Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators

Prepared by the Ministry of Environment

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Acknowledgements

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Preface

The Ministry of Environment's (MOE) *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators* is designed to outline and define the baseline study requirements and information considerations necessary to propose a mineral development project in the Province of British Columbia. The MOE will look at opportunities in the future to develop other guidance documents for mine operation and closure. The document is primarily intended to apply to metal and coal mines and, to a lesser extent, aggregate and industrial mineral projects that are triggered by the Reviewable Project Regulation in the *Environmental Assessment Act* or the *Mines Act*. However, the principles provided in this document apply to all types and scales of mines. This guidance document describes specific studies and the rationale for them, provides recommendations and guidance information, and suggests sources of information and examples. This guidance document is intended to be used by mine proponents and operators undertaking a new project or project expansions. Proponents already conducting studies as part of a development project will be invited to refer to this document for further guidance. This document covers the information requirements for geology/geochemistry, meteorology and air quality, surficial hydrology, hydrogeology, water quality (physical and chemical parameters, aquatic sediments, tissue residues, and aquatic life), fish and fish habitat, and initial environmental impact assessment. Each chapter is written to be stand-alone in its content and in a manner that assumes the user is familiar with the work for that specific field of study.

This guidance document focuses on the collection, analysis, interpretation, and submission of baseline information as part of a proposal to develop a mining project in British Columbia. Baseline data collection and interpretation allows for characterization of the environmental resources prior to mine development and a preliminary assessment of potential impacts. Monitoring the environmental resources before and throughout the construction and operation phases of a mine development provides information to assess the effectiveness of any proposed mitigation measures and to implement adaptive management, if needed. By providing these requirements to the proponent early in the project evaluation stage, the MOE's goal is to ensure effective study design, information collection, and data usage/interpretation that will assist in both the initial project evaluation and throughout the development, operation, and closure of a mine.

This document also discusses the type of information sought by the Ministries of Environment and of Forests, Lands and Natural Resource Operations for the purpose of impact assessment during the mine certification and permitting process. This guidance document does not replace information required by the Environmental Assessment Office.

This document has been prepared by the MOE, but there is significant information overlap with other agencies; where possible, these areas have been identified. The MOE works with multiple agencies throughout the review of a mining proposal and development, and in many cases there are Memorandums of Understanding to facilitate such co-operation. The Ministry of Forests, Lands and Natural Resource Operations, the Environmental Assessment Office, and our federal government counterparts are the regulatory agencies with which the greatest interactions occur.

The information contained in this document is meant to provide guidance and does not absolve any proponent from meeting obligations under Acts and Regulations or Codes of Practice for which the MOE or other regulatory bodies may have authority. It also does not preclude the MOE from requesting additional information or clarification of information that may be provided as a result of this guidance document. Please be aware that additional information may be required by federal government departments that may be involved with the issuance of regulatory approvals for mining works, activities, or operations. Proponents are advised to contact relevant federal agencies in advance of applying for regulatory approvals for mine development or operations. Proponents are also advised to consult with the Environmental Assessment Office, the Ministry of Energy and Mines, the Ministry of Forests, Lands and Natural Resource Operations, and other Ministries as appropriate to ensure their respective requirements are being addressed.

This guidance document will be revised over time as new information becomes available and as policies and legislative changes occur. For example, at the time this version was being completed, the federal government put forward a number of amendments to the *Fisheries Act* and the *Canadian Environmental Assessment Act*. However, the extent of implications for the information included in this document is not yet known. In addition, the Natural Resource Sector Ministries are working toward providing a “one window” approach to permitting. As new information about these initiatives becomes available, this document will be updated.

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List of Acronyms and Abbreviations

ABA – acid base accounting
AIR – Application Information Requirements
AP – acid potential
ARD – acid rock drainage
ARD/ML – acid rock drainage and metal leaching
ARIS – Assessment Report Indexing System

BACI – before-after-control-impact
BCELTAC – BC Environmental Laboratories Technical Advisory Committee
BCGS – BC Geological Survey

CABIN – Canadian Aquatic Biomonitoring Network
CALA – Canadian Association for Laboratory Accreditation
CaNP – carbonate neutralization potential
CCME – Canadian Council for Ministers of the Environment
CES – cumulative effects assessment
CEAA – Canadian Environmental Assessment Agency
CEAA – *Canadian Environmental Assessment Act*
CLIR – Cross-Linked Information Resources

DFO – Department of Fisheries and Oceans (now Fisheries and Oceans Canada)
DL – detection limit (of a laboratory analysis)

EA – environmental assessment
EAA – *Environmental Assessment Act*
EAO – Environmental Assessment Office
EEM – environmental effects monitoring
EIRS – Environmental Information Resources System
EMA – *Environmental Management Act*
EMS – Environmental Monitoring System
EPD – Environmental Protection Division, Ministry of Environment

FDIS – Field Data Information System
FISS – Fisheries Information Summary System
FPCBC – Forest Practices Code of BC

GSC – Geological Survey of Canada

HADD – harmful alteration, disruption or destruction of fish habitat (as per *Fisheries Act* Canada)
HSI – Habitat Suitability Index

IDF – intensity-duration-frequency
IFS – Instream Flow Study
ISO – International Standards Organization

MDRC – Mine Development Review Committee
MEM – Ministry of Energy and Mines
MFLNRO – Ministry of Forests, Lands and Natural Resource Operations
ML – metal leaching
MOE – Ministry of Environment
MPA – Mine Permit Application

NFCP – Nechako Fisheries Conservation Program
NNP – net neutralization potential
NP – neutralization potential
NPR – neutralization potential ratio
NRCan – Natural Resources Canada

PAG – potentially acid generating
PAH – polycyclic aromatic hydrocarbons
PEL – probably effect level
PeWQO – preliminary water quality objectives

QA – quality assurance
QA/QC – quality assurance/quality control
QP – qualified professional

RCA – reference condition approach
RISC – Resource Information Standards Committee
RMDRC – Regional Mine Development Review Committee

SALM – strong acid leachable metals
SBEB – science-based environmental benchmark
SCC – Standards Council of Canada
SHIM – Sensitive Habitat Inventory Mapping
SQG – sediment quality guideline
SWE – snow–water equivalent

TAR – Technical Assessment Report
TEL – threshold effect level
TOC – total organic carbon
TRG – tissue residue guideline
TSS – total suspended solids

VEC – valuable ecosystem components

WIDM – Water Information Data Management database
WQG – water quality guideline
WQO – water quality objective
WSC – Water Survey of Canada

Chapter Summaries

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
1. Introduction	The review of a newly proposed or expanded mine project may be undertaken at the regional level or coordinated through the Province's independent Environmental Assessment Office. The environmental baseline study must collect, assess, and interpret enough physical, chemical, and biological information for the review process to: (i) characterize resources at risk; (ii) determine possible impacts; (iii) predict the significance of impacts and the effectiveness of proposed mitigation; (iv) establish thresholds for indicators of ecosystem health; and (v) facilitate the design of monitoring programs. All studies and monitoring should be planned and conducted by a qualified professional in the relevant field.	Consult representatives in the regional offices of the Ministry of Environment (Environmental Protection Division) and the Ministry of Forests, Lands and Natural Resource Operations about designing and implementing the baseline study before beginning data collection. Start the collection of information as early as possible in the mine development process. MOE requires baseline data collection to occur for an absolute minimum of 12 months (with 24 or more months preferred). Continue baseline monitoring throughout the application review period.	Provincial: Mines Act Environmental Management Act Environmental Assessment Act Reviewable Projects Regulation Concurrent Approvals Regulation Federal: Canadian Environmental Assessment Act

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
General Points about the Baseline Study Applicable to Chapters 2–10		Hire a Qualified Professional with expertise in the relevant study area. Some chapters indicate that the Qualified Professional should be a member of a specific professional association. Store data appropriately and have it available for MOE and MFLNRO staff to access on request. Consult each chapter for information about data reporting. Example tables and graphs are in some chapters and appendices. Consult with MOE and MFLNRO staff about additional requirements for data reporting.	
2. Geology and Geochemistry	The geology of the area is fundamental to the mine development and potential environmental issues. Therefore, the geologic and geochemical baseline study must be linked with other baseline studies described in the document. The geological and geochemical baseline study characterizes the physical environment and materials to	Review existing geological and geochemical information. Collect baseline geological information during initial exploration stages through to advanced exploration and beyond (see Appendix 4 for details of data to collect). Provide detailed information about the potential for metal leaching and acid	Provincial: Mines Act Environmental Management Act Environmental Assessment Act Policy for Metal Leaching and Acid Rock Drainage at

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
	be disturbed; identifies potential impacts from disturbing these materials; and directs the development proposal in order to eliminate, reduce, or mitigate potential impacts on the receiving environment. There is some overlap of the information required by federal and provincial agencies. The proponent should consider preparing the required federal submissions (National Instrument 43-101: Standards of Disclosure for Mineral Projects) at the same time as the information required for the provincial environmental assessment.	rock drainage (ML/ARD).	Minesites in British Columbia
3. Meteorology, Climate, and Air Quality	Meteorology and climate baseline studies assess potential impacts of weather and climate on the project and potential impacts of the project on air quality, climate, and hydrology. The air quality baseline study assesses both incremental and cumulative influences of a project on air quality, climate, and hydrology.	Review existing climatological and air quality information. Demonstrate an understanding of weather and climate over the project's entire footprint. Consult MOE staff to ensure that all instrumentation used conforms to the Ministry's standards.	No legislation referenced in the chapter.

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		Install meteorological station(s) to collect the data listed in this chapter. Conduct air quality dispersion modelling (required for most EA reviews). Determine sampling frequency and period of record.	
4. Surficial Hydrology	The hydrologic baseline study characterizes existing surface water resources and estimates the potential impact of resource development on surface water systems.	Review existing surficial hydrology information. Consult MOE staff to discuss data, guidelines, and standards. Establish hydrometric monitoring sites that will provide required data year-round and for the long term. Conduct a baseline hydrologic study with a minimum of two years of data.	Provincial: Environmental Management Act Water Act
5. Hydrogeology	The hydrogeologic baseline study defines and assesses potential environmental effects on groundwater and interrelated surface water resources.	Review existing groundwater resource information. Establish a network of monitoring locations to adequately characterize	Provincial: Ground Water Protection Regulation (GWPR) under the Water Act

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
	The monitoring program must consider the life cycle of the project with monitoring sites established for baseline, operational, and closure requirements. It may be necessary to conduct numerical modelling; in this instance, contact MOE representatives to discuss the work before actual modelling proceeds.	groundwater quantity and quality and possible groundwater–surface water interactions. Conduct groundwater quantity and quality baseline studies with a minimum of one year of quarterly data. Refer to Chapters 2 (Geology) and 6 (Water Chemistry) for information about chemical hydrogeology.	
6. WQ – Physical and Chemical Parameters	Water quality information provides a crucial component of mine baseline, project impact, operational, and post-closure assessments. The water quality baseline study assesses ambient surface and groundwater conditions before project development to identify whether baseline conditions naturally exceed provincial water quality guidelines and whether site-specific water quality objectives need to be established.	Review existing physical and chemical water quality information. Select adequate upstream and downstream sites, including lakes if applicable. Coordinate the sampling locations for studies identified in Chapters 6 through 10. Collect field measurements and samples for laboratory analyses (see Tables 1 and 2 for parameters and their precision and detection limit objectives). Use an accredited laboratory for all chemical analyses.	No legislation referenced in the chapter.

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		Conduct groundwater quality baseline studies with minimum of one year of quarterly data. Conduct surface water quality baseline studies with monthly sampling (and weekly during periods of maximum hydrograph fluctuation such as freshet and fall rains).	
7. WQ – Aquatic Sediments	The aquatic sediments baseline study identifies spatial and temporal trends in sediment chemistry at key locations in the vicinity of a mine site.	Review existing aquatic sediments information. Determine sampling sites upstream from, adjacent to, and downstream from the proposed mine. Coordinate the sampling locations for studies identified in Chapters 6 through 10. Collect samples for grain size, metals, and organics analyses. Samples must be taken for the <63 µm sediment fraction and should be considered for other fractions. (See Table 4 for parameters and detection limit objectives.) Use an accredited laboratory for sample analyses.	No legislation referenced in the chapter.

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		Sample at least once per year through the baseline and operational phases during late summer low flow periods.	
8. WQ – Tissue Residues	The tissue residues baseline study quantifies tissue contaminant levels and provides reference for future contaminant accumulation in aquatic organisms. The proponent must consider how to minimize unnecessary destructive sampling of fish, amphibian, and aquatic bird species, particularly target species that may be threatened over time.	Review existing tissue residues information. Select sites upstream, adjacent to, and downstream from mine influence. Include lotic (stream) and lentic (lakes, wetlands) environments, if applicable. Coordinate the sampling locations for studies identified in Chapters 6 through 10. Consult with MOE staff to determine the tissues to be collected for the baseline study (usually some or all of periphyton, macrophytes, benthic invertebrates, and fish). Obtain appropriate fish and wildlife collection permits. Collect field measurements and samples for lab analyses (see Table 5 for parameters and detection limit objectives). Use an accredited laboratory for	Provincial: Wildlife Act (requires permits for fish and wildlife collection) Federal: Migratory Birds Convention Act (requires a permit for collection of migratory birds and other wildlife under federal jurisdiction)

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		sample analyses. Conduct the baseline study for a minimum of one year with one sample collection per year at summer/fall low flow period. Fish baseline may extend over two years if necessary.	
9. WQ – Aquatic Life	The aquatic life baseline study provides information about the health of the aquatic ecosystem.	Review existing aquatic life information. Select sites upstream, adjacent to, and downstream from mine influence. Include lotic (stream) and lentic (lakes, wetlands) environments, if applicable. Coordinate the sampling locations for studies identified in Chapters 6 through 10. Determine the organisms to sample (typically benthic and planktonic invertebrates, periphytic and planktonic algae, and macrophytes. (See Chapter 10 for fish sampling.) Consult with MOE staff to determine the most suitable design for analyzing benthic macroinvertebrates (e.g., reference condition approach (RCA),	

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		before-after-control-impact (BACI), or another design). Collect field measurements and samples for identification and enumeration by a certified taxonomist. Conduct the baseline study for a minimum of one year with one sample collection per year in mid-August to mid-September. Two years of data are preferred for the baseline study.	
10. Fish and Fish Habitat	The fish and fish habitat baseline study provides information about fish population abundance and distribution by species and life stage and the habitats fish use on an annual basis.	Review existing fish and fish habitat information. Include all waterbodies to be impacted by the mine footprint and all locations that could impact fish habitat (e.g., the pit, waste dumps, access road, and others noted in the chapter). Select both impact and reference sites that will provide an experimentally robust design for future monitoring. Coordinate the sampling locations for studies identified in Chapters 6 through 10. Obtain appropriate fish and wildlife	Provincial: Wildlife Act (requires permits for fish and wildlife collection) Federal: Fisheries Act Metal Mining Effluent Regulation (under the Fisheries Act) Canadian Environmental Assessment Act

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		collection permits from provincial (for resident fish and anadromous trout) and federal (for anadromous salmon) agencies. Collect fish community data, including presence and absence, species and life stages, abundance, distribution, and life history timing. Collect fish habitat inventory data and enter it into the provincial database using the Field Data Information System (FDIS). If the proponent proposes to divert large quantities of water to and from streams, perform an instream flow study (IFS). Conduct the baseline study for several years at reference and impact sites prior to project development to provide the best possible experimental and statistical power. Analyze the cumulative effects of impacts to fish and fish habitat. See also Chapter 11.	

Chapter	Key Points	Requirements for Proponents and Operators	Relevant Legislation
		Prepare a fish habitat compensation plan for Fisheries and Oceans Canada to consider the authorization of a harmful alteration, disruption or destruction (HADD) of fish habitat	
11. Environmental Impact Prediction	In addition to meeting the data requirements outlined in the preceding chapters, the proponent must provide a synthesis of information to assist the environmental impact and risk assessment for mine certification and permitting.	Characterize the resources at risk. Describe the ecosystem and analyze its sensitivity. Identify potential hazardous conditions and predict impacts. Design an Environmental Effects Monitoring (EEM) program Propose a safe-discharge plan that is protective of the air and the aquatic environment.	Federal: Metal Mining Effluent Regulations (under the Fisheries Act)

1. INTRODUCTION

Mining companies must comply with a complex set of regulatory requirements before obtaining approvals to proceed with mine construction and operation in British Columbia. Depending on the size of the project, the review of a newly proposed or expanded mine may be undertaken at the regional level or coordinated through the Province's independent Environmental Assessment Office (EAO). The criteria for this decision are discussed in some detail below. In either case, the Ministry of Environment (MOE) and the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) will play an integral role in the review and approval process, and will be involved through the construction, operation, closure, and post-closure phases of all mineral property developments. The actual review of a project will normally involve all directly related operations, including the mine itself, processing plant, tailings ponds, associated roads, power lines, rail lines, etc.

The formal environmental assessment (EA) process considers relevant environmental, economic, social, health, and heritage issues together in a single, integrated review. Environmental assessment enables provincial ministers to decide on the overall acceptability of major development proposals within the context of government's regulatory, policy, and technical requirements, and taking into account public and First Nations' input. The EAO's Environmental Assessment Office User Guide and associated documents provide guidance on the EA process and on making an application for an Environmental Assessment Certificate.

If an EA Certificate is issued, the formal environmental assessment is followed by regional permitting processes. Throughout these regional processes, and for specific construction, operational, and closure activities, additional permits will be required from a number of provincial agencies. Among these agencies, MFLNRO issues water licences for surface water diversions and authorizations for work in or about a stream (both under the *Water Act*), and MOE issues waste permits for mine effluent discharges, refuse, and/or air emissions pursuant to the *Environmental Management Act* (EMA).

It is essential that proponents undertaking advanced mineral exploration read this guidance document, meet with regional MOE and MFLNRO representatives to obtain advice on monitoring plans, and initiate baseline information collection **as early in the mine development process as possible**. The different components of any of the studies conducted as part of the environmental assessment process should be planned and conducted by a qualified professional in the relevant field.

1.1 Purpose of this Document

The purpose of this guidance document is to inform mining proponents early in the mine development process of the specific baseline information that MOE and MFLNRO expect will be included in environmental assessment and permitting processes. The Environmental Protection Division (EPD) of MOE typically oversees the development of monitoring programs for air, water quality, sediments, tissues, and aquatic life and is responsible for waste discharge permits and, when appropriate, the development of water quality objectives. MFLNRO, with the help of EPD, focuses on surface and ground water hydrology and sets out the terms of reference for fisheries, wildlife, and habitat studies. This guidance document does not currently provide direction on baseline studies for wildlife; proponents should contact regional MFLNRO offices directly to discuss terrestrial baseline data requirements.

This guidance document defines baseline studies as "information on relevant, pre-existing environmental conditions (i.e., before development) at the site of, or in the area surrounding, a proposed project, to determine actual project effects through comparisons with natural and existing conditions."

1.2 Purpose of an Environmental Baseline Study

An environmental baseline program must collect, assess, and interpret enough physical, chemical, and biological information for the review process to:

- characterize aquatic and air resources at risk;
- determine impact pathways and mechanisms;
- predict the significance of impacts and the effectiveness of proposed mitigation activities related to mine construction, operation, closure, and post-closure;
- establish, ideally as part of the EA process, ecologically relevant and safe thresholds for those parameters that are indicators of ecosystem health and that will be used during the review process to determine potential project impacts. These thresholds will also be used in writing discharge permits and developing subsequent monitoring programs. For air and water quality, thresholds may equal current provincial environmental standards/guidelines (e.g., 2.0 mg/L molybdenum to protect freshwater aquatic life). In some cases, site-specific receiving water quality/quantity or biological objectives, or science-based environmental benchmarks (SBEBs) that vary from provincial guidelines may be established. These guidelines, objectives, or SBEBs may be used in the development of "end of pipe" permit **limits** that must be met during construction, operation, and post closure. The guidelines or objectives may also be identified as *Environmental Management Act* permit management **conditions** that would be used to trigger: (i) additional monitoring, and/or (ii) submission of reports by the permittee regarding influence of a contaminant load on the receiving environment, and/or (iii) more stringent discharge requirements, and/or (iv) additional mitigation measures; and
- facilitate the design of water quality and environmental effects monitoring programs that will allow "before and after" comparisons and/or comparisons between reference (or control) sites and influenced or "test sites." The collection and evaluation of adequate baseline data are fundamental to mine certification and permitting to allow for the detection of unacceptable biological effects or impacts during mine life (Sharpe, 1998).

The detail necessary to meet the above requirements will depend on the complexity of aquatic habitats and the accuracy and precision needed to predict differences. During the environmental assessment and permitting stages, a key objective of the baseline program is to support the proponent's prediction regarding the significance of potential impacts, and to determine what strategies, if any, will mitigate those impacts. Once construction is initiated, the objective of the updated monitoring program is to measure changes from baseline so that the MOE can determine with a high degree of confidence the operation's effect on the environment and the effectiveness of mitigation measures. The permittee must be able to prove that the contaminant concentrations in their discharges remain within permitted levels.

While all baseline data (e.g., water quality, fish tissue, benthos, air quality, etc.) may be used to monitor the significance of project impacts, it is the water quantity/quality data, and in specific cases the air quality data, that are essential to the proponent for developing the impact predictions that must be reported in a mine development application. Accordingly, the initial focus of the baseline study must include hydrologic, water, and air quality monitoring at agreed sample sites and frequencies as early in the development process as possible. The application must, for example, adequately document baseline metal or particulate concentrations at key sites under a variety of flow or emission conditions. The proponent will use this information, in addition to predicted air emission, surface discharge, and groundwater seepage loads from the mine operation, in mass balance calculations to predict concentrations in the receiving environment during operation, closure and post-closure.

