current applied, the operator should slowly sweep the anode from side to side. Current should be applied intermittently since continued application of electrical current to the water will cause herding or avoidance behaviour by fish and reduce catch efficiency. All fish captured during each pass will be placed in aerated buckets of water.

At the conclusion of each pass, total shocking effort (*i.e.*, electrofishing seconds) will be recorded.

Seines can be used to sample lakes along the shorelines, and streams and rivers with slow moving currents. They are useful in capturing small slow-moving, or schooling fish; or spawning fish that are concentrated in shallow water. Seine nets are most effective when used over a smooth bottom, free from snags and dense aquatic vegetation. Two people are needed to effectively fish with a seine net, one on each end of the net. Small seines are usually operated from shore by manpower or wading. The net is pulled along from one or both ends, encircling an area, then pulled into shallow water. To prevent the escape of fish, care must be taken to ensure that the lead line remains in contact with the bottom, and does not ride up over obstructions. Information to be recorded on field sheets for each seine net set includes: a diagram of the set location; a description of the net; time of haul; number of hauls and approximate area (m^2) sampled.

Minnow trapping is a passive fish capture technique that requires minimal effort. Minnow traps are portable traps that capture fish that swim through the small openings at each end. The openings are funnel shaped and directed inwards. Once the fish enters the trap it has a difficult time finding the small hole that it used to enter. The traps can be set tied to shore and/or anchored to the bottom and marked with a float. Bait can be used to attract fish, but is not necessary. If bait is used, the type should be recorded on the field sheet. Traps work best to catch cyprinids and other small fish. Weedbeds or other fish holding structures and culverts are good locations to set minnow traps. Because of the variability in catch between traps and sets, minnow traps are not as efficient as other methods for measuring relative abundance. Minnow traps allow the fish to remain alive and in good condition for a few days. The exact set and lift time must be recorded for all traps set.

All captured fish will then be identified and enumerated, with all non-target fish species subsequently released to the waters from which they were captured and all sentinel species retained in the aerated buckets of water for further processing.

B4.2.2 Non-Lethal Survey Design

Methods for non-lethal sampling, analysis and interpretation will follow recent guidance developed by Environment Canada (2005). A total of approximately 100 sculpin will be targeted in each area, including young-of-the-year, if available. Total length and total body weight will be measured on each specimen in the field and external condition will be noted. Length measurements will be taken using electronic calipers (to the nearest

0.1 mm) and weight will be taken using Pesola™ spring balances (60 g capacity ± 0.5 g, 30 g capacity ± 0.25 g and 10 g capacity ± 0.1 g) or a lab balance (±0.001 g), depending on the size of the fish. Any abnormalities will be recorded. A sub-sample of approximately 10% of fish captured (e.g., 10 per area) will be frozen whole for subsequent laboratory analysis of age using otoliths.

Weight and length will be summarized by separately reporting mean, median, minimum, maximum, standard deviation, standard error and sample size for each sampling area (Environment Canada 2000). Each data set will be assessed for normality and equality of variance before applying any parametric statistical procedures. Size-frequency distributions will also be developed as described by Bonar (2002) and Gray et al. (2002). An effect on the fish population will be evaluated for each of these measures and is defined as a statistically significant difference between exposure area and reference area (Environment Canada 2002). Statistically significant differences in mean weights and lengths between fish from reference and exposure areas will be assessed using Analysis of Variance (ANOVA). Statistically significant differences in length-weight relationships will be assessed using Analysis of Covariance (ANCOVA). Lastly, statistically significant differences between size frequency distributions (weight and length) will be assessed using a two-sample Kolmogorov-Smirnov goodness of fit test (per Gray et al. 2002).

B4.2.3 Lethal Survey Design

Fishing will be conducted until 20 mature male and 20 mature female sculpin are collected. Physiological measurements collected from each fish will include all those recommended for the EEM program (Environment Canada 2002a). Specifically, body length, fresh body weight, external condition, age, gender, fresh gonad and liver weight, fecundity (females only) and egg-size (females only) will be measured/assessed from freshly sacrificed, sexually mature individuals of each sentinel species (20 males and 20 females from each area). Total length will be measured to the nearest hundredth of a millimetre using digital calipers. Fresh body-weight will be measured using an analytical balance with an accuracy of 0.001 g. Heads will be removed and frozen for subsequent age determination using otoliths. The visceral cavity of each sacrificed fish will be opened. The gender and/or sexual maturity level of each sacrificed fish will then be determined and recorded. Whole gonads and livers will subsequently be excised and weighed to the nearest milligram (0.001 g) using an analytical balance with a surrounding draft shield. Following removal and weighing, whole ovaries from each female will be placed in individually labeled sampling jars, preserved with 10% buffered

formalin, and subsequently submitted to a qualified laboratory for determination of fecundity and egg size. During processing, any external or internal abnormalities will be recorded on data sheets. Following processing, fish carcasses will be disposed of in a manner consistent with collection permit specifications and live fish (i.e., those that were only measured) will be returned to locations near their point of collection.