MOE then compares the predicted concentrations with established air quality objectives or water quality guidelines (or site-specific objectives) for specific designated uses (e.g., the protection of fresh water aquatic life or human health). If a predicted concentration fails to meet a specific objective or guideline, MOE may require the proponent to commit to implementing operational design changes and mitigation activities in order to achieve the objective or guideline. If certain baseline conditions exist, a site-specific water quality objective or science-based environmental benchmark above the generic guideline can be proposed by the proponent and reviewed by MOE, using approved methods. If this is not possible, the proponent will need to propose treatment options for thorough evaluation by MOE.

1.3 Expectations for the Baseline Study

This guidance document provides MOE's minimum expectations for the systematic development of baseline data collection studies, the modelling of water and air quality impacts, and report formatting. These minimum expectations may be supplemented by additional requests on a site-specific basis or may be updated as necessary.

Please note that MOE expects an application for mine development to contain and interpret quality-assured environmental baseline data collected over an absolute minimum of 12 months (with 24 or more months preferred). The data must adequately characterize spatial and seasonal variability and must be suitable for use in impact prediction. The 12-month minimum will usually require the proponent to initiate data collection for the baseline program at least 18 months prior to submitting the impact assessment document, assuming that it will take several months to fully analyze the baseline data and incorporate it within the application. Data collected up to three months prior to submission should be included.

MOE also expects the agreed baseline monitoring to continue throughout the application review period, and to be renegotiated, as necessary, prior to the mine construction phase and waste discharge permitting. The proponent should report all baseline data, including those collected subsequent to submission of the EA application, as part of an annual environmental quality review.

The need for data quality assurance (QA) and specific methods to attain QA are identified in many of the following chapters. It is valuable here to provide a general definition of QA that will apply throughout the baseline program required prior to mine development. Taylor and Bailey (1997) define quality assurance as:

> "A system of activities whose purpose is to provide the producer or user of a product or service the assurance that it meets defined standards of quality with a stated level of confidence. It consists of two separate but related activities, quality control and quality assessment."

The BC Field Sampling Manual (MWLAP, 2003) and the BC Environmental Laboratory Manual (MOE, 2009a) outline specific QA/QC guidelines accepted by MOE.

1.4 Provincial Review Processes and Regulatory Authorities

Two principal mine approval processes exist at the provincial level in British Columbia: mandated environmental assessment (EA) reviews and sub-EA projects. These processes are shown in Figure 1. If the size of a project exceeds a specified threshold and if the Executive Director of the Environmental Assessment Office (EAO) deems it necessary, a formal Environmental Assessment will be required of the proposed project in order to gain a certificate under the *Environmental Assessment Act* (EAA). The threshold or "trigger" for projects to be reviewable under the EAA is defined in the Reviewable Projects Regulation at:

http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/13_370_2002

The production capacity "trigger" for new mines in the Reviewable Projects Regulation is equal to or greater than:

- 75,000 tonnes per year of mineral ore for new metal mines;
- 250,000 tonnes per year of clean or raw coal for new coal mines;
- 500,000 tonnes per year or 1,000,000 tonnes over four years for new sand and gravel pits; and
- 500,000 tonnes per year of pay dirt for new placer mines.

Additional triggers apply to mine expansions (see Reviewable Project Regulation).

Under the EAA*,* the Minister of Environment can designate a proposed project as reviewable or a proponent may apply for a project to be designated as reviewable even when it does not exceed the above thresholds.

Proponents should note that they have the option to apply to have their applications for permits and authorizations issued by other provincial authorities reviewed concurrently with the review of their application for an EA certification. Additional information on this option can be found in the Concurrent Approvals Regulation of the EA Act.

Smaller mine or mine expansion proposals that do not trigger a formal EA review (e.g., "sub-EA" projects) proceed directly into the regional permitting process. This process, composed of the related Ministry of Energy and Mines (MEM) and Environmental Protection Division (EPD) reviews, can be similar in nature to that overseen by the EAO, but is directed under legislation specific to MEM, MOE, and other agencies (e.g., MFLNRO, Ministry of Transportation and Infrastructure, etc.). Whichever process is applicable, **the same technical environmental information and assessment will be expected.**

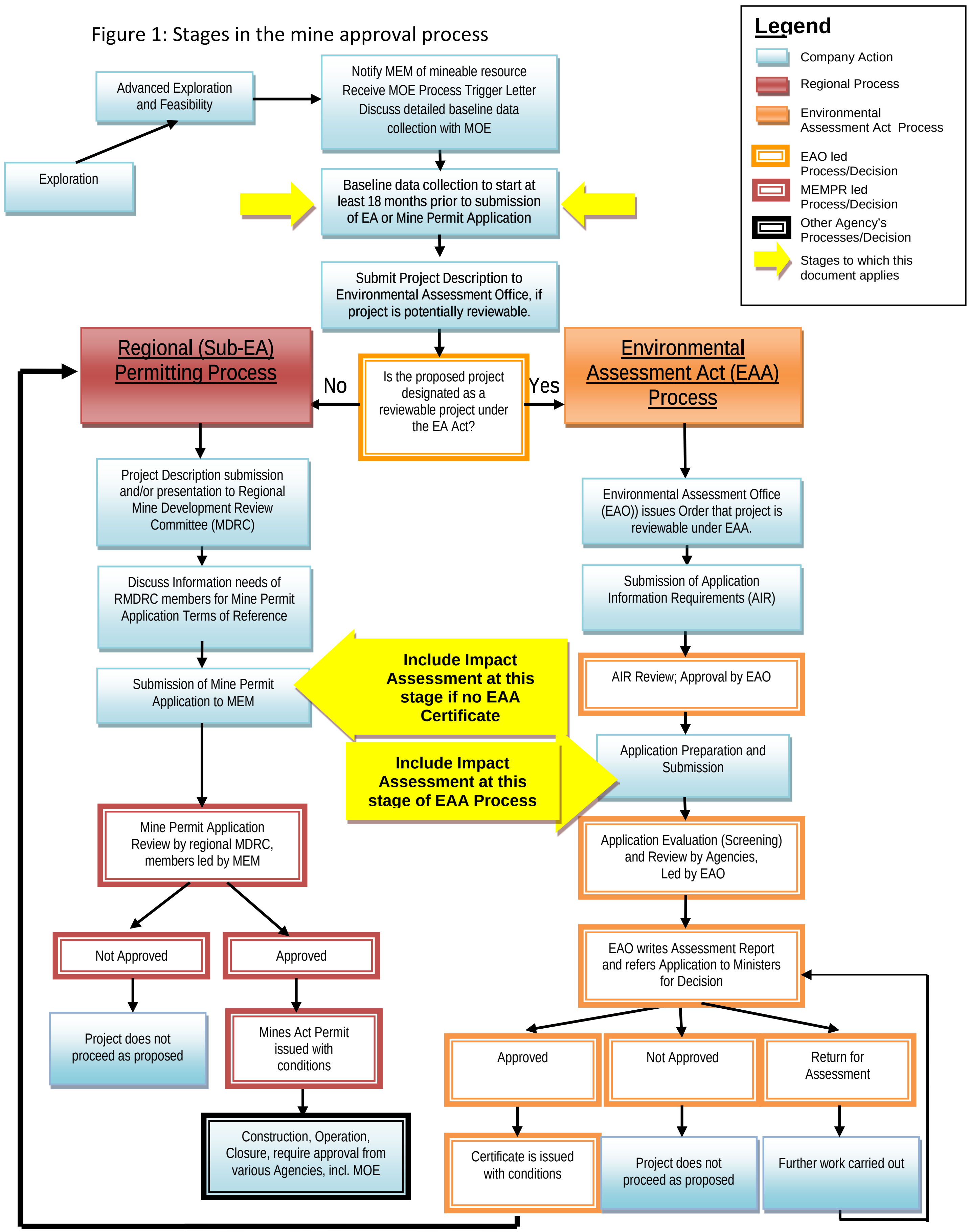
All mine proposals, either as a follow-up to EA mine certification or if proposed as "sub-EA" projects, must proceed through the regional permitting processes. While this necessary step is reasonably straightforward for projects already certified under the *EAA*, it assumes a critical project assessment role for sub-EA projects. In each region of the province, this review process is carried out by a Regional Mine Development Review Committee (RMDRC) that is overseen by MEM and which includes representatives of all relevant agencies, First Nations, and stakeholders (see Figure 1).

As part of the regional process, the MEM directs the Mine Permit Application (MPA) process under the provincial *Mines Act.* MEM approval is required for all mines, prior to construction and regardless of any previous EA certification.

The EPD of MOE issues waste discharge permits under Section 6 of the *Environmental Management Act* (EMA). Prior to doing so, the EPD requires submission for review of a Technical Assessment Report (TAR) that characterizes mine waste discharges and predicts impacts within the receiving environment. For projects that have gone through the EA process, the TAR should reference the EA application where appropriate and include information that is supplemental to the EA. An appropriate amount of EA-level summary may be required in order to put the TAR into context. In general, more reliance by the applicant on the EA process and EA documentation is appropriate for permitting processes.

Just as MEM operational permits are required prior to mine construction, EPD permits must also be obtained prior to effluent, emissions, or solid waste being discharged by the mining operation. Due to the potential for environmental impact related to mine construction, EPD will administer this phase as a prescribed activity under the EMA by way of permit or approval processes. These processes will authorize discharge from the construction site and require specific monitoring and reporting activities.

Figure 1: Stages in the mine approval process



In an effort to encourage mine proponents to contact MOE and MFLNRO early in their planning processes and to make them aware of this guidance document, a Process Trigger Letter has been developed that outlines basic steps of the approval process. MEM will give this letter to proponents no later than when the company informs MEM that they wish to proceed with a mine development. A copy of the Trigger Letter is attached as Appendix 1. MEM should provide the Process Trigger Letter with the Notice of Work application package to ensure that proponents of all potential development projects receive access to the baseline guidance document at an early stage in their project work. Once the proponent receives this letter, they should immediately notify regional MOE-EPD and MFLNRO representatives of their project (for contact information, see Appendix 3).

1.4.1 "Sub-EA" Terms of Reference and Application Timing

In the case of "sub-EA" project applications, considerable overlap exists in the terms of reference of the Mine Permit Application (MPA) required by MEM and the Technical Assessment Report (TAR) required by EPD. This overlap does not, however, extend to the receiving water impact assessment process (i.e., receiving water quality prediction), which is required only in the TAR. EPD requires the TAR submission prior to the discharge of waste, which may occur well after mine construction has been approved under the MPA. To avoid MPA approval of a "sub-EA" project application before the EPD has reviewed and actually approved a discharge application, the submission of a detailed project assessment report (e.g., for baseline development, mine site and effluent characterization, and impact assessment) at the *Mines Act* permit application stage is **strongly** recommended.

Mine proponents who are contemplating a "sub-EA" project application are encouraged to review the following websites:

- to structure a Mine Permit Application (MPA) for permits under the *Mines Act*;
- for guidance on permit applications under the *Environmental Management Act*; and
- for general authorization information.

Proponents are also strongly encouraged to combine the MPA and TAR into a joint submission to both MEM and MOE's EPD, or, at a minimum, to submit the two applications on or near the same date.

In the case of mine proposals that have already received *Environmental Assessment Act* certification, the potential disconnect between MEM and EPD regional review processes is of less importance. Environmental impact will have been predicted and appropriate water quality triggers ideally developed during the EA stage. In this case, regional MPA and TAR processes will occur following EA certification, will be abbreviated, and may be independent.

If a company has stated its intention to develop a mine and wants to enter either the formal EA or regional "sub-EA" process, the proponent needs to follow the stages as summarized in Figure

1. Deficiencies, specifically in baseline data, data assessments, or uncertainties in impact predictions, may lead to delays during the review process or to unnecessarily restrictive permit conditions.

1.5 Federal Involvement

In British Columbia, both the federal and provincial governments may require an environmental assessment (EA) of a project before it can proceed. Federal agencies typically request considerably more information than their provincial counterparts before they are able to determine whether an EA is required under the *Canadian Environmental Assessment Act* (CEAA), and if so, which type of process would be used (screening, comprehensive study, mediation, or review panel). Proponents who will prepare the Project Description in order to determine if an EA is required under CEAA are directed to consult the federal Project Description Guide: British Columbia

The federal environmental assessment process is required whenever a federal government department (federal authority) has a specified decision-making responsibility in relation to a project[1]. This level of environmental assessment is “triggered” when a federal authority:

- proposes a project;
- provides financial assistance to a proponent to enable a project to be carried out;
- sells, leases, or otherwise transfers control or administration of federal land to enable a project to be carried out;
- provides a licence, permit, or approval that enables a project to be carried out; and/or
- has legislated responsibility related to an impact from the project. Such cases include (but are not limited to) impacts to a water body that contains fish or fish habitat (*Fisheries Act*); impacts to navigation (*Navigable Waters Protection Act*); ocean disposal (*Canadian Environmental Protection Act*); involvement of a hydroelectric development aspect on an international river (*International River Improvements Act*), an inter-provincial or international power line (*National Energy Board Act*), or explosives (*Explosives Act*); impacts to an existing or required construction of a railway line (*Railway Safety Act, Railway Relocation and Crossing Act* and *Canada Transportation Act*); or involvement of an oil or gas pipeline (*National Energy Board Act*).

When the two levels of government conduct a review of the same project, their goal is to collaborate in conducting a single, cooperative assessment as per the Canada-BC Agreement for Environmental Assessment Cooperation *(2004)*. The goal is to streamline the processes and minimize the regulatory burden on the proponent while fostering cooperation between the two levels of government, reducing overlap and duplication, and allowing both governments to

[1] At the time this version was being completed, the federal government put forward a number of amendments to the *Fisheries Act* and the *Canadian Environmental Assessment Act*. However, the extent of implications for the information included in this document is not yet known. As new information about these initiatives becomes available, this document will be updated.

allocate public resources more efficiently. In the majority of situations, the harmonized assessment will be led by BC EAO.

Federal agencies should be notified as soon as BC EAO issues a Section 10 order under the BC EAA requiring an Environmental Assessment Certificate for the project. For guidance on policy or project-related issues, contact the Canadian Environmental Assessment Agency.

Canadian Environmental Assessment Agency
Head Office
22nd Floor, Place Bell, 160 Elgin Street
Ottawa ON K1A 0H3
Tel.: 613-957-0700, Fax: 613-957-0862
General Email: info@ceaa-acee.gc.ca

Canadian Environmental Assessment Agency
Pacific and Yukon Office
757 West Hastings Street, Suite 320
Vancouver, BC V6C 1A1
Tel.: 604-666-2431, Fax: 604-666-6990
Email: ceaa.pacific@ceaa-acee.gc.ca

Proponents should be aware that federal and provincial requirements may differ in some aspects. Assessments under the CEAA require cumulative effects assessment, alternatives for the project, and consideration of the capacity of renewable resources to meet needs of future resource users. In some cases, CEAA may include the following information requirements (which may or may not overlap with the provincial Application Information Requirements:

- environmental effects of accidents and malfunctions;
- need for the project;
- alternate means of carrying out a project; and/or
- follow-up program.[2]

In all cases, proponents need to discuss the specific requirements under CEAA with federal officials at the Canadian Environmental Assessment Agency.

[2] The CEAA follow-up program typically involves environmental effects monitoring, but it could also include an assessment of the accuracy of the assessment and the effectiveness of the mitigation.

2. GEOLOGY AND GEOCHEMISTRY BASELINE

2.1 Purpose and Objectives of Geology and Geochemistry Baseline

Chapter 2 introduces the proponent to a comprehensive set of geologically and geochemically related information requirements and guidelines for consideration if the project advances beyond the exploration phase. This work includes the initial steps in assessing the metal leaching and acid rock drainage (ML/ARD) potential of the project. An awareness of the ultimate review requirements early in the project assessment will enable the proponent to maximize data collection during exploration and project planning. Other disciplines discussed in this guidance document, such as meteorology, water quality, and surface and groundwater hydrology, are integral to the overall ML/ARD evaluation and ultimately any development scenario.

In this context, baseline conditions are the existing geological and geochemical conditions of the deposit and surrounding environment at the time when the proposed mine development will occur. The geology and geochemistry baseline study considers the mode of formation of the deposit, the changes that have occurred to the deposit over time, and the changes that may be reasonably expected in the future.

The primary purposes of a detailed geological and geochemical evaluation for a proposed mineral extraction development are to:

1. characterize the physical environment of the project area in its current state;
2. determine the current composition and characteristics of the materials to be disturbed;
3. identify potential impacts that the disturbance of these materials may have on the receiving environment and the degree and magnitude to which these impacts could occur; and
4. utilize the collected information to direct the development proposal in order to eliminate, reduce, or mitigate the project's potential impacts on the receiving environment.

The geologic component of a mine development is the fundamental basis for the project's existence and therefore will comprise a significant portion of the initial information collected. The deposit type, location, physical environment, mineralogy, geochemistry, structure, and other features will determine the economics, development strategy, potential short- and long-term environmental issues, and ultimately the legacy of a given project. The collection of this information also coincides with the requirements to satisfy the Standards of Disclosure for Mineral Projects; National Instrument 43-101.

The geology of the deposit and how it reacts to ambient conditions once exposed, as well as mining and processing influences, will impact the drainage chemistry and ultimately the receiving environment. The detailed characterization of the deposit enables early predictions of potential changes to the water quality emanating from the deposit area and associated infrastructure and forms the basis for the mine design, monitoring requirements, treatment options, and other operational and post-closure considerations.

At the exploration stage, a wide variety of geologic, geochemical, geophysical, and other exploration strategies are used to identify and focus on a specific target. It is at this stage that the collection of baseline information about the project setting, geology, and geochemistry begins. This information can be used for a future development proposal.

This chapter, and the associated Appendix 4, provides guidance to the proponent to initiate appropriate information collection at the exploration stage. The chapter also includes many of the detailed information requirements (environmental assessment and permitting) to be addressed if the project is to advance through permitting and into operation. Although the majority of information will be collected during the advanced exploration stage and feasibility studies, preliminary characterization programs may be initiated early on so it is important at that time to consider the ultimate information requirements.

A major concern with all mineral development projects is the potential for short- and long-term ML/ARD development, its potential impact on the receiving environment, and the operator's ability to prevent its occurrence or mitigate its impacts. The information requirements described below and in Appendix 4 are designed to assist in the evaluation of this potential and are critical for project development. Further information requirements may be necessary as more project details become available. Conversely, some requested information may no longer be necessary as the project evolves. The important theme is to consider the development holistically through all stages of the mine life-cycle: exploration, construction, operation, and closure. Mine closure may comprise the most extensive period of time for proponent involvement (e.g., hundreds of years). Prevention of ML/ARD through predictive work and mine planning is a critical and preferred over-arching aspect of any mining development proposal.

2.2 Review of Existing Geological and Geochemical Information

Regional studies or previous exploration and development work within or adjacent to the project area may provide initial information about the baseline geology and geochemical conditions. Sources for this type of information include the Geological Survey of Canada (GSC) and the British Columbia Geological Survey (BCGS), both of which contain numerous links to various information sources. This initial research could include the use of the following:

- Published regional geology and geochemical reports (i.e., GSC, BCGS)
- Soils and geologic maps (e.g., BCGS Terrain and Soils Maps)
- Exploration and development reports (e.g., Assessment Report Indexing System (ARIS) and MINFILE Mineral Inventory)
- Geophysical information (e.g., GSC and BCGS regional airborne surveys, ground surveys, etc.)
- Regional structural studies (e.g., BCGS Surficial Geology and Hazards)
- Aerial and on-site photographs

- Water quality data (e.g., MOE Water and Air Monitoring and Reporting program, Environment Canada Fresh Water Monitoring program, GSC and BCGS regional surveys)

A list of information considerations is provided in Section 5.2 (Review of Existing Hydrogeology Information), which is illustrative of the linkage between the physical study area, meteorology/climate, hydrology, hydrogeology, geology, geophysics, and geochemistry.

2.3 Regulatory Context

Regulatory governance is provided through multiple levels of provincial and federal government agencies. To a lesser extent, international and local agencies may also be involved. At the provincial level, MOE, MEM, and MFLNRO are three agencies that have varying degrees of involvement with resource development projects.

As detailed in the Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia, issued in 1998 by MEM and the Ministry of Environment, Lands and Parks (now MOE), these two Ministries share the responsibility for regulating ML/ARD from proposed, new, and existing mines. In addition to the 1998 Policy, there is a Memorandum of Understanding between MEM and MOE about the characterization and disposal of process by-products to on-site impoundments. The involvement of both Ministries starts during exploration and continues into post-closure through a combination of environmental assessment, permitting, and regulatory oversight.

The following websites contain legislation, policy, guidance documents, and other supplemental information that are of direct interest to the proponent.

Provincial Legislation and Policy

- Environmental Management Act (EMA)
  - Waste discharge authorizations; guidelines, information, forms.
- Environmental Assessment Act (EAA)
  - Environmental Assessment Guidance Documents
- Mines Act
  - Health, Safety and Reclamation Code for Mines in British Columbia, 2008
- Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia *July, 1998.*

Related Information Sources and Documents

- Aggregate Operators Best Management Practices Handbook for British Columbia
- Canadian Institute of Mining and Metallurgy (CIM);
  - CIM Definition Standards on Mineral Resources and Mineral Reserves
  - CIM Estimation of Mineral Resources and Mineral Reserves Best Practice Guidelines
  - Mineral Exploration Best Practices Guidelines
- Environment Canada
  - Environmental Code of Practice for Metal Mines
- Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in B.C.
- Handbook for Mineral and Coal Exploration in British Columbia
- International Network for Acid Prevention (INAP)
  - INAP Draft Global Acid Rock Drainage (GARD) Guide
- Mine Effluent Neutral Drainage (MEND)
  - MEND Reports
  - Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials, MEND Report 1.20.1, 2009.
- Natural Resources Canada, Science and Technology; Environment
- CANMET Mining and Minerals Sciences Laboratory

For further detailed information requirements, please contact the appropriate regulatory agency or information source.

2.3.1 Linkage with National Instrument 43-101: Standards of Disclosure for Mineral Projects

In Canada, mine proponents must complete the requirements for the *National Instrument 43-101, Standards of Disclosure for Mineral Projects* (NI 43-101), which is a standardized set of requirements and guidelines that details how scientific and technical information about mineral projects may be reported to the public. There are also two companion documents: Companion Policy 43-101CP and Form 43-101F1 Technical Report. Amendments to these forms came into effect on June 30, 2011. The NI 43-101 details the applicable standards of disclosure, while the Companion Policy 43-101CP supplements NI 43-101 and provides guidance and interpretation. Form 43-101F1 outlines the detailed contents required for the preparation and content of the technical report by providing specific instructions for 27 subject areas. The instructions refer to both the content form and substance. These documents and further information may be obtained through the Canadian Council of Professional Geoscientists (National Guidelines) or from the British Columbia Securities Commission.

There is a strong linkage between the information required to fulfill NI 43-101 requirements and the information required for the environmental assessment review. Some of the information is directly applicable (e.g., geology), while other information requires a shift in focus (e.g., the geochemical characterization of waste rock and ore). However, the proponent can provide a significant foundation for the baseline monitoring and environmental assessment by addressing the NI 43-101 requirements, such as project location and setting, deposit geology, mineral resource and reserve estimates, mineral processing, and metallurgical testing. Some specific examples include:

- ***Item 11 (mineralization):*** "Describe the mineralized zones encountered on the property, the surrounding rock types and relevant geological controls, detailing length, width, depth and continuity, together with a description of the type, character and distribution of the mineralization."
- ***Item 19 (Mineral Resources and Mineral Reserve Estimates):*** This item lists 13 requirements, two of which (g & h) address how the estimates of mineral resources and mineral reserves may be materially affected:
  (g) "… by any known environmental, permitting, legal, title, taxation, socio-economic, marketing, political or other relevant issues," and
  (h) "…by mining, metallurgical, infrastructure and other relevant factors."
- ***Item 25 (Additional Requirements):*** This item includes 10 areas of interest, such as:
  (e) Environmental considerations; a discussion on bond posting, remediation and reclamation; and
  (h) Economic analysis, which includes a "…sensitivity analysis with variants in metal prices, grade, capital and operating costs."

Information provided by the proponent for the NI 43-101 submissions should also be incorporated into the Environmental Assessment or regional mine development review committee documentation.

Clearly there is a strong linkage between the information requirements for security exchange purposes and ultimately for the overall environmental review. The proponent can benefit greatly by considering both evaluations at the same time, as a comprehensive NI 43-101 submission may form a significant portion of the environmental assessment review information requirements.

2.4 Geology and Geochemistry Characterization

Proponents will collect baseline geological information during initial exploration stages through to advanced exploration and beyond. Information collected at the early stages can have a dual purpose, being used for resource determination (CIM Definition Standards on Mineral Resources and Mineral Reserves) and for identifying features that may affect the overall project design and the project's potential impacts on the environment. Collection strategies could include:

- remote sensing to determine a wide variety of project characteristics (Canada Centre for Remote Sensing);
- regional and local surface geology mapping;
- surficial geophysical studies to further define geology and related structural features;
- stream sediment and surface/seep water sampling surveys to characterize regional and local geochemistry and water chemistry;

- overburden mapping and sampling for characterization and geochemical signatures; and
- identification of surface features such as gossans, vegetation dead zones, etc.

Once advanced exploration strategies are initiated, such as trenching and drilling, more detailed and refined information will be collected. Some important aspects include:

- mapping and sampling of trenches;
- logging and sampling of drill cores; and
- bulk sample collection.

During this work, detailed geologic and initial mill process characteristics are identified, including the lithology, mineralogy, structure, alteration, distribution, metals' recovery, milling requirements, and many other features. The use of computer logging programs has greatly increased data collection, storage, and manipulation capabilities for exploration data. As such, a large amount of information necessary to characterize the deposit in terms of potential for environmental impact may initially be collected during early stages of the deposit characterization. Knowing the ultimate use of the information for potential project development enables the proponent to begin the important planning phase early in the project assessment. This deposit baseline information is critical in determining what the potential effects of the mining project may be on the receiving environment.

As an exploration project advances towards a feasibility study, infill diamond drilling is often required to supplement the database for reserve calculations. A common gap in the potential ML/ARD database at this stage (especially for open pit developments) is the characterization of peripheral waste rock due to a lack of drilling in the outer margins of the deposit. To avoid future drilling requirements and evaluation delays, the in-fill drilling program design should include the drilling of the peripheral areas, especially where preliminary mine plans have been developed. To enable design flexibility, the geology and ML/ARD characterization beyond the actual ore body needs to be sufficient to characterize the variability of the materials to be disturbed. The characterization must also be extensive enough to accommodate various mining scenarios; (e.g., pit expansion or wall push-back for geotechnical concerns).

One component of the advanced exploration program is the initial evaluation of the ML/ARD potential of the project. This is a critical component of project assessment due to the long-term nature of ML/ARD issues and the potential for severe environmental and economic costs. As such, the greater the emphasis placed on this issue at the early stages of exploration, the clearer the picture will be in terms of the long-term ML/ARD concerns. Field work may provide early evidence of acid generation and/or metal leaching through observations and subsequent targeting of features such as gossans, vegetative dead zones, areas of mineral staining, elevated water chemistry, or other such indicators.

Should a project be proposed for permitting and development, whether through the Environmental Assessment process or the regional (sub-EA) review process, the following general information is necessary to assist in a balanced evaluation. The proponent must have the capacity to:

- characterize and quantify ML/ARD potential of all materials to be disturbed during site development;
- identify, develop, characterize, and segregate materials acceptable for construction purposes;
- evaluate the lag time to ARD onset (if applicable), and the significance of any ML/ARD generated, for materials to be exposed;
- design and construct a mining project that minimizes the amount of potentially acid generating (PAG) material exposed;
- implement and maintain mitigation strategies during the life of the mine and post-closure;
- contain and collect ML/ARD originating from any site-related source(s) during operation and post-closure;
- evaluate the quality and characteristics of surface, seepage, and ground water potentially or directly influenced by the development;
- ensure infrastructure functionality through changing environmental conditions; and
- maintain the infrastructure and financial responsibility for post-closure ARD collection, treatment, prevention, and mitigation, including monitoring and maintenance.

2.5 Specific Information Requirements

Due to the significant concerns regarding ML/ARD from mineral development, substantial detailed information is required to assess long-term potential risks. Many of the key study requirements discussed in Appendix 4 should be addressed as early as possible during the initial project evaluation. It is recognized that the information gathered is iterative in nature as the various programs advance; however, having a comprehensive understanding of the ultimate requirements will assist the proponent in the proper collection of the information. The specifics noted in Appendix 4 provide a mixture of requirements including baseline understanding, environmental assessment, preliminary permitting considerations, and initial impact assessment requirements. The details in Appendix 4 are provided to further emphasize the overall linkage of the initial baseline data collection with the on-going project assessment.

2.6 Conclusion

Baseline collection of geologic and geochemical information for environmental assessment occurs in lockstep with information acquisition required for the economic evaluation of a project. As a result, a significant amount of information collected may be used for both purposes, and importantly, will be collected early in the project history. Due to the potential severity and extremely long-term nature of ML/ARD issues related to mining projects, a substantial amount of information is required during the project assessment to properly evaluate the risks and provide direction for decision-making and development scenarios. It is very important to link the geologic and geochemical baseline characterization with other baseline characterizations described in this document, as they are all intimately linked throughout project design, development, and closure. By understanding the breadth and scope of these information requirements, the initial collection may, and should, begin at the earliest stages of exploration.

3. METEOROLOGY, CLIMATE, AND AIR QUALITY

3.1 Purpose and Objectives of Monitoring

3.1.1 Meteorology and Climate Monitoring

The purpose of a meteorological study for proposed resource development projects (e.g., mines) is to characterize the atmospheric environment in its current state and to develop an understanding of:

1. potential impacts that weather and climate can have on a project (e.g., mine and plant site, haul roads, railroads, etc.); and
2. potential impacts that a project can have on air quality, climate, and the hydrological environment.

Wind speed and direction data are usually required to predict the distribution of trace metals in soils from fugitive dust derived from tailings and waste rock piles. They are also needed to select sites for permanent camp and mineral processing facilities in order to accommodate predominant wind patterns and mitigate the effects of fugitive dust. Air temperature, net radiation, wind, turbulence and sometimes precipitation data (for cases where deposition is important) are typically required for atmospheric dispersion modelling, although there may be a need for additional parameters or measurements at various levels above ground. Such modelling is required for most environmental assessment reviews to determine a project's potential effects on ambient air quality. Snowmelt and precipitation data are necessary for runoff prediction and calibration of regional hydrologic analysis. Solar radiation, precipitation, and evapotranspiration data are required to estimate design parameters for water management infrastructure[3].

The better the baseline data (e.g., long record, appropriate siting, instrumentation and QA/QC, relevant parameters measured), the more certainty there will be in understanding the relationship between a project and air quality, meteorology, and climate. Better baseline data will also facilitate the preparation of a comprehensive project document.

3.1.2 Air Quality Monitoring

The purpose of monitoring baseline air quality for proposed resource development projects is to characterize the current state of the substances in the atmosphere and to develop an understanding of:

[3] Depending on the specifics of a project, there will be a need to calculate or measure (or both) evapotranspiration. For additional guidance on this issue, refer to the document Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop evapotranspiration – Guidelines for computing crop water requirements.

1. potential incremental influences that a project can have on air quality, climate, and the hydrological environment; and
2. potential cumulative influences that a project and existing emission sources in the area can have on air quality, climate, and the hydrological environment.

In pristine environments, where air emissions are unlikely to exceed provincial ambient air quality objectives, it is necessary for a proponent to demonstrate a clear understanding of provincial air quality objectives as well as policies developed by the Canadian Council of Ministers of the Environment (CCME) in the document Continuous Improvement and Keeping Clean Areas Clean (CCME, 2007).

Also, it is likely that EA projects will require some sort of atmospheric dispersion modelling. Determining background air quality concentrations is an essential component of this task. For more information on establishing the background air quality conditions for air quality assessments using dispersion modeling, refer to Section 10.1 of Guidelines for Air Quality Dispersion Modelling in British Columbia (MOE, 2015).

3.2 Review of Existing Information

3.2.1 Meteorology and Climate Information

To better understand the atmospheric environment a project will be situated in, the proponent should conduct a thorough climatological assessment, after confirming data collection requirements with a MOE Air Quality Meteorologist. Climate data can be obtained from Environment Canada's National Climate Archive (data may have to be purchased). Along with MOE, other provincial ministries, such as the Ministry of Forests, Lands and Natural Resource Operations and the Ministry of Transportation and Infrastructure, collect climate data throughout the province. A discussion of normal and extreme climate variables (wind, temperature, precipitation, snowfall etc.) is expected in any Environmental Assessment (EA) application, as well as a discussion on interannual variability expected during different climate cycles (e.g., the El Niño Southern Oscillation). Finally, an EA application will need to demonstrate an understanding of the following guidance document: Incorporating Climate Change into Environmental Assessments (Barrow and Lee, 2000).

3.2.2 Air Quality Information

If air quality data is available, a thorough data review should be undertaken to better understand the baseline environment. Data may be available from MOE or from other proponents who have operations in a nearby area and have already collected sufficient data. A discussion on average and extreme concentrations is expected, along with a discussion on the seasonal nature of baseline concentrations.

If no air quality data exists or is applicable, it is likely that baseline monitoring will be required. Air Quality monitoring programs should be developed in consultation with MOE, including parameters measured (and associated instruments), frequency of measurements and spatial distribution of instruments across a site. For more information refer to section 3.5.2

3.3 Site Selection

To ensure that meteorological and air quality stations collect representative data, stations and sensors must conform to standards set by both the federal and provincial governments. Proponents should identify potential sensitive receptors in the area prior to establishing sampling sites. For more information, refer to the following U.S. Environmental Protection Agency documents:

1) Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements Version 2.0 (Final) (USEPA, 2008).
2) Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Ambient Air Quality Monitoring Program (USEPA, 2008)

In mountainous terrain, meteorological conditions can vary greatly from valley bottom to alpine elevations and also from one valley system to another. For this reason, depending on the size of a project, a proponent may need to install more than one (sometimes many) meteorological station. A proponent is expected to demonstrate an understanding of weather and climate over a project's entire footprint. This understanding should be proportional to the potential for weather and climate to impact a project (and vice versa); professional judgement must be used to determine the necessary extent of the meteorological monitoring network.

3.4 What to Measure

The parameters deemed 'necessary' will vary dependent on the scope of the proposed project, the magnitude and type of emissions, the sensitivity of the airshed and ecosystems, and whether or not there is a requirement to input meteorological parameters into an atmospheric dispersion model. Below is a list of parameters that the proposed baseline study for meteorology, climate, and air quality should consider:

<u>Parameters for Hydrologic Analysis</u>

Data should be collected at an hourly interval, year-round unless otherwise noted or not practical (e.g. pan evaporation not required during freezing winter conditions)

1. Precipitation
   - 1.1 Summarized hourly, daily, and monthly
   - 1.2 Snowpack information:
     - 1.2.1 Snow water equivalent, collected bi-weekly or monthly, approximately concurrent with regional snow surveys
     - 1.2.2 Accumulation/melt

1.2.3 Depth
1.2.4 Spatial Distribution
2. Evaporation
   2.1 Pan evaporation
   2.2 Wind speed
   2.3 Dew point temperature
   2.4 Duration of sunshine/sunshine hours
   2.5 Net radiation
3. Daily minimum temperature

Parameters for Air Quality Monitoring and Air Quality Dispersion Modelling

Must include:

1. Hourly Mean Temperature (°C)
2. Mean Scalar Wind Speed (m/second)
3. Mean Wind Vector Direction (degrees)
4. Mean Wind Vector Magnitude (m/second)
5. Unit Vector Wind Direction (degrees)
6. Hourly Relative Humidity (%)

Winds are typically measured at 10 m above ground, but measurements at higher elevations may be required depending on the emission source. For example, if the emissions are from a 60 m stack, consideration should be given to measuring wind at elevations that are more representative of the conditions experienced at the point of emission.

May be required, depending on dispersion model used:

7. Hourly Sigma Theta, the standard deviation of the horizontal wind direction, using the Yamartino method (degrees)
8. Pseudo Hourly Sigma Theta (15-min int.) (degrees)

The proponent must contact an MOE Air Quality Meteorologist prior to beginning baseline monitoring to establish an agreed-upon methodology for dispersion modelling and data collection requirements, siting, and methodology. Failure to collect appropriate information is likely to lead to delays in assessment and permitting.

Parameters for Climate Monitoring and Data Completeness

1. Daily maximum temperature
2. Daily maximum wind speed and wind direction at maximum speed
3. Barometric Pressure

3.5 Frequency and Period of Record

3.5.1 Meteorology

In order to create a valid baseline dataset and continuously improve data quality, after confirming data requirements with a MOE Air Quality Meteorologist, a proponent should begin to collect high-quality data at the inception of the project and continue collection through the entire project life. Given the nature of the changing climate, it is important to have a balance of both new and historical data. Where historical data are not available, a proponent will need to augment their baseline with regional data to synthesize a complete baseline dataset. As well, since the meteorological monitoring network in B.C. is sparse with limited spatial applicability due to complex terrain, there is growing interest in the use of mesoscale meteorological weather forecast models as a means to produce meteorological output in areas where no observations exist. Guidelines on the use of this type of model output for these purposes are found in the Guidelines for Air Quality Dispersion Modelling in British Columbia (MOE, 2006b).

The sampling frequency and period of record will be determined according to the scope of the proposed project, the magnitude and type of emissions, the sensitivity of the airshed and ecosystems, and whether or not there is a requirement to input meteorological parameters into an atmospheric dispersion model. For example, determining climate conditions will likely require a longer period of record with less temporal resolution, whereas, a rigorous dispersion modelling exercise in complex terrain may require data from more than one meteorological station collected for up to five years. (Dispersion models generally require between one full year and five years of meteorological data collection.)

If dispersion modelling is required, guidance on meteorological monitoring requirements can be found in the document Guidelines for Air Quality Dispersion Modelling in British Columbia. Proponents will need to consult with the appropriate MOE regional office to reach agreement on whether dispersion modelling is required, and if so, which model is appropriate. As different atmospheric dispersion models have different data input requirements, model section is a critical driver of meteorological monitoring requirements.

3.5.2 Air Quality

At the time of printing this guidance document, there is no standardized policy for baseline[4] air quality monitoring in BC for EA projects. This is meant to reflect the uniqueness of each project; i.e., different project types located in different environmental settings necessitate different baseline monitoring. Proponents are encouraged to consider the following points:

[4] 'Baseline air quality' means the pre-construction ambient air quality resulting from both anthropogenic and natural emissions.

- Air quality monitoring programs should be planned early, in consultation with MOE. Extensive monitoring may be required, especially for major projects located in sensitive airsheds[5].
- In many circumstances, one year of baseline data may be necessary. Sometimes it may be necessary to enhance a monitoring program on a seasonal basis to develop a better understanding of worst-case seasonal air quality.
- Where both baseline PM_{10} and $PM_{2.5}$ monitoring is conducted, this monitoring should be conducted simultaneously so that an accurate $PM_{2.5/10}$ ratio can be calculated. Contact the MOE for instrumentation requirements, the possibility of equipment sharing, or the potential to use data from a nearby station that may help in establishing the baseline conditions.

As a general rule, it is better to contact staff in the MOE early in the EA process given the need to ensure data are collected in a way that will meet the objectives of the program and to avoid unnecessary delays and costs.

3.6 Methods, Instrumentation, and QA/QC

Meteorological instruments should conform to the standards used by MOE. The proponent should contact the Water and Air Monitoring and Reporting Section of MOE in Victoria, BC, to ensure that appropriate instrumentation is used for the project. Annual or biannual auditing of the meteorological stations by MOE or approved staff may be necessary.

Data should be stored in a Ministry-approved data logger (e.g., Campbell Scientific 23X). The proponent should consult MOE staff to ensure the instrumentation conforms to Ministry standards.

Quality assurance and quality control (QA/QC) procedures are important, because it is necessary to have a high level of confidence in the data being used to make resource management decisions. For information regarding QA/QC procedures for meteorological and air quality data, refer to:

1) Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements Version 2.0 (Final) (U.S. Environmental Protection Agency, 2006b)

[5] The following definition of "sensitive airshed" is currently being proposed for Ministry policy adoption. Note there are actually two definitions, one addressing 'degradation' and the other addressing 'precaution':

1. An area of degraded air quality, where ambient levels are approaching or exceeding established air quality criteria adopted by the province. This may include provincial and national objectives and standards.
2. An area where the level of impact posed to the environment, human health, or quality of life (e.g., visibility impairment, plume blight, economic development, and odour) from air pollutants requires a more stringent regulatory approach than would normally be applied.

2) Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part I, Ambient Air Quality Monitoring Program Quality System Development (U.S. Environmental Protection Agency, 1998
3) National Air Pollution Surveillance Network Quality Assurance and Quality Control Guidelines (Environment Canada, 2004)
4) Federal Register, Part II, National Ambient Air Quality Standards for Particulate Matter, Final Rule (U.S. Environmental Protection Agency, 1997)

3.7 Data Storage and Reporting

All collected data should be presented in a “Results” section of annual baseline study reports, in the EA application and, where applicable, in permit applications. Data presentation should qualitatively and quantitatively compare and contrast the monitoring results from the different meteorological (and air quality) stations to each other as well as to climatological norms. Graphs, tables, charts, and windroses are all acceptable. Professional judgement should be used to determine the best possible data presentation method. The report should include a sub-section discussing any anomalous data and levels of uncertainty.
The proponent must contact an MOE Air Quality Meteorologist prior to beginning baseline monitoring to establish an agreed-upon methodology and scope for data analysis and interpretation. Failure to appropriately analyze, interpret, or present collected data is likely to lead to delays in assessment and permitting.

4. SURFICIAL HYDROLOGY

4.1 Purpose and Objectives of Hydrological Monitoring

The purpose of the hydrologic study for a proposed resource development project is to characterize existing surface water resources and to estimate the impact that resource development is expected to have on these systems. Similarly, a thorough understanding of the water management needs associated with the mine proposal is required to correctly design mine water systems such as milling processes, tailings impoundments, treatment plants, sedimentation ponds, culverts, and diversion ditches and to clarify post-closure water management scenarios. The main objectives of the baseline hydrology study are to:

- provide calibration data for the development of integrated mine site water balances and hydrologic regionalizations;
- evaluate seasonal and inter-annual patterns in surface water discharge (including intermittent/ephemeral streamflow);
- provide baseline information on the surface water resource for subsequent water quantity and water quality modelling and monitoring (dilution modelling, in-stream flow estimates, runoff modelling etc.); and
- provide annual and event data for flow frequency analyses (i.e., low flows, peak flows, etc.).