All ageing structures will be processed by a qualified fish age determination laboratory. Primary ageing structures will be embedded and hardened in epoxy resin, sectioned using a low-speed isomet diamond saw, mounted on a glass slide and aged under a compound microscope using transmitted light. For each structure, the age and edge condition will be recorded along with a confidence rating for the age determination. For quality control purposes, 10% of the processed samples will be sent to a second fish ageing expert for independent age confirmation.

All fish ovary samples will be processed by a qualified biological laboratory. Methods utilized for fecundity estimation will be fully consistent with the technical guidance (Environment Canada 2002), with the number of eggs in each sample enumerated using stereo-microscopes and ten percent of egg samples re-counted to verify the precision of fecundity estimates. For quality control purposes, fecundity re-counts will be conducted on 10% of the processed fecundity samples.

Consistent with EEM technical guidance (Environment Canada 2002), summary statistics including mean, median, minimum, maximum, standard deviation, standard error and sample size will be calculated by species, area and gender for “lethal” endpoints related to age, growth, condition and reproductive health. Each data set will be assessed for normality and equality of variance in order to determine the suitability of parametric statistical procedures. Statistical differences in each test endpoint between reference and exposure areas (by species and sex) will be made using either ANOVA or Analysis of Covariance (ANCOVA) in a manner consistent with Environment Canada (2002) guidance.

B4.3 Fish Processing

The appropriate procedures outlined in the following subsections must be followed in the field in order to ensure accurate measurements of physiological variables. During fish collection or immediately after fish collection is completed, the species of every fish caught should be identified and if possible, the sex of the every specimen of sentinel species (for population evaluation) should also be identified. Sexing of each specimen will provide a count of females and males caught relative to the goals of the program,

such that live fish that are not needed can be released. All fish that are being collected for further processing should be placed in a cooler with sufficient ice for return to the field laboratory where additional measurements will be taken as described below.

B4.3.1 Length

Length will be taken using a standard measuring board or electronic calipers. Total length is measured from the tip of the snout to the dorso-ventrally compressed lobes of the caudal fin. Fork length is the distance between the tip of the snout and the middle of the caudal fin, if applicable. When taking a measurement, ensure that the snout of the fish is at the end of the board and that it is lying flat. Rulers, meter sticks or tape measures can be used if a measuring board is not available. Length measurements should be reported to the nearest millimeter. A precision of $\pm$ 0.2 cm or better must be met.

B4.3.2 Body Weight

Fresh weights can be taken on scales or electronic balances. When using weigh scales, insert the hook behind the gill cover below the lower jaw. Always use a scale or balance that is most accurate for the size of the fish being weighed. A precision of $\pm$ 5.0% is stipulated. Make sure that the scale or balance is calibrated with hand weights and zeroed prior to taking the measurement.

B4.3.3 Age

Two appropriate ageing structures should be collected from each fish (e.g., listed in Environment Canada 2002). Typically, fish scales are collected as one of the ageing structures, if present. Scales are removed by using the sharp point of the filet knife and scrapping in the direction of the tail. Scales will loosen and can be collected on the edge of the knife. The scales (approximately 10) should be placed on wax paper, which is folded and inserted into the scale envelope. Scales must be relatively clean. Ensure that at least ten scales are collected that are relatively clean and undamaged. Bony structures such as spines or fin rays should be stipped of as much tissue as possible and removed cleanly (being sure to include the base - “knuckle”) from the fish. If the fish is being sacrificed for other purposes, take more than just the first one or two spines or rays, to give the laboratory a choice of structures and thus provide the best age estimate.

B4.3.4 Liver Weight

Fish livers are located in the anterior end of the visceral cavity behind the heart and ahead of the stomach. They typically have a brownish pink colour with several lobes. **Livers will deteriorate quickly if the fish is not stored with lots of ice.** When removing the liver, ensure that you collect all of it, but be careful to remove obvious fat deposits and the gall bladder before weighing the liver to the nearest 0.001 g on the electronic balance. Livers must be weighed to a precision of ± 1.0%. Balance accuracy should be assessed each day using standardized weights and calibrated if necessary.