It is important to collect the most accurate baseline data possible using accepted or standardized practices and procedures. Information for all aspects of open-water stream-flow measurements can be found in the Resource and Inventory Standards Committee (RISC) Manual of British Columbia Hydrometric Standards – Version 1.0 (RISC, 2009b). The proponent must use the most current version of this hydrometric manual as a reference or guideline for conducting hydrometric surveys to collect baseline data for the EA process.

Before beginning the hydrology study for a proposed development, the proponent should contact regional representatives of the Province of British Columbia to discuss the grade of data required and how the guidelines and standards presented in the RISC hydrometric manual will be applied to the project. If the standard requires modification to accommodate site-specific conditions, the proponent should clearly describe and discuss the adaptations before commencing the study.

The assessment is expected to be performed to the current standard of professional practice and sealed by an appropriate qualified professional.

4.2 Review of Existing Hydrology Information

Review of existing information on the surficial hydrology of a site should be conducted prior to the collection of field data. The review should (at a minimum) include information from the following and other related sources:

- Published reports and literature pertinent to either the specific basin or relevant hydro-climatic parameters that could affect the proposed project, including:
    - Completed Watershed Assessments
    - Peer-reviewed literature
    - Reports from research institutes (e.g., the Pacific Climate Impacts Consortium, PCIC), extension projects, government
    - Other reports available through MOE's Cross-Linked Information Resources (CLIR).
- A regional analysis of baseline hydrological parameters, using data from the Water Survey of Canada (WSC), or the U.S. Geological Survey (USGS) (if project is located in or near a trans-boundary watershed).
- A regional analysis of precipitation, incorporating Intensity-Duration-Frequency (IDF) curves for nearby Environment Canada stations and data from one or both of the following sources:
    - Adjusted and Homogenized Canadian Climate Data (AHCCD)
    - National Climate Data and Information Archive
    - The above sources can be complemented by downscaled and interpolated climatic variables from the ClimateBC and ClimateWNA projects.
- A regional analysis of snow water equivalent (SWE) using data from the BC Snow Survey network.
- Provincial water licences (including springs).
- Existing water users, Community Watersheds, and traditional users.
- Aerial/ortho-photography, topographical maps, GeoBC coverages, Water Survey of Canada, iMapBC, Fish Wizard, and Community Mapping Network.
- British Columbia Streamflow Inventory (Coulson and Obedkoff 1998).

The above information should be used to provide an outline of the general characteristics for the watershed(s) of interest. These characteristics could include, but are not limited to:

- maps including basin delineations, candidate WSC and climate stations, project site;
- basin hypsometry and area;
- source areas including groundwater and glaciers;
- bio-geoclimatic zones;
- critical wetland/riparian areas;
- diversions (including roads and other infrastructure that would act as a diversion);
- stream crossings;
- dams;
- streamflow consistency (e.g., perennial, intermittent, ephemeral);
- hydrologic regime (e.g., nival, pluvial, mixed, etc.); and
- monthly distributions of temperature, precipitation, and streamflow from regional stations.

4.3 Site Selection

Many phases of the environmental assessment and subsequent permitting process (should a project go ahead) depend on reliable hydrometric data. The proponent should consider that hydrometric stations will likely need to function for several years; therefore, correct siting and a durable installation will be key to generating a hydrometric dataset adequate for the immediate needs of environmental assessment and potential future needs of other permits under the various statutes (e.g., Environmental Management Act, Water Act, etc.). In addition, reliable and accurate hydrometric data will be required during all other phases of the mine life, including operations and closure. Further relevant information can be found in the Compendium of Forest Hydrology and Geomorphology (FORREX, 2010; see Chapter 17, page 587, "Water Quantity – Streamflow").

When establishing hydrometric monitoring sites, the proponent should follow the RISC standards and ensure that any deviation from the standards is defensible and documented. To ensure that the program will address the specific information requirements of the various review processes, it is recommended that the proponent discuss the design of a baseline hydrometric network with regional representatives from the Province of BC (e.g., Ministry of Forests, Lands and Natural Resources and Ministry of Environment) prior to development.

As a general rule, multiple stations within the study area will be necessary to adequately characterize the dynamics of the surface water systems and to ensure data gaps can be filled in the event of equipment malfunction. The final decision on the selection of gauging sites requires information on physiographic features and conceptual mine plans and, therefore, must be decided on a case-by-case basis in consultation with Ministry staff.

When establishing a hydrometric network, the proponent should first consider the data needs of the project as a whole in terms of accuracy and spatial extent. There are many useful and objective statistical methods for network design; the exact network configuration will rely on the professional judgement of the project hydrologist. The network design should be referenced to quality literature sources and should, at a minimum, address the following considerations:

- The network design should consider the inherent variability of the project footprint and the necessary accuracy of the data to be collected. Projects that span several hydrologic subzones (e.g., using the Coulson-Obedkoff system) will need to account for that high level of spatial heterogeneity in the placement and density of hydrometric stations.
- Projects with a high degree of topographic variability should consider installation of meteorological and hydrometric stations at varying elevations in order to quantify the effect of elevation on precipitation/runoff ratios.
- Glacial outflow should be measured, as this can substantially increase summer flows.
- The availability of useful historic regional data can also be a factor in the design of the hydrometric network. Project footprints that overlap basins with long-term hydrometric records may require installation of fewer project-specific hydrometric

stations to develop the hydrological parameters of interest (unit-area runoff depths, frequency-magnitude analyses, etc.).

- Scale issues are often problematic in British Columbia since most of the available historical hydrometric information is drawn from relatively large watersheds that tend to generalize hydrologic parameters of interest due to their large spatial extent. The design criteria for a proposed project's water management infrastructure are often based on small-scale areas within a larger watershed. Therefore, the criteria are not well represented by the existing provincial hydrometric network, which has a bias toward large watersheds. Filling this scale gap is often a critical component of project hydrologic network design.
- Network design should reflect the proposed mine plan and probable discharge and Environmental Effects Monitoring (EEM) program locations, as pre-operational data for those locations can be critical in obtaining discharge permits.
- Sites should be chosen that will provide an accurate representation of all inflows and outflows to tailings storage facilities, sediment control ponds, diversion works, and levels within storage areas.
- Stations should be situated in an area where they are unlikely to be moved as a result of construction/operation/closure activities, so that baseline data can be compared with the monitoring data collected as part of the ongoing operation/closure of the mine.
- Where a stage-discharge rating curve is required, the station must be situated according to the RISC guidelines, and attempts must be made to measure discharge at all flow levels (within the limits of worker safety).

All monitoring sites for surface water, e.g., hydrometric monitoring sites, should be geo-referenced and photographed from different angles to show the physical characteristics of the gauging site. For all hydrometric monitoring sites, it is mandatory that staff gauges are surveyed periodically and controlled for shifts in elevation against fixed reference points (or bench marks). Installation of an automated stage recorder that collects water depth measurements at regular and frequent intervals (hourly or sub-hourly for smaller basins with rapid response times) is highly recommended for each site. Similarly, choosing equipment that can be deployed 12 months of the year is recommended.

4.4 What to Measure

Hydrometric stations should collect and record as much continuous water level (stage) data as possible (e.g., instantaneous measurements at 15-minute intervals). Continuous data are preferable when calibrating surface-water models, because such data improve temporal resolution and reduce the risk of missing critical events (e.g., maximum and/or minimum flow). Water-level readings from the staff gauge should be taken at the same time as discharge measurements and as often as possible in between gauging in order to augment automated data, assist in correcting sensor drift, and benchmark estimated data from a nearby station to infill record gaps in the event of an equipment malfunction. Taking photographs during each site visit is recommended to create a visual representation of the stream flow over time. This photo record is also very helpful to reviewers who may not be able to visit the site in person.

Several measurements of discharge are critical for the development of a site-specific rating curve that allows continuous water level data to be converted to discharge estimates. Accurate discharge measurements are central to providing the necessary data for all aspects of the hydrology baseline study and subsequent mine water-management programs.

Several methods are available for calculating discharge, and the suitability of a given method will depend on the streamflow, channel characteristics at the measurement site, and professional judgement. A summary of methods is contained in both the RISC manual and the Compendium of Forest Hydrology and Geomorphology (FORREX, 2010; see Chapter 17, page 588, Table 17.4). A minimum of 10 data points, well distributed over the full range of flows, is necessary to create a stage-discharge relationship. Discrete measurements of stream discharge and stage should occur at least once per month during the first year of baseline data collection, with an emphasis on timing the visits to capture the extreme high and low flows. Once the rating curves have been developed and the proponent's hydrologist is comfortable with the stage-discharge relationship, a modified discrete gauging schedule should be discussed with a representative from the Province of British Columbia (e.g., Ministry of Forests, Lands and Natural Resources and Ministry of Environment) regional offices.

Note that significant high-water events have the potential to alter the channel form and thus the rating curve. New discharge measurements should be taken as soon as possible following a significant event to determine if the current rating curve is still applicable and if not, to provide the basis for development of a new curve.

4.4.1 Winter and Ice-Affected Hydrology

Surface discharge measurements should be collected during both open-water and ice conditions. Winter discharges are important for a number of permitting and EA purposes such as base flow/low flow estimates and assessing impacts to the aquatic ecosystem. Flow measurements under ice or during winter conditions can be difficult to collect and instrumentation may be adversely affected by cold weather conditions. Specialized equipment and techniques will be needed to safely and accurately collect winter data. A reliable stage-discharge relationship does not exist under ice-affected conditions (with rare exceptions), in which case frequent discharge measurements, index (indirect) methods, or other techniques may be required to establish a suitable data record. Regardless, winter hydrometric data of known and acceptable quality is achievable and necessary to adequately assess the impact of a proposed project, especially if the critical low flows occur during the winter.

The available RISC standard does not address the topic of winter hydrology specifically. The Water Survey of Canada does, however, offer some guidance about Discharge Measurements From Ice Cover that may be useful.

The proponent is responsible for ensuring that the methods and techniques chosen are appropriate to the monitoring sites and that the monitoring activities carried out at these sites are in accordance with workplace safety policies.

4.5 Frequency and Period of Record

For surface water flow data, a minimum of two years of data must be collected in order to evaluate the accuracy of rating curves. This minimum requirement also allows more robust comparison with regional station data, allows relationships to be developed and validated with on-site and regional precipitation data, and allows the proponent to address gaps or errors that occur during the first year of data collection. The length of hydrologic record required for a baseline hydrology study will vary depending on the quality of existing onsite data and nearby stations or regionalized data, and it may be longer than two years. The hydrologist should provide a rationale for the acceptable accuracy of all hydrologic parameter estimates in order to allow an objective determination of the necessary length for the hydrologic record. It is useful in the project design phase to have a general sense of the accuracy of the design input data in order to avoid the under- or over-design of project infrastructure.

The site-specific hydrometric data must be of sufficient accuracy and record period to enable meaningful and statistically significant relationships to be developed with regional data sets and to constrain the probable range of hydroclimatic conditions at the site of interest.

4.6 Methods, Instrumentation, and QA/QC

Consistent and rigorous quality assurance and quality control (QA/QC) practices will enable collection of meaningful and scientifically credible data. Results and conclusions resulting from data and practices that do not meet accepted QA/QC guidelines may be rejected by regional MOE representatives, jeopardizing the environmental certification of a proposed project or the granting of a discharge permit. QA/QC is important in every aspect of a sampling program, from program design through the field work and finally to interpretations of results.

The accepted methods for evaluating the quality of data collected are provided in the RISC Standards document. Different levels of data quality are assigned grades. These grades convey the level of confidence that other users can place in the data and should therefore be stated when presenting hydrometric data. Documentation of the QA/QC process will help determine what grade of data is actually attained. Documentation should include information on:

- error bounds of instruments, dataloggers, conversion factors, rating curves, etc.;
- operational limits of sensors (i.e., performance in sub-zero temperatures);
- sensor drift and correction procedures;
- benchmark surveys and shift corrections;
- sensitivity analyses;
- chronological record of field visits, maintenance, and calibration programs;

- corrections for ambient temperature and barometric pressure if required for instruments to provide accurate readings (e.g., unvented pressure transducers); and
- whether discharge data has been estimated by extrapolating beyond measured discharge on the rating curve (may introduce error at the low and high ends of the curve).

4.7 Data Storage and Reporting

Hydrometric data should be stored so that they can be made available to external reviewers upon request. The raw data files from data loggers must be stored externally so that the data can be recovered if any file should become corrupted in a database.

With respect to the reporting of hydrometric data, the report must include a discussion on the precision, accuracy, completeness, and comparability of the data to inform decision makers of the confidence that they can place in the dataset.

The baseline study report should include descriptions of, references to, and rationales for the selected analytical methods used to derive hydrologic estimates from the data (e.g., project hydrometric data and other hydrometric or hydrologic data). At a minimum, the report should include the following:

- Frequency analysis of annual events, including:
    - maximum instantaneous discharge for 1:2, 1:10, 1:25, 1:50, 1:100, and 1:200 recurrence intervals;
    - 7-day low flow estimates (annual and June-September) for Q_2, Q_5, Q_{10}, and Q_{20} recurrence intervals;
    - probable maximum flood;
    - wet- and dry-year precipitation estimates for 1:2, 1:10, 1:25, 1:50, 1:100, and 1:200 recurrence intervals; and
    - probable maximum 4-day precipitation (plus maximum probable 4-day snow melt).
- Mean annual and mean monthly discharges and variability.
- Methods of data regionalization and transformation, including:
    - table of all candidate regional stations with pertinent meta-data (location, basin area, unit-area runoff depths, basin and discharge characteristics);
    - criteria used to select candidate stations for regional analyses;
    - change-point analysis if two or more records have been joined;
    - regression analyses; and
    - spatial scaling and weighting of regional data.
- If a hydrologic model is employed, describe the structure, assumptions, calibration, and validation statistics (Nash-Sutcliffe, RMSE, R^2, bias, etc.).

The results of all analyses should be accompanied by statistical estimates of parameter reliability and variability, error of the estimate, and/or confidence intervals.

The presentation of hydrologic information should include hydrographs of all gauged and ungauged (if synthetic records are used) watersheds, flow duration curves, and graphical and tabular representations of frequency analyses, regionalizations, and stage-discharge curves. Raw data should be included as an appendix, preferably in digital format.

Other relevant references include:

- Compendium of Forest Hydrology and Geomorphology in BC (FORREX, 2010)
- Handbook of Hydrology (Maidment, 1992)
- Hydrology of Floods in Canada: A Guide to Planning and Design (NRCC, 1989)
- Hydrotechnical Considerations for Dam Safety (CDA, 2007)
- Manual of British Columbia Hydrometric Standards Version 1.0 (RISC, 2009b)
- USGS – Statistical Methods in Water Resources (Helsel and Hirsch, 2002)
- Guide to Hydrological Practices, Vol. I (WMO, 2008) and Vol. II (WMO, 2009)

5. HYDROGEOLOGY

5.1 Purpose and Objectives of Hydrogeology Monitoring

The purpose of a hydrogeologic study for a proposed resource development project is to define and assess the potential environmental effects from that development on the groundwater and interrelated surface water resources and to develop prevention, mitigation, and monitoring measures to ensure that the quantity and quality of the groundwater resource are maintained for present and future uses. The main objectives of the baseline hydrogeologic study are to:

- provide baseline information on the extent, physical and chemical characteristics, uses, and potential of the groundwater resource in and around the proposed development for subsequent water quantity and water quality impact prediction and monitoring;
- outline measures to ensure that the groundwater resource is maintained for present and future uses;
- characterize the pre-development groundwater flow regime for calibration of a numerical flow model to be used subsequently to predict impacts to water quantity and quality (if modelling is required);
- evaluate seasonal changes in groundwater flow patterns, groundwater levels, and groundwater quality, where applicable; and
- delineate/map groundwater flowpaths and possible changes resulting from proposed developments.

The hydrogeologic study should be planned and conducted by a qualified hydrogeologist or groundwater specialist who is a member of the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC), i.e., a Qualified Professional.

Proponents are reminded that the scope of the project elements under assessment may differ between the provincial EA process and the federal *Canadian Environmental Assessment Act* (CEAA) process, and the differences may affect design of the baseline studies. Therefore, it is important that the assessment be sufficiently broad in terms of project elements, spatial scale, and temporal scale to meet the requirements of both processes, where applicable.

The *Ground Water Protection Regulation* (GWPR) under the *Water Act* of British Columbia must be followed during the construction, maintenance, and closure of monitoring wells and geotechnical wells (including boreholes, test wells, and test pits). It is recommended that proponents upload well construction information on any production or monitoring wells associated with the project to the provincial groundwater database (WELLS). Database through the MOE's electronic water well data entry tool e-WELLS.

MOE's review of the groundwater study for a mining project will follow the legislative mandate and guiding principles outlined in Appendix 7 and the rationale outlined in Appendix 8.

5.2 Review of Existing Hydrogeology Information

A compilation of existing information on the groundwater resources of the study area should be conducted prior to collection of field data. Local groundwater resource information includes the following and other related sources:

- Published geology and hydrogeology reports[6] and aerial photographs
- Soils and geologic maps and aquifer classification mapping[7]
- Well record data (accessed via MOE's Water Well Search Application and provincial observation well network data
- Exploration test holes and test pits
- Geophysical information (e.g., aerial survey, borehole logs, etc.)
- Aquifer response test results (e.g., pumping tests, packer tests, tracer tests, etc.)
- Geotechnical information (e.g., rock quality, packer tests, etc.)
- On-site photographs
- Seepage data
- Information from structural geology studies (including regional structures and stratigraphy and detailed site-specific structural geology assessments)
- Water Survey of Canada stream flow records
- Provincial water licences, including licensed springs
- Water quality data from Environment Canada's Water Quality Monitoring Program and through the Water, Air, Monitoring and Reporting Section of the Environmental Protection Division at MOE in Victoria, B.C.
- Digital Elevation Model (DEM) for both surface water and groundwater modelling (note: the DEM may need to be corrected by "ground-truthing to surveyed points)
- Climatic data through Environment Canada's National Climate Archive (data may have to be purchased)

The types of data that should be sought are provided below. Some of these data are also required for the assessment of surface water hydrology or geology and may sometimes be undertaken collaboratively. In remote areas, existing information of this type will likely be quite limited.

[6] These reports should include previous documentation for nearby mining or other resource development projects, e.g., EAO's Project Information Centre (e-PIC): a100.gov.bc.ca/appsdata/epic/html/deploy/epic_home.html; electronic reports filed in the MOE's ***Ground Water Reference Library*** and ***Ground Water NTS Filing System*** for NTS Mapsheet areas: www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/library.html; and MOE's Cross-linked Information Resources (CLIR) website: www.env.gov.bc.ca/clir

[7] Mapped aquifers are categorized by demand, productivity, and vulnerability in **Imap**: geobc.gov.bc.ca/. MOE and MFLNRO groundwater specialists will have additional information available for specific aquifers of interest.

The following themes should be included in the hydrogeological background assessment:

Study Area (Site, Local Area, and Regional Context)

- Location and site boundaries for the proposed development, including catchment delineation (regional-scale and site-scale)
- Topography (select the map scale, infrastructures, and surface drainage network) should indicate both pre- and post-development topography and drainage network
- Geomorphology and physiography
- Land use/land cover and vegetation
- Aerial photographs and satellite/airborne imagery

Meteorology/Climate

- Precipitation, temperature, evaporation, evapotranspiration
- Comparison of on-site climate data with longer-term Environment Canada climate data
- Discussion of climate change
- Location of stations and recorded years

Hydrology

- Summary of available stream flow data:
    - Definition of the up-gradient areas for the selected stream-gauging stations
    - Elevation profiles of the important streams and river(s)
    - Hydrograph separation to estimate the base flow contribution to major streams from groundwater discharge
    - Recharge estimate for the areas upgradient or upslope of the mine site
- Location of stations and recorded years
- Springs/seepage areas

Hydrogeology

- Borehole test data (e.g., drill stem tests, packer tests, etc.)
- Hydrogeologic test data (e.g., yield during drilling, pumping tests, packer tests, slug tests, tracer tests, etc.)
- Summary of available hydraulic properties (e.g., hydraulic conductivity, transmissivity, storativity) and historic groundwater level monitoring in the region
- Location of stations and recorded years
- Geotechnical borehole logs

Geology

- Soil maps and surficial geology maps/reports and geologic setting (e.g., cross-sections, maps)
- Stratigraphy (e.g., stratigraphic column, continuity and extent of formations) and lithology (e.g., sedimentology, properties)
- Structural geology (e.g., joints, regional and local faults, fracture zones, karst, etc.)
- Sediment thickness map

- Rock quality designation and structural properties
- Geological drill core logs

<u>Geophysics</u>

- Rock quality designation and structural properties
- Borehole logs
- Surface (e.g., seismic, electrical resistivity)
- Satellite remote sensing data
- Airborne surveys

<u>Geochemistry</u>

- Available surface water quality
- Available groundwater quality and its relation to geologic/hydrogeologic variability and variable scale of groundwater flow system
- Soil, rock, historic tailings in the area
- Anthropogenic influences

<u>Water Use and Conflicts</u>

- Surface and groundwater use (current and proposed)
- Water licences (including licensed springs)
- Water issues and conflicts
- Transborder issues, where appropriate

5.3 Site Selection

Monitoring sites must be established to collect data on groundwater levels and/or groundwater quality. Where a monitoring well will measure both groundwater level and quality, this chapter should be read in conjunction with Chapter 6 (Water Chemistry). Monitoring sites should be geo-referenced and photographed from different angles to ensure they can be recognized and mapped. It is recommended that sites be surveyed for geodetic elevation, specifically with reference to ground (and/or top of casing) elevation at the monitoring well location.

The design of a groundwater monitoring system requires careful analysis and should be done by a Qualified Professional with expertise in hydrogeology. The monitoring objectives should be kept foremost in mind when siting, designing, and constructing the well. When the general location for monitoring water levels is chosen, the specific site should be, as much as possible, minimally affected by nearby pumping.

The site investigation plan should consider the groundwater characterization advice for contaminated site investigations in Groundwater Investigation and Characterization (MOE, 2009b). The type and amount of baseline hydrogeologic data that should be obtained will depend on the complexity of the geologic setting, the size of the assessment area, the types of impacts that can be anticipated from the proposed operations, and the degree of confidence needed in the site characterization to make sound project assessments. Proponents need to ensure that groundwater data have sufficient spatial and vertical coverage to characterize the three-dimensional groundwater flow regime at both the site and off-site in the receiving environment. Additionally, the monitoring program must consider the life cycle of the project with monitoring sites established for operational and closure requirements.

Monitoring sites should not be selected simply for the purpose of providing broad spatial coverage. For each monitoring site, the proponent should be able to articulate the issue or question that can be resolved by obtaining data at that location. Some examples for selecting groundwater monitoring sites include:

- understanding local and regional hydrogeological processes and characteristics, e.g., groundwater discharge and recharge areas;
- quantifying the degree of groundwater interactions with surface water;
- surface water licencing considerations;
- biological importance of groundwater in streams, e.g., baseflow component of streamflow; and
- understanding the impact of existing contaminated sites.

In a similar fashion, the selection of monitoring sites and data to be collected at each site should be undertaken with specific forethought given to the data required for impact prediction. When planning baseline data collection, it is helpful to consider how the attributes of the data may also contribute to a reduction in prediction uncertainties associated with subsequent impact predictions. For example, simultaneous monitoring of both groundwater and surface water may be required to understand the interaction between them at the mine site.

At a minimum, a sufficient number of groundwater monitoring locations should be established within a given permeable hydrostratigraphic unit (aquifer) to adequately determine groundwater flow directions and hydraulic gradients. A representative number of monitoring wells must be up-gradient from the proposed mine for background control and to establish groundwater level trends before the project begins and for the duration of the project.

Monitoring should be representative of different hydrostratigraphic units (e.g., shallow unconsolidated aquifers should be monitored separately from deeper bedrock units). Spacing of monitoring wells will depend on the degree of uniformity of the hydrogeological setting and appropriate representative scale of measurement. Care should be taken not to cluster too many monitoring wells near the ore body. For example, using the existing exploration holes for monitoring wells may be inappropriate because of the risk that these wells could exert an undue influence in the calibration of numerical flow models.

All permeable units potentially affected by mine works should be monitored. Nested installations are typically used to determine vertical hydraulic gradients, but there are many other options available for vertical discretization. Even in the case where surficial and bedrock units have generally low hydraulic conductivity, monitoring wells are required to characterize the groundwater system. The preceding generalizations need to take into account both site-specific hydrostratigraphy and the mine plan.

Monitoring well construction must conform to the minimum construction standards in the GWPR for permanent monitoring wells. Typical monitoring well[8] installation standards may be found, for example, in Subsurface Assessment Handbook for Contaminated Sites (CCME, 1994).

5.4 What to Measure

Hydrogeologic measurements supplement existing information for the assessment, prevention, mitigation, and monitoring of potential environmental effects from the project and provide site-specific data. In addition, hydrogeologic measurements are needed to delineate groundwater flowpaths for determining impact pathways.

Field investigations are intended to:

- provide baseline information on geology, hydrogeologic properties, boundary conditions, surface water hydrology, groundwater flow (directions, velocities, and mass flux rates), surface and groundwater quality, groundwater–surface water interactions, and site water balance;
- support the development of groundwater flow models, if required. For example, in fractured bedrock environments, field evidence is needed to support the use of a continuum model (if used) and the assumption of isotropy (if assumed) and to confirm travel times (i.e., actual field evidence of total porosity (n), specific storage (S_s), and specific yield (S_y) for bedrock formations);
- allow for preliminary design and assessment of mitigation measures (e.g., dewatering/injection/treatment works);
- allow for assessment of residual impacts following implementation of mitigation measures;
- allow development of an ongoing monitoring program; and
- identify issues that may influence post-closure behaviour of the mine site.

If possible, field investigations should include methods that will characterize hydrogeologic variables at appropriate spatial and temporal scales (e.g., pumping tests to establish hydraulic properties for dewatering, etc.) and boundary conditions.

Below is a list of suggested aspects of groundwater investigation. The hydrogeologic field investigation and data collection should include the following aspects of groundwater investigation:

- inventory of neighbouring well users and regional groundwater use (including First Nations users) and surface water use (water licences, including licensed springs). The inventory of groundwater users should include some level of ground-truthing, such as verifying with

[8] A monitoring well or observation well is analogous to a piezometer.

local personnel about their knowledge of the area, site visits, and inspection of recent air photos, because not all wells are registered in the provincial repository (WELLS);

- measurement of water levels in surface waters (e.g., pits), as these data may be essential to interpretation of groundwater levels and flow;
- characterization of site geology and hydrogeologic properties using specific techniques, including:
    - conducting pumping tests (see Guide to Conducting Well Pumping Tests) and interpreting the results (see Allen, 1999; Carmichael et al., 2009; and Renard et al., 2009),
    - packer tests including slug tests (see Butler 1996 and 1998). Often, packer testing is used to isolate specific borehole intervals, such as faults, to estimate hydraulic conductivity with sufficient spatial representation,
    - bench-scale or field-scale material testing,
    - fracture characterization to confirm that use of a continuum model, if used, is justified,
    - borehole geophysics/borehole flow meters, and
    - tracer tests and surface geophysics;
- baseline monitoring of water levels and water quality from:
    - on-site wells and exploration boreholes (geotechnical/monitoring wells, streambed piezometers, exploration holes, adits, test/production wells), in addition to wells on neighbouring properties,[9]
    - natural discharges (springs or seeps, on/off-site streams), and
    - local or site-scale streams (those influenced by the project).

Field data collection should allow the proponent to adequately characterize the groundwater flow system and identify aquifers and boundary conditions, hydraulic properties, water budget and groundwater–surface water interactions with adequate certainty. For fractured bedrock aquifers, the field data should provide enough information to determine whether the use of a continuum model[10] is appropriate for modelling groundwater flow in fractured bedrock in the study area. At mine sites where there is likely to be a groundwater–surface water interaction,

[9] New mineral development projects frequently occur where there has been historic mining activity and where there may be flooded open pits, flooded shafts, or flowing portals that provide valuable monitoring opportunities for hydrogeological information on:

1) brown-field baseline groundwater quantity and quality;
2) potential long-term unmitigated impacts to groundwater for a particular type of mineral deposit.

If measuring water levels in exploration boreholes, the data are only useful if supported by information on the depth of the borehole, and if available, some indication of the status of the borehole, e.g., depth of any surface casing, open hole interval, an indication on the drillers log where water was first encountered, where the main flows may have entered the borehole, etc.

[10] A continuum model is a model that looks at flow, chemical transport from a “macroscopic” scale. It does not look at flow or transport in individual pores but treats the porous medium as a bulk entity. Conversely, a discrete fracture model can incorporate characteristics of specific types of porosity (such as discrete fractures or faults) of the porous medium in modelling flow and transport, but usually requires these types of porosity to be well characterized.

water chemistry is one technique that should be used to assess the relative contribution of groundwater to surface water.

A numerical model may be required to understand the groundwater, and possibly surface water, interactions and flow regimes at the project site. In this context, the term “modelling” refers to the use of computer-based numerical methods to obtain approximate solutions to the coupled equations of groundwater flow and solute transport (Reilly and Harbaugh, 2004). Groundwater flow simulations require an understanding of geology and the hydraulics of groundwater flow as well as a command of numerical simulation methods. When solute movement is to be simulated, the complexity of the problem increases. Data requirements for a numerical model (Reilly and Harbaugh, 2004) include site-specific information on:

- unconfined and confined aquifers: groundwater flow and storage changes, fine-grained confining units and interbeds;
- faults and other barriers: resistance to horizontal groundwater flow, potential for faults to be conduits for groundwater flow (i.e., the fault’s impact on velocity of flow and localized preferential flow paths);
- confining units: groundwater flow and storage changes;
- rivers: exchange of water with aquifers;
- drains and springs: discharge of water from aquifers;
- ephemeral streams: exchange of water with aquifers;
- reservoirs: exchange of water with aquifers;
- wells: withdrawal or recharge at specified rates;
- recharge from precipitation and irrigation water use; and
- evapotranspiration.

To address the complexity and avoid potential misuse of groundwater models, a document has been written to provide guidance to industry and government agencies, based on best practices, on how to develop, use, and review groundwater models used to assess environmental impacts due to mining and large groundwater extraction projects. The BC MOE Groundwater Modelling Guidelines (Wels et al, 2012) should be utilized if a groundwater model will be used to answer specific questions or to achieve a specific objective.

5.5 Frequency and Period of Record

The frequency of sampling should be commensurate with the processes being observed.
For the groundwater quality baseline, the recommended minimum period of record is one year of quarterly data (see Section 6.5). This is the minimum period required to assess seasonal variations during the initial project evaluation phase. Attempts should be made to make measurements or collect samples at times of maximum/minimum hydrologic conditions (e.g., after spring melt, during low flow) to define the full range of seasonal variability.

For groundwater quantity, it is preferred to record continuous water level data using water level sensors (i.e., daily measurements are preferred for key monitoring wells). For the groundwater quantity baseline, the recommended minimum period of record is one year of continuous water level measurements to understand the groundwater level trends at the mine site. The observation well hydrograph can be compared with a provincial observation well hydrograph in the vicinity, if available, to confirm the trends observed.

The monitoring program will continue, with adjustments as necessary, throughout the life of the project and post-closure.

5.6 Methods, Instrumentation, and QA/QC

Reliable water level recorders are available with resolution of <5mm that will accomplish the task of continuous water level recording. Manual readings should be taken at every site visit and compared to data logger readings on-site to ensure equipment is functioning correctly. If non-vented pressure transducers are used, then a separate logger for barometric pressure should be deployed. Sensor calibration should be checked quarterly, and sensors should be re-calibrated when sensor drift exceeds 2% of the actual value. Data should be downloaded on a regular interval to minimize the possibility of lost records due to sensor malfunctions. Where a well is flowing, the artesian pressure should be measured when the flow has been stopped and there is no leakage.

Consistent and rigorous quality assurance and quality control (QA/QC) practices will enable collection of meaningful and scientifically credible groundwater quality data. Results and conclusions resulting from data and practices that do not meet accepted QA/QC guidelines may be rejected by regional MOE representatives, jeopardizing the environmental certification of a proposed project or the granting of a discharge permit. QA/QC is important in every aspect of a sampling program, from program design through the field work and finally to interpretations of results.

One of the major issues with groundwater quality samples is insufficient well development, which can lead to elevated levels of suspended sediments and total metals in the water quality samples. Dissolved metals may be better for use in groundwater QA/QC assessments if sample turbidity measured in the field is greater than 50 NTU. Appendix 7 discusses an approach to ensuring that analytical metal concentrations in groundwater are reliable estimates for the purposes of regulatory decision-making.

5.7 Data Storage and Reporting

Data should be stored in a database or spreadsheet. The raw data files from data loggers must be stored so that data can be recovered if corrupted in a database. Likewise, original copies of laboratory reports and field test reports for parameters such as field turbidity should be stored and accessible. The database or spreadsheet must provide summary statistics. Estimates of a variable's range, typically defined as the central 95% confidence interval, should be presented for most hydrogeological variables, along with best central estimates (mean, median, or maximum likelihood) and standard deviations. For instance, it may be appropriate to report on the median and range of hydraulic conductivity values for an area or a formation but not for an individual well. The database or spreadsheet files should be readily available to government representatives in electronic format for review and verification.

Some data are best presented in graphic form but may be included in digital form also. These hydrogeologic measurements (and related analysis) should be reported in an appendix, e.g., borehole logs, pump or slug test data and analysis, grain size, etc.

Good-quality maps, cross sections, and figures are key to explaining and understanding the project and ensuring a timely regulatory review. The following should be outlined in relation to the proposed development footprint:

- Conceptual model showing hydrostratigraphy, recharge/discharge boundaries, groundwater divides, and impermeable boundaries
- Extent of unconfined and confined unconsolidated aquifers and permeable bedrock formations
- Characterization of the hydraulic conductivities of both the unconsolidated and bedrock formations, especially in locations where groundwater and surface water are likely to interact
- Geo-referenced locations and elevations of wells (including monitoring wells and geologic borings) and natural discharges
- Potentiometric water level contours and inferred groundwater flow paths in permeable formations (aquifers) and across low permeability formations (aquitards)

Reporting on hydrogeology must cover all aspects of the baseline study, with appropriate analysis, interpretation, and assessment of environmental significance by Qualified Professionals. In addition, proponents should discuss uncertainties that are inherent to the characterization of the groundwater system and provide, at a minimum, a qualitative evaluation of their potential significance in the assessment of project impacts. Aspects of the physical hydrogeology of the study area that must be discussed in the EA application include the following:

General description of:
    - geographic setting,
    - landforms, glacial coverage, topography, surficial soils, and drainage,
    - hydrologic zone, and
    - climate, including precipitation and evapotranspiration potential.
- Detailed description of:
    - geologic setting and geomorphology,
    - hydrostratigraphy, and
    - fault zones.
- Characterization of aquifers and aquitards:
    - areal extension, thickness, continuity, heterogeneity,
    - nature of porous medium (e.g., flow through primary porosity vs fractures), porosity, hydraulic conductivity

  - evidence of whether the aquifer hydraulic properties are isotropic or anisotropic,
  - storage characteristics (specific storage for confined aquifers, specific yield for unconfined aquifers), and
  - degree of confinement and vulnerability to contamination.
- Groundwater flow systems (local and regional) and flow patterns:
  - recharge/discharge zones,
  - estimates of groundwater recharge and discharge flow rates,
  - water table maps,
  - groundwater flow paths and estimates of residence times for different stratigraphic units, and
  - detailed site water balance.
  - groundwater–surface water interactions:
  - quantity of groundwater flowing into/out of surface waters in each affected watershed pre-development, during operations, and post-closure, and
  - potential for groundwater–surface water interactions to affect water quality in surface water.
- Proposed uses of groundwater.
- Existing groundwater / surface water uses potentially affected by the project.

If numerical models were required for impact prediction, the work done to develop and calibrate these numerical models[11] should be documented in a separate technical report and included as an appendix to the EA application. The electronic files required to run the model simulations should be readily available to government representatives, on request, for review and verification. At the EA Certificate application stage, the calibrated model should be used in a sensitivity study to identify key parameters influencing system behaviour and to provide an early evaluation of prediction uncertainty. This study is important since data are typically not available everywhere to complete meaningful model verification.

Aspects to be discussed in the EA application about the baseline chemical hydrogeology of the study area are covered in Chapters 2 (Geology, ML/ARD) and 6 (Water Chemistry).

[11] Before the modelling work proceeds, it is useful to provide information to MOE for review and comment on the conceptual model, data supporting the model, specific objectives of the model, modelling area, and other modelling specifics (see Wels et al. 2012 for more information).

6. WATER QUALITY: PHYSICAL & CHEMICAL PARAMETERS

6.1 Purpose and Objectives of Water Quality Monitoring

As a natural resource, water is essential to all life and to the health of the environment. Water quality describes the physical, chemical, biological, and aesthetic characteristics of water, which strongly influence its suitability for aquatic life, wildlife, livestock, irrigation, human consumption, and industrial use. Contaminants may be dissolved or suspended in the water column, through which they can be transported off site, taken up by organisms, or transferred to other matrices (e.g., sediment, soil, air, tissue), where they may cause significant impacts. Thus, water quality information provides a crucial component of mine baseline, project impact, operational, and post-closure assessments.

The main objectives of water quality monitoring related to mining are to:

- assess the ambient surface and groundwater conditions before effects from the proposed mine(s) occur (i.e., baseline monitoring);
- identify whether baseline concentrations naturally exceed provincial water quality guidelines [12] and whether site-specific water quality objectives[13] or SBEBs[14] need to be established;
- use baseline information to predict and assess impacts;
- determine the need for monitoring and management during the life of the mine; and
- allow the comparison of baseline data with operational and post-closure water quality data in order to identify whether water quality is affected by mine-related activities and to verify that established water quality guidelines or objectives are being met and water quality is being protected.

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[12] BC Water Quality Guidelines are safe levels of substances for the protection of a given water use, including drinking water, aquatic life, wildlife, recreation, irrigation, and agriculture. They are developed in order that water quality data can be assessed and site-specific water quality objectives can be prepared. The BC Approved Water Quality Guidelines can be viewed at: www.env.gov.bc.ca/wat/wq/wq_guidelines.html.

[13] Site-specific Water Quality Objectives (WQOs) are numerical concentrations or narrative statements that establish the conditions necessary to support and protect the most sensitive designated use of water at a specified site. Objectives are typically based on generic water quality guidelines (WQGs), which may be modified to account for local environmental conditions or other factors. In BC, site-specific WQOs are developed as per Ministry of Environment Policy and Guidelines (see Section 6.2). WQOs are signed off by the Assistant Deputy Ministers of Environment.

[14] Science-based environmental benchmarks are quantifiable receiving environment parameters or attributes protective of freshwater aquatic life that are developed by a qualified professional through a rigorous scientific process with the intent to inform management decisions and guide mitigative actions for a regulated mining activity at a specific location. The Framework for the Development and Use of Freshwater Science-Based Environmental Benchmarks for Aquatic Life in Environmental Management Act Permitting for Mines can be found at: http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/guidance-documents/tg8_framework_for_sbebs.pdf

Water quality assessments should be conducted by a Qualified Professional who has sound education and experience relevant to the specific subject (e.g., surface water, groundwater quality).

Chapters 6 through 9 provide detailed guidance for water quality baseline data collection. Alternative monitoring programs may be acceptable but should be discussed and accepted by the regional Groundwater Hydrogeologist (MFLNR) and/or the Impact Assessment Biologist (Environmental Protection Division, MOE) before investing in a monitoring program.

6.2 Review of Existing Water Quality Information

Water quality is well studied in some areas of BC, and there are numerous sources to check for ambient information, including the BC government database and the federal government. However, mine development properties are often in remote locations, and relevant ambient surface water and groundwater quality information is often scarce or totally absent for these areas. In particular, groundwater quality is rarely assessed, except in areas of potential contamination (often situated in urban settings or around industries). Neighbouring mine sites may provide the most closely located applicable data. Information may also be available from regional MOE offices.

Some sources of groundwater and surface water data are:

- BC MOE Environmental Monitoring System (EMS) (a database that includes all water quality data collected by the BC MOE and by selected waste discharge permittees);
- BC MOE Water Information Data Management database (WIDM) stores water information from across the province, such as, snow data and groundwater observation well data;
- groundwater/surface water data collected at the mine site by historic proponents;
- groundwater data summaries from other mining properties in the vicinity with similar mineralogy or surface water data from neighbouring streams;
- regional MOE and MFLNRO office representatives; and
- other industry(ies) operating in the area.

Additional sources of regional water quality data can be found at the following websites:

- Environment Canada – Hydrometric information from the National Water Data Archive
- Environment Canada – Regional Publications from the Water Quality Monitoring Program
- Health Canada – Environmental and Workplace Health
- Natural Resources Canada (NRCan) – Information regarding existing mines

The information from these sources may not be free of charge, and the appropriate authority may need to be contacted to access the information.

When using data from the above sources, the proponent must keep in mind that relatively recent baseline information will be required for baseline development and impact assessment, particularly of surface water. We recommend discussing acceptable data age with MoE regional staff.

Relevant BC government documents to be reviewed prior to developing a water quality monitoring program include:

- Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (Cavanagh et al., 1998);
- BC Field Sampling Manual (MWLAP, 2003);
- Guidelines for Interpreting Water Quality Data (MELP, 1998);
- Continuous Water-Quality Sampling Programs: Operating Procedures (MOE, 2006a);
- Approved Water Quality Guidelines (MOE, 2010);
- Guidance for the Derivation and Application of Water Quality Objectives in British Columbia (MOE, 2012);
- A Framework for the Development and Use of Freshwater Science-Based Environmental Benchmarks for Aquatic Life in Environmental Management Act Permitting for Mines.

The necessary conditions to support and protect the most sensitive water use (including aquatic life) must be identified as early as possible for surface water and groundwater that could be affected by mine activities. Identifying these conditions can be done by comparing existing water quality and mine-effluent-affected water quality to water quality guidelines (WQGs, see document list above). WQGs provide water quality ranges for the protection of designated water users (including aquatic life).