B4.3.5 Gonad Weight

Gonads should be removed from the surrounding tissue using forceps and scissors if necessary. Note the sex of the fish prior to measuring the gonad weight. The weight of the whole gonads should be measured to the nearest 0.001 g on the electronic balance. Gonads must be weighed to a precision of ± 1.0%.

If the fish is a female, ovarian subsamples should be removed after the total weight of the ovaries has been measured. A subsample should be taken from the ovary consisting of a portion from each end and a portion from the middle. Weigh the subsample to the nearest 0.001 g of the electronic balance and record the weight. Subsamples should then be placed in a PET jar and preserved with 10% buffered formalin prior to submitting to a qualified laboratory for measurements of fecundity and egg weights.

B4.3.6 Fecundity and Egg Weight Procedures

Large-Bodied Fish

Field Procedures

1. Remove whole gonads and weigh on an electronic balance to the nearest 0.001g.
2. Remove subsamples from ovaries. Take a portion from each end and mid-section of one ovary and weigh to the nearest 0.001g.
3. Place subsample in a vial and preserve in 10% buffered formalin.

Lab Procedures

1. Rinse field subsample into an 18 μm sieve to remove the preservative.

2. Weigh preserved field subsample to the nearest 0.001g.
3. Remove three sub-subsamples each consisting of a minimum of 100 eggs from each ovarian subsample and weigh each sub-subsample to the nearest 0.001g.
4. Count the number of eggs in each sub-subsample.
5. Represerve eggs and archive.
6. Calculate the number of eggs in the original preserved subsample based on each of the three sub-subsamples as follows:

$$preserved\ subsample\ fecundity = \frac{weight\ of\ preserved\ subsample}{weight\ of\ sub-subsample}\ x\ number\ of\ eggs\ in\ sub-subsample$$

7. Calculate average preserved field subsample fecundity from three sub-subsample estimates.
8. Calculate total fecundity for each female as follows:

$$total\ fecundity = \frac{weight\ of\ whole\ gonad}{weight\ of\ unpreserved\ subsample}\ x\ average\ preserved\ subsample\ fecundity$$

9. Calculate individual egg weight for each female as follows:

$$individual\ egg\ weight = \frac{weight\ of\ whole\ gonad}{total\ fecundity}$$

Small-Bodied Fish

Field Procedures

1. Remove whole gonads and weigh on electronic balance to nearest 0.001g.
2. Place entire gonads in vial and preserve in 10% buffered formalin.

Lab Procedures

1. Rinse preserved gonads into an 18 μm sieve to remove the preservative.
2. Weigh preserved gonads to nearest 0.001g.
3. Remove three subsamples each consisting of a minimum of 100 eggs from the whole gonad and weigh each subsample.

4. Represerve eggs and archive.

5. Calculate the number of eggs in the whole gonad as follows:

$$total\ gonad\ fecundity = \frac{total\ weight\ of\ preserved\ gonads}{weight\ of\ subsample}\ x\ number\ of\ eggs\ in\ subsample$$

6. Calculate average total gonad fecundity from three subsample estimates.

7. Calculate individual egg weight for each female as follows:

$$individual\ egg\ weight = \frac{weight\ of\ unpreserved\ gonad}{total\ fecundity}$$

B4.4 Supporting Environmental Variables

Water temperature, dissolved oxygen, pH and conductivity, will be measured at each fish sampling area. Habitat characteristics, including wetted channel width and depth, extent of canopy coverage, surrounding land use, and general stream morphology, will also be recorded at each study area.

APPENDIX C

PHOTOS

C.1: Upper Faro Creek (FC)

C2: Upper Guardhouse Creek (W10)

C3: North Fork Rose Creek upstream of Mine (upstream of R7)

C4: South Fork Rose Creek upstream of Haul Road

C5: Rose Creek between X14 and R2

C6: Rose Creek Valley downstream of R2

C7: Rose Creek near R3

C8: Rose Creek (top center = R4) and Anvil Creek (left = R6 and bottom = R5)

C9: Anvil Creek near R6

C10: Anvil Creek near mouth at Pelly River (A1)

C11: Pelly River near Anvil Creek mouth

C12: Pelly River at Anvil Creek mouth

C13: Vangorda Creek upstream of Mine (V1)

C14: Confluence of Shrimp Creek (upper left) and Vangorda Creek (mid left and lower centre)

C15: West Vangorda Creek upstream of Haul Road

C16: West Vangorda Creek near V5

C17: Lower Vangorda Creek near V8