If WQGs are not suitable (e.g., when natural concentrations exceed water quality guidelines), site-specific water quality objectives (WQOs) or science-based environmental benchmarks (SBEBs) may be developed to define acceptable receiving water quality. The process for setting WQOs is described in "Guidance for the Derivation and Application of Water Quality Objectives in British Columbia," listed above. While the development of WQOs is the responsibility of the MOE, project proponents can submit data for consideration in this process. The process for setting SBEBs is described in "A Framework for the Development and Use of Freshwater Science-Based Environmental Benchmarks for Aquatic Life in Environmental Management Act Permitting for Mines", also listed above.

In developing WQOs, the MOE first establishes preliminary water quality objectives (PeWQOs) for each priority contaminant based on the lowest WQG levels to protect the most sensitive water uses at the site. The applicability of the PeWQO to the site is then evaluated against a number of factors, including the background levels of the variables. Where background levels are naturally higher than WQG levels, the MOE may base the PeWQOs on background concentrations to avoid water quality degradation. The MOE may also determine that site-adapted WQOs are appropriate and that the PeWQO can be modified to account for unique characteristics of the waterbody (e.g., to account for toxicity ameliorating factors or the sensitivity of resident species).

Once the MOE is satisfied the PeWQOs are protective of the designated water uses, they are approved and adopted as formal WQOs. Once approved by the MOE, WQOs become Ministry policy and are considered in decisions made by the MOE affecting water quality. Data collection methods, analytical approaches, and reporting required for the MOE's objectives-setting exercise must be discussed with and approved by the MOE's regional Environmental Impact Biologists.

Either WQGs or WQOs should be used to assess the predicted impacts from the proposed project.

6.3 Site Selection

Possible water quality sampling locations should be discussed with regional MOE and MFLNRO representatives before a large expenditure is made on the program. All sites for both groundwater and surface water quality monitoring should be geo-referenced, mapped, and photographed from different angles. It is prudent to include as many sites as possible early in the baseline study, with the intent of eliminating some sites once potential and actual impacts from mine facilities and the water quality variability and trends are better understood.

6.3.1 Groundwater

- The main goal of groundwater quality monitoring site selection is to establish baseline conditions and allow for trend assessment of groundwater conditions related to each major mine facility (e.g., waste rock dumps, tailings impoundments, coarse refuse, etc.). Monitoring well installations should be directly down-gradient or down-flow from any areas with potential seepage from mine facilities, including at the foot of tailings impoundments. In addition, at locations where mining impacts are possible at more than one depth (e.g., multiple aquifer setting or deep/thick aquifer horizons), nested or multi-level monitoring wells should be installed to different depths.
- For baseline conditions, water quality in the mineralized zone(s) to be mined should be sampled and assessed separately from ambient, down-gradient, or down-flow groundwater quality.
- Wells should be suitable to accommodate water quality sampling and transducer installation.
- Monitoring locations and monitoring priorities should be expected to be modified during the life of the mine.

- An appropriate number of monitoring wells to provide adequate representation of ambient groundwater conditions in the project area should be located immediately up-gradient from all potential mine influences.
- The use of an existing water supply well may be acceptable. However, acceptability depends on a number of factors, such as whether the well taps into the aquifer of interest, whether the well is being used or not (for instance if it is not being used, it may be necessary to pump it for longer to get a representative sample), whether the sample can be collected before the water goes through any treatment device, etc. For that reason, the use of a water supply well should be discussed with MOE and MFLNRO groundwater staff regarding acceptability before relying on these data
- With respect to location of monitoring sites, please also review Section 5.3.
- Review the footnote in Section 5.4 that references additional data collection from historic mine workings.

6.3.2 Surface Water

- Sampling sites should be established in all areas potentially affected by the proposed construction, operation and closure phase of the mine. This includes upstream and downstream of all proposed discharges, seepage points, and non-point contaminant sources. Far field sites need to be established where downstream or cumulative effects can be anticipated.
- Reference sites should be established upstream of all mining areas in each potentially affected watershed. Where proposed mine development in the headwaters prevents the establishment of upstream reference sites, other suitable reference sites, such as adjacent watersheds with similar catchment areas and geologic settings, should be considered in consultation with regional MOE representatives.
- For lakes that may be affected by the mine, sites should be established at the point of discharge or seepage, at the point where mine-impacted streams enter the lake, and at the deepest location of the lake. Additional sites may be required as both “impact” and “reference” sites. The bathymetry of the lake and seasonal limnology (temperature, chemical gradients, stratification, turnover, and flushing rates) need to be established. If vertical profiling reveals the presence of lake stratification with regards to temperature, conductivity and dissolved oxygen, water sampling at multiple lake depths must be undertaken. The depth of sampling should be based on the depth of the temperature and/or chemical gradients in the water column, with all potentially affected lake layers represented in the sampling program.
- Water quality and surface flows should be monitored at the same locations so that loading calculations and predictions of downstream receiving water concentrations can be made and compared with provincial WQGs. Accurate loading calculations and predications are particularly important at proposed compliance sites, where water quality will have to meet ambient guidelines, site-specific WQOs, or other waste discharge permit requirements during construction, operation, and closure.

6.4 What to Measure

When developing a baseline, a full suite of analyses is required to provide a complete picture of the natural constituents in the water. During operation and post-closure, analytical work may be reduced depending on a supporting rationale and findings that certain constituents are below detection limits (DL). Based on the MOE's experience, the parameters listed in Tables 1 and 2 should be collected as part of the routine analyses for baseline studies. Parameters for field collection are provided in Table 1 and for laboratory analyses in Table 2.

The detection limit for each water quality parameter of interest must be less than the respective WQG, ideally by one order of magnitude. These detection limits may not be achievable by all laboratories or for all samples (for example, where dilutions are required due to high dissolved solids or other matrix effects). Table 2 provides detection limit objectives that meet the intent of the above requirement.

The proponent is responsible for ensuring that updated and appropriate detection limits are used.

Provincial WQG reports are listed at the following website: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines.

Table 1: Core list of general water quality field measurements and associated precision objectives.

Measurements	PRECISION Objectives (smallest increment that must be measured and reported)
Physical Measurements	
Dissolved Oxygen (DO)	±1 mg/L
Flow*	See Chapter 4
Odour	
pH	±0.01 pH units
Redox Potential (ORP Eh)	±1 mV
Specific Conductance	±2 µS/cm
Temperature	±0.1 °C
Turbidity	±0.1 NTU

*Stream flow information is required at specific sampling sites that are used to calculate expected concentrations from proposed loadings dilution.

In addition, other parameters may need to be included in the water quality baseline study depending on the type of mine proposed or the characteristics of the natural environment or receiving water bodies. For example, the need to measure the following parameters should be discussed with regional MOE representatives on a case-by-case basis:

- COD (chemical oxygen demand)
- Microbial indicators of fecal contamination (if sewage discharge is proposed or drinking water use may be affected)
- Total carbon
- Cyanide species
- Tritium (to assess groundwater age)
- Stable isotopes ^{18}O, ^{2}H (to assess groundwater age and provenance)
- Radioactive elements such as Ra-226, Pb-210, Po-210, Th-230 (relevant in areas where radioactive elements are present in the local geology)

Table 2: Core list of general water quality analytes and associated detection limit objectives (as of 2011).

PARAMETER	DETECTION LIMIT	PARAMETER	DETECTION LIMIT
Physical Parameters		**Total & Dissolved Metals (cont.)**	
pH	Reported to 0.01pH units	Arsenic (As)	0.2 µg/L
		Barium (Ba)	0.1 µg/L
Specific Conductance	2 µS/cm	Beryllium (Be)	0.1µg/L
Total Hardness	1 mg/L	Bismuth (Bi)	0.5 µg/L
Total Dissolved Solids	10 mg/L	Boron (B)	10 µg/L
Total Suspended Solids	2 mg/L	Cadmium (Cd)	0.01 µg/L
Turbidity	0.1 NTU	Calcium (Ca)	50 µg/L
Colour	5 CU	Chromium*(Cr)	Unspeciated: 0.5 µg/L; Hexavalent: 1 µg/L
Major Anions		Cobalt (Co)	0.1 µg/L
Alkalinity – Total	1 mg/L	Copper (Cu)****	0.2 µg/L
Acidity	2 mg/L	Iron (Fe)	10. µg/L
Chloride (Cl^-)	500 µg/L	Lead (Pb)	0.1 µg/L
Fluoride (F^-)	20 µg/L	Lithium (Li)	1 µg/L
Bromide (Br^-)	50 µg/L	Magnesium (Mg)	100 µg/L
Sulphate (SO_4^{2-})	500 µg/L	Manganese (Mn)	0.2 µg/L
Nutrients		Mercury**(Hg)	0. 01 µg/L
Nitrate Nitrogen	0.005 mg/L	Molybdenum (Mo)	0. 1 µg/L
Nitrite Nitrogen	0.005 mg/L	Nickel (Ni)	0.5 µg/L
Nitrogen – Total	0.05 mg/L	Potassium (K)	100 µg/L
Ammonia Nitrogen	0.02 mg/L	Selenium***(Se)	0. 3 µg/L
Ortho phosphorus - Dissolved	In Lakes: 0.001 mg/L	Silicon (Si)	50 µg/L
	Other: 0.005 mg/L	Silver (Ag)	0.01 µg/L
Phosphorous – Total	In Lakes: 0.002 mg/L	Sodium (Na)	100 µg/L
	Other: 0.005 mg/L	Strontium (Sr)	0.2 µg/L
Organics		Thallium (Tl)	0.01 µg/L
Total Organic Carbon	0.5 mg/L	Tin (Sn)	0.2 µg/L
Dissolved Organic Carbon	0.5 mg/L	Titanium (Ti)	10 µg/L
Total & Dissolved Metals		Uranium (U)	0.01 µg/L
Aluminum (Al)****	10-20% of guideline or 1 µg/L	Vanadium (V)	1 µg/L
Antimony (Sb)	0.1 µg/L	Zinc (Zn)****	1 µg/L

* Measure unspeciated first, if >1µg/L then also measure hexavalent.
** Mercury is more likely detected in tissue and sediment samples.
*** Note specific selenium-related sampling protocols under the sediment, fish tissue, and aquatic life sections of this document.
**** The low detection limits indicated for aluminum, copper, and zinc apply to water with <1NTU turbidity or dissolved analysis.

- Total phenol and/or BTEX (benzene, toluene, ethylbenzene, xylene) (appropriate if the proposed project may lead to hydrocarbon contamination)
- Redox potential (ORP Eh) (in streams with ARD effects)
- Polycyclic aromatic hydrocarbons (PAH; need to be included for all coal mines and facilities with potential for PAH discharges or seepages and areas that may contain naturally high PAH concentrations)

6.5 Frequency and Period of Record

Frequency and period of record may vary among projects based on water quality concerns and among sampling sites. MOE recognizes the need for flexibility on a site-specific basis in order to design effective programs. Thus, programs that divert from the general guidance provided below may be acceptable but should be discussed with relevant MOE staff. The following general guidance is given relative to various phases.

For ground and surface water quality baseline studies, proponents are responsible for reporting the *a priori* statistical power of their sampling plan (for two to three critical parameters) to provide reviewers of the Environmental Assessment with an understanding of the strengths and weaknesses of the program.

6.5.1 Groundwater Quality Baseline

The minimum period of record for the groundwater quality baseline study is one year of quarterly data, which allows an assessment of seasonal variability. Quarterly sampling should continue into the construction and operational phases. Sampling should be evenly spaced (approximately) throughout the year, with no sample taken less than 60 days (unless the program is designed to sample more frequently than quarterly) or more than 120 days after the previous sample. Sampling frequency should also be commensurate with the processes being measured.

Attempts should be made to make measurements or collect samples at times of maximum/minimum hydrologic conditions (e.g., after spring melt, during low flow) to define the full range of seasonal variability. The average dates of highest and lowest groundwater levels should be determined and samples collected with ±2 weeks of these dates. The other two quarterly samplings should be done at dates approximately halfway between the dates of highest and lowest groundwater levels.

Groundwater sampling from newly installed monitoring wells should be conducted at least one week following well installation and development so that the well establishes equilibrium with conditions in the surrounding geologic materials.

6.5.2 Surface Water Quality Baseline

If pilot study data are not available for surface water to determine statistical power a priori, the MOE requires a minimum of monthly sampling with additional weekly sampling (i.e., 5 samples in 30 days) during periods of maximum hydrograph fluctuation (e.g., freshet or fall rains) at core baseline sampling locations. The proponent must be aware that BC Long-term average (i.e. chronic) WQGs are intended to protect the most sensitive species and life stage against sub-lethal and lethal effects for indefinite exposures. An averaging period approach is used for these WQGs. This approach allows concentrations of a substance to fluctuate above and below the guideline provided that the short-term maximum is never exceeded and the long-term average is met over the specified averaging period (i.e., 5 samples in 30 days). If the monitoring frequency at a site is insufficient to meet the requirements for the specified averaging period of the long-term average WQG, then individual samples will be compared against the long-term average WQG. The long-term average WQG is in place to allow occasional fluctuations (always below the short-term maximum WQG).. This first year of baseline data collection can be used as a pilot study to calculate statistical power for the following years.

Once the temporal and spatial variability of water quality parameters are firmly established through the baseline study and early operational phase monitoring, chemical constituents in water that have low variation from sample to sample and a low probability of exceeding guidelines may be analyzed less frequently. It may take several years of regular sampling to characterize the extent of seasonal variability in solute concentrations. Some parameters such as metals will likely be of special interest and may require a higher sampling frequency. If proponents want to change the sampling frequency, they consult with regional MOE office representatives.

Some chemical constituents in water, sediments, and tissues of organisms, such as selenium and mercury, may be of special concern. Sampling protocols for these parameters may change subject to emerging science, so proponents should check with regional MOE representatives about the most current requirements. Guidance for sediment and tissue baseline data collection is provided in Chapters 7 and 8 of this document.

Baseline surface water quality measurements can continue into the construction, operational, and closure phases. However, sampling frequency may be adapted as needed:

- Due to elevated risk of erosion and soil runoff during mine construction (and early operational phases), daily turbidity measurements with weekly TSS analysis and weekly reporting are recommended during the construction and early operational phases.
- Requirements for monitoring effluent quality and receiving environment quality during the operational phase will be defined in permit documents and supported by a technical assessment. The monitoring frequency will depend on the specific situation. For example, an increase in contaminant concentration in site discharges

or in the receiving environment, confirmed by repeat samples, may trigger changes in the monitoring program in order to identify sources and protect water quality.

- Monitoring frequency at the closure stage will depend on specific circumstances and needs to be discussed with regional MOE representatives at the time. Companies can expect to continue monitoring surface waters and possibly groundwater at a prescribed frequency and duration after the cessation of mining.

6.6 Methods, Instrumentation, and QA/QC

Consistent and rigorous quality assurance and quality control (QA/QC) practices will enable collection of meaningful and scientifically credible data. Results and conclusions from data and practices that do not meet accepted QA/QC guidelines may be rejected by regional MOE representatives, jeopardizing the certification of a proposed project or the granting of a discharge permit. QA/QC is important in every aspect of a sampling program from program design through the field work and laboratory analyses and finally to interpretations of results.

In Canada, laboratories may seek voluntary accreditations of their ability to conduct specific test methods according to ISO 17025 standards. The major Canadian providers of laboratory accreditation services are the Canadian Association for Laboratory Accreditation (CALA) and the Standards Council of Canada (SCC). Both of these organizations promote high standards of defensibility and scientific excellence through programs that incorporate blind proficiency testing and regular on-site audits of the laboratory's management system. The advantage to the proponent of using an accredited laboratory is being confident that the results of analytical measurements are accurate and precise. All samples must be tested by a laboratory that is accredited to ISO 17025 standards for the relevant test methods.

MOE-approved laboratory test methods and laboratory QA/QC requirements are specified in the latest version of BC Environmental Laboratory Manual (MOE, 2009a).

Sampling for both surface and groundwater should follow the procedures outlined in the most recent version of the BC Field Sampling Manual (MWLAP, 2003).

Sample bottles, required sample volume, holding times, and specific preservation should be discussed with the analysing lab. Samples should be kept at a temperature ≤10 °C (but not frozen) during shipping and handling.

Proponents must institute an appropriate QA/QC program to evaluate and ensure confidence in the data collected. Consistent and documented field procedures, collection methods, transportation times, and laboratory procedures, as well as the use of replicates and blanks are all necessary elements in the quality assurance program. Details of a proponent's QA/QC program should be discussed with MOE representatives in the appropriate regional office. General guidance for QA/QC in water quality programs is given in the most recent version of the 2003 British Columbia Field Sampling Manual (Part A). All water quality data must meet quality assurance criteria that are set at the beginning of the project. For examples and guidance in setting quality assurance criteria, see the most recent version of the 2003 British Columbia Field Sampling Manual (Appendix 3). The U.S. EPA document Guidance on Systematic Planning Using the Data Quality Objectives Process (USEPA, 2006a) provides additional background.

Field and laboratory QA/QC reports must be submitted to the appropriate regional MOE office or EAO with the data in electronic format.

A table of sampling sites should be created in order to track sampling locations through the environmental assessment process. Table 3 provides an example table to track sampling locations. Sites are commonly added, moved, or renamed during baseline studies. A table provides a systematic way firstly to locate, track, and evaluate each sampling site relative to the sampling program as a whole and secondly to understand the rationale for selection and/or deletion of certain sites.

A timely and effective review of water quality results can identify lost or rejected data resulting in data gaps. A timely review can also provide early detection of possible trends that could initiate re-sampling to confirm results and/or identify the need to increase sampling frequency for further investigation.

6.6.1 Groundwater

The following preliminary measures must be undertaken prior to groundwater sampling:

- Monitoring wells must be properly designed, installed, and developed.
- Indicator parameters (e.g., temperature, turbidity, pH, and conductivity) must be measured and must have stabilized during purging.
- To verify that the well has stabilized, a minimum subset of parameters (i.e., temperature, electric conductivity, and either turbidity or dissolved oxygen) should be monitored until three successive readings fall within the following limits:
    - pH ±0.1 units
    - electrical conductivity ±3%
    - dissolved oxygen ±10%
    - turbidity ±10%
    - redox ±10mV
    - temperature ±0.2°C

Stable field measurements are likely to indicate a quasi-equilibrium condition and indicate a mixture of formation waters that enter the well screen from permeable formations (i.e., aquifers).

For baseline characterization of groundwater quality, MOE and MFLNRO require analysis for both total and dissolved metals. For dissolved metals, all groundwater samples should be field filtered where possible, preferably within a few minutes of sampling, due to the potential for precipitation of some metals upon exposure to oxygen. Consult the laboratory in advance for guidance on suitable filtration systems, and ensure that a filter blank is collected and submitted for analysis with the samples. All samples for total metals and all field-filtered dissolved metals samples should be preserved with nitric acid in the field. Refer to the BC Environmental Laboratory Manual (MOE, 2009a) for sample preservation and holding time requirements.

Table 3: Example table for tracking sampling locations during the environmental assessment process (strikeouts indicate discontinued water quality monitoring stations)[15].

Site #	Location	Lat	Long	Sampled From	Sampled To	Rationale to initiate, terminate
WQ 001	Mine Creek d/s bridge	xxx N	yyy W	September 1996		Reference site for proposed treated discharge
WQ 002	Mine Creek at u/s Mine Boundary			August 1994		
WQ 003	Mine Creek d/s Tailings Pond			March 1998		Immediately downstream of proposed tailings pond
WQ 004	Mine Creek u/s confluence Big Creek			September 1996		
WQ 005	Big Creek near confluence			August1994		
WQ 006	Seepage Recycle Pond			September 1996		
WQ 007	Pit Sump			September 1996		
~~WQ 008~~	~~Seepage Recycle Pond u/s well~~			October 1998	March 2004	u/s well became dry
WQ 009	Seepage Recycle Pond d/s well			October 1998		
~~WQ 011~~	~~Too-too Creek u/s Mine Creek Confluence~~			September 1996	March 2004	Flows intermittent, data not meaningful

[15] Additional columns should be added to provide information on the media (e.g., surface water or groundwater) sampled at each site and the sampling frequency. Where mixing is incomplete (e.g., aquifers, deep lakes), it is important to record the elevation of the sampling point as well.

WQ 012	Too-too Creek d/s Mine Creek confluence			September 1996		
WQ 013	Too-too Creek at mouth			August 1994		Far-field site

If field turbidity exceeds the target (50 NTU), then a Qualified Professional (e.g., P.Eng. or P.Geo. with expertise in hydrogeology) must assess the reasons for high turbidity. If turbidity in a water quality sample from a well is not due to faulty monitoring well design, construction or development, but rather to the geology of the saturated zone (e.g., clay-rich glacial deposits and high natural flow rates), the well may be sampled and results submitted. The assessment should include the expected mobility of colloid-sized particles within the groundwater system.

Details about the requirements for groundwater sampling for metals are summarised in Appendix 7.

In all other respects, groundwater quality sampling should generally follow the most recent version of the BC Field Sampling Manual (MWLAP, 2003).

6.6.2 Surface Water

Surface water baseline sampling should consider the following:

- Manual sample collection is preferred and should follow the BC Field Sampling Manual.
- Where increased frequency is required for intensive data collection during critical seasons (e.g., freshet, summer/winter low flows), automated bottle samplers and/or continuous monitors (e.g., multi-parameter sondes) are acceptable, provided that the program is discussed and agreed to by regional MOE representatives. Data collection from *in situ* instruments containing sensors for parameters such as turbidity, specific conductance, temperature, pH, and dissolved oxygen is also an option, especially in settings where intensive monitoring of seepage is required. If continuous automated data are collected, the Continuous Water-Quality Sampling Programs: Operating Procedures (MOE, 2006a) must be followed.
- If the risk of contamination from field filtering exceeds the risk of changes in dissolved metals concentrations during transport to the laboratory, then filtering samples in a controlled laboratory situation is preferred for dissolved metals in pristine surface water samples. Dissolved metals samples that will be lab filtered must not be field preserved. Field filtering is required if samples will arrive at the laboratory 72 hours after collection, if the water samples are visibly turbid, if the sampled system is visibly biologically active (e.g., turbid due to phytoplankton, or anticipated to have increased bacterial activity due to abundant organic material), or if the samples are collected from anaerobic waters (e.g., the bottom waters of

seasonally or permanently stratified lakes and pit lakes, or seepages emanating from suboxic aquifers). If field filtering will be conducted, consult the laboratory in advance for guidance on suitable filtration systems, and ensure that a filter blank is collected and submitted for analysis with the samples. All samples for total metals and all field-filtered dissolved metals samples should be preserved with nitric acid in the field.

6.7 Data Storage and Reporting

When presenting data, the proponent should refer to Guidelines for Interpreting Water Quality Data (MELP, 1998) as a starting point. Any data report should include data quality objectives, lab and field QA/QC results, and information about how datasets were handled based on the QA/QC results. It is important for proponents to not only present the baseline data but also interpret and discuss the data in context of the project and the environment.

Water quality data can become voluminous. An early decision on how to best structure, store, and report water quality results is important. Graphical and tabular displays of data are strongly encouraged to supplement text. Maps showing monitoring locations are required.

Databases and spreadsheet formats should be discussed with appropriate regional MOE representatives. Data should be assembled by parameter, station, and sampling date. Data should be stored in a workbook so that inter-site comparisons as well as comparisons with guidelines can be made, temporal trends shown, and data presented graphically. The database should be capable of calculating basic descriptive trend statistics including number of samples; number of results below detection limit; maximum, minimum, mean, and median values; standard error; standard deviation; and 95% confidence intervals. The database should also calculate monthly and annual values (e.g., presented in box plots). In graphs, tables, and text, calculations of mean values should be accompanied by a measure of precision (e.g., standard error, standard deviation, or confidence intervals). Always indicate which measure of precision is displayed (e.g., mean ± standard error).

The detection limit (DL) should always be tabulated with the data. For the calculation of summary statistics for datasets with data below the DL, special methods and software scientifically recognized for this purpose should be used (e.g., as per Huston and Juarez-Colunga, 2009). The proponent must identify instances where approved provincial WQGs, WQOs, or permit limits are exceeded and whether temporal or spatial trends exist. Examples of the preferred format for presenting seasonal water quality data in tables and charts are contained in Appendix 5. The proponent is responsible for ensuring that sampling sites and data are entered into the provincial database (EMS), following discussion with regional MOE representatives. Many laboratories are able to facilitate this requirement for their clients.

For all groundwater samples, except for those collected from improperly designed or constructed monitoring wells, the field and laboratory turbidity values should be reported together with analytical results for total (preserved, unfiltered) and dissolved (0.45 µm filtered, preserved) metals. Data from improperly designed or constructed monitoring wells should **not** be submitted without first discussing the situation with regional MOE representatives. A field turbidity exceeding 200 NTU will be taken to indicate faulty monitoring well design or construction.

Groundwater quality characteristics, including anomalies and variations in the area, should be discussed in the report. If turbidity in a water quality sample from a well is not due to faulty monitoring well design or construction, but rather is due to the geology of the saturated zone (e.g., clay-rich glacial deposits and high natural flow rates), the well may be sampled and results submitted. However, the report must specify that groundwater quality data are provisional due to high turbidity, and the report should contain an assessment of the expected mobility of colloid-sized particles within the groundwater system.

7. WATER QUALITY: AQUATIC SEDIMENTS

7.1 Purpose and Objectives of Aquatic Sediments Monitoring

Sediments represent an important component of the aquatic environment near mine sites. Bottom sediments support aquatic life by providing habitat for attached algae, rooted plants, sediment microorganisms, and burrowing or sediment-feeding invertebrates. All of these provide a food base or habitat for local fish. Fine-grained sediments can bind contaminants (e.g., metals, nutrients, and organics) that may be discharged by mines. Sediment characterization can be advantageous to impact assessment, because fine sediments tend to integrate periodic or storm-based contamination events that may be missed by regularly scheduled water quality sampling. Also, particularly during mine construction and early operational phases, sediment loads themselves can be well above natural levels, and are of interest. Either degraded sediment chemistry or the addition of large quantities of fine sediment to the aquatic environment can adversely affect structure and/or function of the aquatic system. Guidelines for the protection of aquatic life have been established for many metal and organic parameters. Accordingly, sediment characterization is a necessary component of mine baseline, operational, and post-closure assessments.

This chapter provides detailed guidance for sediment baseline data collection, focusing on sediment chemistry. Alternative monitoring programs may be acceptable but should be discussed and accepted by the regional Impact Assessment Biologist (Environmental Protection Division, MOE) before investing in these monitoring programs.

7.2 Review of Existing Aquatic Sediments Information

Sediment inventory data may be available from the following and other related resources:

- Sediment data collected at the mine site by historic proponents
- Sediment data collected at adjacent mine sites
- BC Ministry of Environment database system (EMS) via regional offices
- Metal Concentrations in Bottom Sediments from Uncontaminated BC Lakes (MELP, 1992)
- Local MOE reports and files
- University databases
- Environment Canada: https://wateroffice.ec.gc.ca/search/search_e.html?sType=sed Natural Resources Canada (NRCan)
- MEM: http://www.empr.gov.bc.ca/mining/geoscience/pages/default.aspx

7.3 Site Selection

The sediment program is intended to identify spatial and temporal trends in sediment chemistry at key locations in the vicinity of a mine site. Key locations for fine-grained sediments will normally include main stem depositional zones (i.e., slow flowing parts of lotic streams or rivers) and/or standing, lentic habitats (i.e., water bodies characterized by stagnant or sluggish flow, such as lakes/ponds, oxbows, wetlands or backwaters). Key locations should include sites upstream from, adjacent to, and downstream from the proposed mine.

Coordination of sampling locations for sediments with those for water (Chapter 6), tissues (Chapter 8), benthic organisms (Chapter 9), and fish habitat (Chapter 10) is ideal, as it provides opportunity to examine relationships between these components of the aquatic community. Fine bottom sediments may not be widespread, however, particularly in steeper-gradient areas where mines are often developed. So while integration of these components is preferred, sampling locations for sediments will have to be located where fine sediments are available.

Given that many higher-slope mine environments may lack lentic (wetlands, oxbows, etc.) habitats altogether, attempts should be made to identify and sample the small pockets of fine sediment that exist in lotic (stream) habitats. Caution needs to be exercised, because depositional areas can be spatially quite small and not necessarily representative of broader conditions within the stream. At a minimum, representative sediment sites within each potentially affected water body should be located and sampled.

Lentic habitats are usually located on the floodplain. While they may not be directly linked to the main receiving stream, they may receive surface runoff or groundwater seepage from a nearby mine and therefore would be part of the initial receiving environment. These habitats should be identified and included in the baseline sediment study.

Where lentic habitats need to be identified as part of baseline development for a particular metal (such as selenium), recent aerial photos or satellite imagery of appropriate resolution should be reviewed. The choice of imagery should be appropriate to size of the baseline study area and the complexity of the patterns and processes of interest in the landscape, but generally, multi-spectral images of 50 cm to 5 m spatial resolution should be appropriate. This initial work should be reported to EPD and should be followed by ground-truthing and possibly aerial reconnaissance.

All sample sites must also be geo-referenced, mapped and photographed. Because multi-replicate sites can be several hundred metres long, both the lower and upper extent of each site should be geo-referenced. Each replicate area should be photographed, looking both upstream and downstream over the site, showing banks and an overview of typical substrate and flow pattern.

Sediment sites can be transient, their location dependent on freshet and storm-derived realignments of the stream channel. Accordingly, the proponent needs to characterize sites by grain size and to target the <63 µm (silt/clay) fraction of the sediment spectrum in order to normalize for large-scale changes in the depositional regime.

7.4 What to Measure

Aquatic sediments serve as a record of insoluble particles that are discharged to the water, as well as dissolved contaminant fractions that preferentially bind to sediments. Finer sediment particles are of greater interest in terms of contaminant loads, because most chemical contaminants (e.g., metals and polycyclic aromatic hydrocarbons (PAHs)) preferentially bind to silts and clays. These smaller sediment fractions are also the ones more commonly ingested by benthos, which are therefore at risk of contaminant bioaccumulation

MOE recognizes the guidance of Mudroch and Azcue (1995), as follows:

> *2.4 SAMPLING OF FINE-GRAINED SEDMENTS*
>
> *Bottom sediments are naturally variable. Their physico-chemical properties change horizontally across a water body and vertically down the sediment profile. The bottom sediment of the study area should be subdivided into different groups, which are expected to be as homogeneous as possible. The first division of the sediments should be by particle size distribution, with fine-grained (<63 µm) sediments representing one group that is particularly important to the assessment of sediment quality.*
>
> *It is generally accepted that fine-grained suspended and bottom sediment particles (silt and clay with particle size <63 µm) accumulate greater concentrations of contaminant (references), particularly those with low water solubility, than coarse particles (particle size >63 µm). The fine-grained particles exhibit properties (more) suitable for different physico-chemical sorption and ion exchange of contaminant than the coarse particles. Further, fine-grained sediments support a large part of the benthic community by supplying the food in sediment organic matter associated with the fine-grained particles. Therefore, the assessment of sediment quality must be carried out on the fine-grained sediments sampled in areas of the water body where permanent accumulation of sediment is taking place.*

Sediment selection to 2 mm (very coarse sand) provides insufficient sensitivity for proper assessment of sediment chemistry. These larger particles will have only limited biological and chemical relevance. From a sampling perspective, there is a low probability of being able to repeatedly collect a particular mix of silt and clay substrate during future, comparative programs when the allowable size limit ranges up to 2 mm. Also, most mine sites use effective sediment control measures that retain coarser fractions including sands, leaving only the silt and clay fractions to be exported. Each of these points support the focus on <63 µm.

Within British Columbia, the most comprehensive stream sediment databases are those available from the Natural Resources Canada and MEM websites (listed in Section 7.2). Data in these databases are generated by analyzing the <177 µm fraction of active stream sediments.

This chapter focuses on collection of the <63 µm (silt/clay) fraction, but proponents should discuss program objectives with regional MOE representatives to determine whether the sampling program should also include the <177 µm fraction.

In general, sediment samples that target the silt-clay range (<63 µm) should be collected for analysis by the laboratory. Grain size analysis can be performed on the bulk sample, but the analysis needs to include components of the silt/clay fraction (e.g., at least <3, 3–39, and 39–63 µm) in order to allow data normalization within this fraction between replicates and sites. The value of the grain size analysis in this case is to support interpretation of the sediment chemistry, not to measure increases in total suspended sediment discharges and substrate percent fines that may occur as a result of mine operation. Once dried and partitioned using screens that will not contaminate the sample, the <63 µm sediment fraction should be analyzed for metals, total sulphur, and total organic carbon.

Because organics are usually analyzed using the wet fraction to avoid contaminant loss caused by drying, PAH (and associated moisture), total organic carbon, and grain size analyses should be analyzed on the unscreened (or coarsely screened to 1.0 mm) bulk composite sample of the finest material that can be collected from the sample site. The measure of grain size serves primarily as a tool to allow quality assurance checks of sample variability (sampler collection methods) and to normalize data, rather than to develop a baseline for comparing possible future increases to the percent fines. Effort should still be made to collect the finest available sediment fractions. PAH results are reported on a dry weight basis (i.e., moisture corrected).

Table 4 details the parameters that should be analyzed in aquatic sediments as part of a mine baseline study, although the actual parameters included may vary with mine type. Laboratory detection limits should be less than or equal to $1/5^{th}$ of the respective sediment quality guidelines or, when those are not available, less than or equal to $1/5^{th}$ of the lowest background concentrations measured by the laboratory in typical samples. The detection limits in Table 4 are based on concentrations proposed as “consensus detection limits” by the BC Environmental Laboratories Technical Advisory Committee (BCELTAC) and in most cases meet the objectives above. These limits may not be achievable by all laboratories or for all samples. Note that consensus detection limits for boron, mercury, sodium, and sulphur are not $1/5^{th}$ of their respective guidelines nor of the lowest typical background concentrations, but they are believed acceptable for sediment baseline development associated with most mine proposals. Of particular interest, the consensus detection limit for mercury is 0.05 µg/g. A mercury detection limit of 0.025 µg/g would be required in order to be less than or equal to $1/5^{th}$ of the interim sediment quality guideline. This detection limit is achievable by most laboratories when using specific methods. ***The proponent is responsible for ensuring that updated and appropriate detection limits are used.***

Table 4: Parameters for laboratory analyses of sediments (reported as dry weight).

PARAMETER	DETECTION LIMIT OBJECTIVES	PARAMETER	DETECTION LIMIT OBJECTIVES
Particle Size Distribution and/or texture analysis (of <2 mm)	Report grain size in mm, not mesh #	Moisture Content	1 % wet wt
Total Organic Carbon (TOC)	0.05 %	Sulphur (S) (Combustion-IR)	200 µg/g
Polycyclic Aromatic Hydrocarbon (PAH) Compounds	to 0.05 µg/g. To be discussed with laboratory	Manganese (Mn)	0.2 µg/g
Aluminum (Al)	100 µg/g	Mercury (Hg)	0.05 µg/g
Antimony (Sb)	0.1 µg/g	Molybdenum (Mo)	0.1 µg/g
Arsenic (As)	0.2 µg/g	Nickel (Ni)	0.8 µg/g
Barium (Ba)	1 µg/g	Phosphorus (P)	10 µg/g
Beryllium (Be)	0.1 µg/g	Potassium (K)	100 µg/g
Bismuth (Bi)	0.1 µg/g	Selenium (Se)	0.1 µg/g
Boron (B)	5 µg/g	Silver (Ag)	0.1 µg/g
Cadmium (Cd)	0.05 µg/g	Sodium (Na)	100 µg/g
Calcium (Ca)	100 µg/g	Strontium (Sr)	0.1 µg/g
Chromium (Cr)	1 µg/g	Thallium (Tl)	0.1 µg/g
Cobalt (Co)	0.3 µg/g	Tin (Sn)	0.2 µg/g
Copper (Cu)	0.5 µg/g	Titanium (Ti)	1 µg/g
Iron (Fe)	100 µg/g	Vanadium (V)	2 µg/g
Lead (Pb)	0.1 µg/g	Uranium (U)_	0.05 µg/g
Magnesium (Mg)	10 µg/g	Zinc (Zn)	2 µg/g

The BC Strong Acid Leachable Metals (BC SALM) digestion method must be used for the analysis of all metals in sediments. **Note that special requests must be made in advance for laboratories to analyze only the <63 µm fraction for sediments, since the BC SALM method measures the <2 mm fraction by default.**

It is important to note that this program is not intended to measure changes in stream substrate composition that may occur due to mine development. The need for a suitable program to measure changes in substrate grain size from baseline through operation to post-closure should be discussed with regional MOE representatives for each mine proposal. Guidance is provided in the RISC document "Guidelines for Monitoring Fine Sediment Deposition in Streams".

7.5 Frequency and Period of Record

Sediment sampling should be conducted at least once per year through the baseline and operational phases during late summer low flow periods. Post-closure programs will be negotiated as necessary.

Fine sediments may be difficult to locate in the lotic stream environments of many mines. A sediment sampling site may need to be hundreds of metres long so that several locations can be sampled. Each location sampled at the site provides a replicate sample for that site. Each replicate should be representative of the immediate area and should be a composite collected by taking a minimum of three scoops of sediment with a utensil (spoon/scoop) or dredge. Accordingly, each sample is assumed to incorporate variability. While three dredge collections per sample may provide sufficient volume from a wetland, many spoon scoops (10–20+) may be required to collect one sample from a typical lotic environment that exhibits sparse fine-grain deposits.

MOE identifies three design options for sediment programs near mine sites:

7.5.1 Spatial Variance Program (Standard)

The spatial variance program is MOE's preferred method of sediment assessment for testing inter-site variability and is the default program for mine baseline development. It focuses on the collection and analysis of replicate samples from each site (e.g., reference, near field, and far field), with collections occurring once per year. Three to ideally five samples should be collected per site to test statistically both within-site and between-site variability. One of the replicates collected at every other site should be "field split" (as described under "Sample Collection" in Section 7.6 below) to assess sampler and laboratory quality assurance/quality control (QA/QC). The results of the field split can also be compared with the laboratory's internal split-sample results. This method allows within-site, between-site, and temporal data comparison, but it does not incorporate or test seasonal variability.

7.5.2 Spatial/Temporal Variance Program

This program focuses on the collection of one sample from each site (e.g., reference, near field, and far field), with collections occurring several times per year. The periods of interest are summer low flow, fall low flow, and pre-freshet low flow. Every third site should be "field split" to assess sampler and laboratory QA/QC. One site in the mine area should also be sampled and analyzed in more detail (five replicates) in order to assess quantitatively within-site contaminant variability. This program also statistically tests between-site variability over a one-year period by pooling the seasonal data over that year.

7.5.3 Basic (Non-Statistical) Program

This basic program focuses on the annual collection of a single sample from each site (e.g., reference, near field, and far field), with collections occurring once per year. Every third site should be "field split" to assess sampler and laboratory QA/QC, and five replicates should be collected and analyzed at one site to measure within-site variability. While this program incorporates within-site variability with the "field split" sample, it does not statistically test for this variability other than at the single five-way replicate site. It also does not statistically test for between-site variability. Collection should occur during the summer/fall low flow period. To expedite the overall baseline study, sediment sampling may be timed with the biological data collection typically required in August or September.

In the case of cumulative effects assessments of discharges to lentic (mainly lake) environments from multiple developments over time (e.g., historical mines, older operating mines, etc.), and where the baseline is not pristine, consideration should be given to sediment coring in the profundal zone, preferably at the lake's deep station, to a depth equivalent to the true pre-development baseline. The analysis of this sediment core will help assess the effects of additional effluent from the proposed new development in comparison with both pre- and current development periods. Additional studies should be considered that provide information on interactions between sediments and the overlying water column in terms of contaminant transfer, whether the sediments act as sinks or sources, and what their contribution to cumulative effects may be.

7.6 Methods, Instrumentation, and QA/QC

For a general description of sediment sampling methods, refer to the BC Field Sampling Manual (MWLAP, 2003 or later). For analytical methods, refer to the latest version of the BC Environmental Laboratory Manual (MOE, 2009a or later).

Consistent and rigorous quality assurance and quality control (QA/QC) practices will enable collection of meaningful and scientifically defensible data. Results and conclusions resulting from data and practices that do not meet accepted QA/QC guidelines may be rejected by regional MOE representatives, jeopardizing the environmental certification of a proposed project or the granting of a discharge permit. QA/QC is important in every aspect of a sampling program from program design through the field work and laboratory analyses and finally to interpretation of the results.

The sediment program is to obtain representative samples of submerged, fine-grained streambed sediments (silt/clay) by collecting at least one composite sample per site. Grain size variability within and between sites should be minimal. Field QA will be assessed through the use of replicate and "field split" sample collections, as previously noted

In Canada, laboratories may seek voluntary accreditations of their ability to conduct specific test methods according to ISO 17025 standards. The major Canadian providers of laboratory accreditation services are the Canadian Association for Laboratory Accreditation (CALA) and the Standards Council of Canada (SCC). Both of these organizations promote high standards of defensibility and scientific excellence through programs that incorporate blind proficiency testing and regular on-site audits of the laboratory's management system. The advantage to the proponent of using an accredited laboratory is being confident that the results of analytical measurements are accurate and precise. All samples must be tested by a laboratory that is accredited to ISO 17025 standards for the relevant test methods.

The use of appropriate sediment standards, inserted randomly into field sample batches, should also be considered. These could include a project standard, prepared in-lab from a bulk sample taken in the project area and distributed to a number of laboratories for comparative analysis to evaluate the precision of project data. The second standard can be purchased from several sources including National Research Council Canada's Certified Reference Material (CRM) Program and contains certified values, allowing estimation of data accuracy. These CRM standards should be of similar matrix to the project sediments, and reference values should be obtained by the same analytical method used on the project sediments.

A more in-depth description of sampling methods recommended for the mining industry is provided below:

Preparation

- Prior to sample collection, confirm with the analyzing laboratory the sediment volumes necessary to conduct all planned chemical tests. The metals package, TOC analysis, and sulphur analysis may each require a minimum of 10 g dry weight of silt/clay. PAH analysis typically requires a dry weight of approximately 5–10 g.
- Sediment samples can be collected by spoon or scoop utensils from shallow submerged areas, or with the use of dredges (e.g., Ekman, Peterson, Ponar) or core samplers from deeper lentic sites (e.g., ponds).
- Sediments that are to undergo metals analysis should be collected with plastic or PTFE utensils (spoons or scoops) that have been washed with dilute nitric acid (2-5%).
- Sediments to be analyzed for organics should be collected with acetone washed stainless steel utensils.
- Appropriate cleaning of utensils with acetone and de-ionized water (for organics) or nitric acid and de-ionized water (for metals) is recommended between sites to avoid cross contamination.
- Separate containers can be used for metals/sulphur, PAH/organics, grain size, and percent moisture/total organic carbon. However, the preferred and simpler method

involves collecting a single bulk sample (500 mL) for each of metals and PAH, with their related parameters. A smaller bulk sample (250 mL) should be sufficient in cases where the entire sediment sample is believed to be silt/clay. Assurance must be gained from the laboratory that these bulk samples will be thoroughly homogenized and properly sub-sampled for metals, PAH, grain size, TOC, and other parameters of interest.

Sample Collection

- Do not disturb bottom sediments before deploying the sampling device.
- Collect sediments from areas and depths that have not been recently exposed to air, while maintaining a fairly convenient depth of collection.
- Collect samples from a depth of approximately 2–3 vertical cm into the substrate (at least in lotic environments). Sub-samples collected from dredges should not be taken from near the unit's walls.
- Collect each sample as a composite of sediment from several (minimum of three) submerged silt/clay locations, preferably using two (one large, one small) stainless steel utensils for organic analysis or two (one large, one small) plastic utensils for metal analysis.
- Collect sediments from shallow water by gently scooping from the fine sediment locations with a large spoon or scoop. Visually inspect the sample to confirm the dominance of fine-grained sediments and, if acceptable, transfer the material into 500 or 250 mL bulk metals or PAH/organic containers using a second, smaller spoon.
- Collect samples by proceeding in an upstream direction within each site and as each sample is collected to avoid contamination, with each additional spoonful of sediment contributing to the appropriate bulk container. Collection of a specific sample is complete when the bulk containers have been filled.
- Collect one to five replicate samples from each site, depending on the program design (as described in Section 7.5 above).
- At every third sample (basic program) to every fifth sample at alternate sites (spatial variance program), collect "field split" samples (i.e., two of each container) by alternating spoonfuls of material between the containers until full. Select split-sample locations that contain sufficient sediment quantities for the intended collection.
- For the basic and spatial/temporal programs, collect five replicates from one representative site to assess within-site variability. Ensure similar grain size distribution in each sample container. The replicate variability will indicate the suitability of the "one sample per site method" normally applied with the basic program.
- Record field observations including depth of sample (top 2–3 cm), sediment vertical profile (abundance of fine sediment at the site), sediment texture and colour, and presence in the sediment of living organisms, debris, biofilms, odour, or oily sheen.

Sample Handling

- Use the recommended sediment preservation, storage conditions, and hold times from the latest version of the BC Environmental Laboratory Manual (MOE, 2009a or later) also found in Appendix 6.
- Sediment analyses will depend on program objectives. Sediments collected for metals analysis should be lab dried to a constant weight at ≤60 °C (consistent with BC SALM method), gently ground to break loose aggregates and screened to 63 µm (silt/clay) prior to analysis for metals, and related sulphur, TOC and grain size or "texture" analysis of only the fine fraction. Given the selective method of sample collection, grain size analysis of the bulk metals sample would be artificial and is considered unnecessary. The laboratory must be informed of cases when the 63 µm fraction is to be analyzed.
- To avoid the loss of volatile components, PAH and other organics are typically analyzed wet weight on unscreened or coarsely screened samples, with the full range of grain size analysis and the moisture and TOC analyses being used to normalize each sample result after the organics have been analyzed. The BC aquatic life guidelines for sediment PAH are reported in terms of %TOC.
- Laboratory detection limits should be less than or equal to $1/5^{th}$ of the respective sediment quality guidelines or less than or equal to $1/5^{th}$ of the lowest background concentrations measured by the laboratory in typical samples.
- Consider establishing a sample archive of dried and homogenized pristine material (300 to 500 g) for future investigations.

7.7 Data Storage and Reporting

Data should be assembled by parameter, station, and sampling date into a database that includes statistical summaries such as number of values, minimum, maximum, mean, median, number of results below detection limit, standard deviation, standard error, etc. The laboratory detection limits and sediment guidelines for aquatic life must be tabulated along with the data, and any values that exceed the guidelines should be highlighted. Data, with units, should be reported as dry weight and clearly identified as such. Data may be presented in graphs and/or on maps showing areas with elevated levels of parameters if any are detected. The proponent is responsible for ensuring that site data are also entered into the provincial database system for storage (EMS), following discussion with regional MOE representatives. Many laboratories are able to facilitate this requirement for their clients.

All sample sites must be geo-referenced, mapped, and photographed from different angles. Also, a table of sampling sites should be created in order to track sampling locations through the environmental assessment process (e.g., see Table 3 in Chapter 6 and Appendix 10). Sites are commonly added, moved, or renamed during baseline studies. A table provides a systematic way to locate, track, and evaluate each sampling site along with the sampling program as a whole.

8. WATER QUALITY: TISSUE RESIDUES

8.1 Purpose and Objectives of Tissue Residue Monitoring

Biological tissues are important sampling media in mine-related baseline study and impact assessment. Similar to sediments, tissues can absorb metal or organic contaminants discharged by operational or post-closure mines. Contaminants may be taken up directly from the water column via facilitated diffusion (e.g., inorganic metals) or, in the case of organic selenium and methyl-mercury, may be taken up via dietary sources, stored in fat and proteins, and biomagnified up the food chain (concentration increases via diet through three or more trophic levels). Regardless of the mode of uptake, the quantification of tissue contaminant levels is a necessary part of the baseline study, providing reference for future contaminant accumulation in aquatic organisms. Significant change from baseline concentrations may trigger additional impact assessment and/or the implementation of contingency mitigation measures that should have been developed as part of the mine review process.

While tissues do provide important data, the proponent must consider how to minimize unnecessary destructive sampling of fish, amphibian, and aquatic bird species, particularly target species that may be threatened over time (e.g., heavily sampled surrogate species, small isolated populations, rare or endangered species, etc.). Different techniques or selection of tissue types that enable non-destructive sampling might be required and should be discussed with regional MOE staff before monitoring begins.

The aquatic organisms usually collected for tissue residue analysis include birds, attached algae (periphyton), aquatic macrophyte vegetation, benthic invertebrates (including bivalves), amphibians, mammals (hair or tissue), and fish. Avian (usually bird eggs) or mammalian tissue assessment is often included where mercury or selenium has been found to be an issue. The actual tissues collected within any given baseline study should be discussed with regional MOE representatives before monitoring commences.

This chapter provides detailed guidance for tissue residue baseline data collection. Alternative monitoring programs may be acceptable but should be discussed and accepted by the regional Impact Assessment Biologist (Environmental Protection Division of MOE) before investing in the monitoring program. Given increasing concern with the exposure of aquatic life to selenium at many BC mine sites, this chapter emphasizes the collection of tissues for analysis of this metalloid.

8.2 Review of Existing Tissue Residue Information

Tissue inventory data may be available from the following and other related sources:

- Tissue data collected at the site by historic proponents
- Tissue data collected at adjacent mine sites
- BC Ministry of Environment database system (EMS) via regional offices

- Metal Concentrations in Fish Tissues from Uncontaminated BC Lak1es (MELP, 1992)
- Local MOE reports and files
- University databases
- Environment Canada environmental indicators
- Natural Resources Canada (NRCan)
- Canadian Environmental Assessment Agency

8.3 Site Selection

Site selection for tissue residue monitoring may be largely determined by the availability of tissues. Where and what to measure are closely related.

The habitat types that can be monitored include lotic (stream) riffles, lotic depositional areas, and lentic wetlands, oxbows, backwaters, and lakes. While all tissue types might ideally be sampled from each of these waters, habitat type may determine what tissues can actually be collected. Fish tissues, along with sediments, tend to be relatively easy to collect in sufficient volume and number of replicates. It is often difficult, however, to collect sufficient volume of periphyton or benthic invertebrate tissues for chemical analysis, particularly if moisture content is to be measured along with metals. Periphyton and benthic invertebrates may also be limited in riffle areas of typical, low nutrient environments. Fish may be unavailable in isolated wetlands or oxbows or in higher elevation lotic habitats upstream from migrational barriers.

Site selection for tissue collection requires careful consideration. Selection should be based on many factors, including:

- the contaminant of interest (specific organic or metal contaminant);
- where the contaminant of interest is taken up (primarily from lentic sediments or directly from the water column);
- how and by what organisms the contaminant of interest is taken up;
- the importance of the organism to human or natural predator consumers;
- organism availability and mobility (specifically of fish);
- life stage and maturity of the organism to be sampled (in terms of contaminant contact and tissue availability); and
- the presence of, access to, and safety of sampling the organism's preferred habitat.

At a minimum and within each affected water body/watershed, locations upstream from, adjacent to, and downstream from mine influence should be targeted for tissue sample collection. Regional MOE representatives should be consulted during the site selection process or to confirm proposed sites. All tissue sample sites should be geo-referenced and photographed (upstream, downstream, substrate, flow pattern, banks, and vegetation).

The selection and sampling of tissues at sites far downstream from the proposed mine development require careful consideration during baseline planning. Ortho-photos or satellite imagery of appropriate resolution with ground or aerial survey follow-up can be used to identify potential sites. Samples should include those of far-field lakes, main stem depositional reaches and floodplain backwaters, side channels, oxbows, etc. The surface contact between lentic areas and the main stem, and the degree of contamination potentially caused to those lentic areas, should be considered. Emphasis should also be placed on sampling far-field water bodies that are connected to the main stem by surface flow. Groundwater flow from the main stem to these remote lentic areas may be limited and of lesser concern.

Sites selected for the collection of tissues should correspond with sediment sampling locations, particularly if contaminant uptake is via the food chain that originated in those sediments (i.e., for organic selenium or methyl mercury). While lentic (e.g., oxbow) and main stem depositional (e.g., pool) habitats will be the preferred location for sampling contaminants such as selenium, main stem riffle habitats may be preferred for other contaminants or specific biota (e.g., periphyton in response to nutrient loading) or may need to be sampled if main stem depositional habitats are lacking.

8.3.1 Periphyton and Macrophytes

Periphyton is defined here as a broad assemblage of organisms composed of attached algae, fungi, and bacteria, their secretions, associated detritus, and various species of microinvertebrates that occur on the sediment surface, sometimes referred to as “biofilm”. The biofilm is considered by some research to be the most relevant aquatic compartment for assessing selenium bioaccumulation. Periphyton is thought to facilitate the conversion of selenate to bioavailable organic selenide.

For consistency with other media, and in particular for baseline studies where selenium is of interest, periphyton should be collected from the same depositional habitats sampled for sediment and invertebrates. However, periphyton may be difficult to collect from deep water, soft substrate (lentic) environments without the use of artificial substrates or alternate collection techniques. While perhaps of less relevance (at least for selenium assessment), periphyton may need to be collected from main stem lotic riffles. In this case, periphyton for contaminant analysis should be collected at the same locations as samples taken for chlorophyll-a and community structure analyses (see Chapter 9).

The aquatic environment downstream from mine sites typically becomes phosphorus limited during mine life as nitrate from blasting residues leaches into receiving waters. Poor sewage management or the addition of inorganic phosphorus from equipment washing stations or fertilizer applications may promote the excess growth of attached algae, with possible implications for selenium biomagnification. This possibility should be discussed with MOE staff and considered during site selection.

Macrophytes are defined here as aquatic plants that are often rooted or with roots and that have distinct component structures large enough to be visible to the naked eye. Macrophytes are included in the food preferences of many waterfowl. Selenium can enter many structures of aquatic plants, primarily through the roots, to accumulate in the roots and/or in stems, leaves, shoots, and seeds. Because the form and concentration of selenium may vary between structures within a plant, a consistent sampling program (e.g., of mature leaves or whole plants) should be maintained throughout the baseline study and operational monitoring programs. While lentic and main stem depositional environments should be more commonly selected for the collection of macrophytes, lotic riffles may be used for the collection of aquatic moss tissues.

8.3.2 Benthic Invertebrates

Benthic invertebrates can be expected to occur in each of the three habitat types (lotic riffles, lotic depositional areas, and lentic wetlands, oxbows, backwaters, and lakes) and, depending on program objectives, should be collected from each type. The collection method should be site specific, with bulk-sampling kick nets used in riffle zones and dredges used in deeper depositional or lentic habitats. A lack of invertebrates in lentic zones may require reliance on lotic riffle sites. Artificial substrates (e.g., gravel baskets) or in-situ cages (e.g., containing mussels) could also be considered. It may be very difficult to collect sufficient invertebrate tissue mass from just one species. Therefore, practicality usually dictates the pooling of invertebrate species for chemical analysis.

8.3.3 Fish

In selecting sites for fish sampling, particular attention must be given to species site fidelity and species age-class and size-class distributions relative to the mine site location. Each of these three factors has ecological and/or toxicological significance that may affect contaminant uptake. Where possible, two species (one sport fish and one non-sport fish) should be collected, with more samples taken of the non-sport species. At least one sampled species should have relatively high site fidelity (i.e., low mobility within/between watersheds). A small-bodied fish such as slimy sculpin is appropriate as a species with high site fidelity; rainbow trout may be only moderately useful.

It must be recognized that high-value sport species or species under particular legislative protection (and thus of high interest) may also be highly mobile (e.g., bull trout) to the point where their use in assessing a specific mine may not be practical. The number of sites sampled in each watercourse may then be less for highly mobile species (including mountain whitefish). These mobile species may be better assessed in a wider geographical context by way of regional cumulative effects assessment.

Early discussions with MOE staff can help to determine the best indicator fish species for the specific project and area. Tissue databases should be developed for each watercourse in the mine area.

Proponents are cautioned that collecting fish for monitoring purposes, including for mine baseline studies, requires a provincial and/or federal collection permit/license, depending on the species collected. For collection of resident fish species and anadromous trout (steelhead), the BC *Wildlife Act* requires a fish collection permit, which can be procured through the regional MOE office.

To collect anadromous salmon, the federal *Fisheries Act* requires a scientific collection license, which can be procured through the Pacific Region Fisheries and Oceans Canada office in Vancouver or Whitehorse Yukon (for projects in north-western BC).

If collecting organisms defined under the BC *Wildlife Act* as "wildlife" (e.g., amphibians, some reptiles, resident birds, and mammals) for any purpose, a permit will be required.

To collect migratory birds under the federal *Migratory Birds Convention Act* and other wildlife under federal jurisdiction, proponents should contact the Canadian Wildlife Service to obtain a scientific collection permit (call 604-940-4700).

Some discussion with regulators may be necessary in planning how much lethal sampling will be allowed. Lethal sampling may be necessary to obtain data for the country foods assessment (for Health Canada), fish tissue metals concentrations, maturity, fish health (Environmental Effects Monitoring under the *Metal Mining Effluent Regulations*), and some age structures (otoliths). All efforts should be made to minimize lethal sampling by determining all federal and provincial data requirements and using as few fish as possible to meet these requirements.

With larger fish, options for non-lethal sampling should be practiced wherever possible. Environment Canada's guidance for the technique can be found in Guidance for Fish Tissue Analysis for Mercury (Environment Canada, 2005).

8.4 What to Measure

The parameters that should be analyzed in aquatic tissues as part of a mine baseline study are listed in Table 5. While the parameters and tissues of interest may vary depending on the mine type, the table provides a reasonably complete list of the parameters that should be measured and their currently available detection limits. Laboratory detection limits should be less than or equal to 1/5th of the respective tissue quality guidelines (the lower concentration of aquatic life or consumption) or, when those are lacking, less than or equal to 1/5th of the lowest background levels measured by the laboratory in typical samples. Tissue guidelines are lacking for many of the metals usually analyzed. The detection limits in Table 5 are based on concentrations proposed as "consensus detection limits" by the BC Environmental Laboratories Technical Advisory Committee (BCELTAC) and in most cases meet the objectives above. These limits may not be achievable by all laboratories or for all samples. ***The proponent is responsible for ensuring that updated and appropriate detection limits are used***.

Tissue percent moisture allows conversion between wet-weight and dry-weight measures. This is particularly important for interpreting fish tissue selenium data, as this parameter has both dry-weight and wet-weight aquatic life guidelines. Proponents are encouraged to discuss minimum sample weight requirements with their laboratory as part of baseline development. Tissue samples with excessively high moisture (i.e., >90% in some periphyton, macrophyte, benthic invertebrate, and bird egg samples) should be dried at ≤60°C and weighed directly prior to acid digestion in order to minimize unnecessary error associated with moisture corrections. Data for these high-moisture organisms should be reported as dry weight, with detection limits being five times greater than those listed in Table 5, based on the assumed 80% moisture. Percent moisture may be reported from associated sub-samples of these tissues, if sufficient sample volumes exist and the measure is requested. All data reports must clearly indicate whether analytical results are being reported as dry weight (dwt) or wet weight (wwt).

Table 5: Parameters for laboratory analyses of tissue residue in aquatic biota (reported as µg/g wet weight for lower-moisture (approx. ≤90%) tissues).

PARAMETER	DETECTION LIMIT OBJECTIVES	PARAMETER	DETECTION LIMIT OBJECTIVES
Moisture Content	1 % wet wt	Mercury (Hg)	0.002 µg/g
Aluminum (Al)	0.4 µg/g	Methyl Mercury (MeHg) if required	0.002 µg/g
Antimony (Sb)	0.002 µg/g	Molybdenum (Mo)	0.01 µg/g
Arsenic (As)	0.005 µg/g	Nickel (Ni)	0.01 µg/g
Barium (Ba)	0.01 µg/g	Phosphorus (P)	5 µg/g
Beryllium (Be)	0.002 µg/g	Potassium (K)	10 µg/g
Bismuth (Bi)	0.02 µg/g	Selenium (Se)	0.02 µg/g
Cadmium (Cd)	0.002 µg/g	Silver (Ag)	0.01 µg/g
Calcium (Ca)	2 µg/g	Sodium (Na)	2 µg/g
Chromium (Cr)	0.01 µg/g	Strontium (Sr)	0.01 µg/g
Cobalt (Co)	0.004 µg/g	Thallium (Tl)	0.001 µg/g
Copper (Cu)	0.01 µg/g	Tin (Sn)	0.02 µg/g
Iron (Fe)	1 µg/g	Titanium (Ti)	0.06 µg/g
Lead (Pb)	0.004 µg/g	Uranium (U)	0.001 µg/g
Magnesium (Mg)	2 µg/g	Vanadium (V)	0.02 µg/g
Manganese (Mn)	0.02 µg/g	Zinc (Zn)	0.1 µg/g

8.5 Frequency and Period of Record

Tissue sampling should be conducted once a year through the baseline period or as negotiated, depending on the strength of the existing data or the sensitivity of the specific target group. The minimum requirement prior to mine construction is a one-year baseline study that provides approved biological tissue data. In most cases, sample collection should occur during the summer/fall low flow period. To expedite the overall baseline study, tissue sampling may be timed with the biological program (for community structure; see Chapter 9) typically required in August or September. Post-closure sampling programs should be negotiated as necessary.

Considering the difficulty of collecting sufficient quantities of some tissues, two program types are recommended. Observations recorded in the field are media specific, and numerous and are discussed below:

8.5.1 Spatial Variance Program (for fish and for other organisms as negotiated)

This is MOE's preferred method of biological tissue assessment for testing inter-site variability. This program focuses on the collection and analysis of multiple fish samples from each site (e.g., reference, near field, and far field), with collections occurring up to once per year. Ideally, an *a priori* power analysis should be conducted using historical tissue data from fish in the same or nearby watersheds to determine a suitable sample size. If this is not possible, eight replicates should be collected per site to describe statistically both within-site and between-site variability. One of the replicates collected at each site should be split to assess sampler and laboratory quality assurance/quality control (QA/QC). This method allows within-site, between-site, or temporal data comparison, but it does not incorporate or test seasonal variability. If fish are rare or difficult to catch, the samples may be collected over a two-year period during the baseline study. However, in this case, the first year of data should be considered a pilot study and the necessary baseline sample size be confirmed with an *a priori* power analysis prior to sampling in the second year.

8.5.2 Basic (Non-Statistical) Program (for periphyton, macrophytes, and benthic invertebrates)

This basic program focuses on the annual collection of single composite samples from each site (e.g., reference, near field, and far field). The basic program is appropriate for collecting organisms that may be relatively difficult to locate in sufficient density to support replicate collections. Collection should occur during the summer/fall low flow period when other biological sampling is underway.

Every third sample should be "field split" to assess sampler and laboratory QA/QC. One site in the mine area should also be sampled and analyzed for up to five replicates, if possible (i.e., if sufficient biomass exists for replicate sampling), in order to quantitatively assess within-site variability of the chemical of concern. The MOE recognizes that obtaining five replicates at one site may not be logistically possible for periphyton samples due to analytical biomass requirements. Data from the five replicates help to assess the suitability of collecting only one sample at other sites. While this program incorporates within-site variability into each composite sample, it does not statistically test this variability other than at the single five- replicate site. This program does not statistically test for between-site or temporal variability.

8.6 Methods, Instrumentation, and QA/QC

For a general description of tissue residue sampling methods, refer to the latest version of the BC Field Sampling Manual (MWLAP, 2003 or later). For analytical methods, refer to the latest version of the BC Environmental Laboratory Manual (MOE, 2009a or later).

Consistent and rigorous QA/QC practices enable the collection of meaningful and scientifically defensible data. Results and conclusions resulting from data and practices that do not meet accepted QA/QC guidelines may be rejected by regional MOE representatives, jeopardizing the environmental certification of a proposed project or the granting of a discharge permit. QA/QC is important in every aspect of a sampling program from program design through the field work and laboratory analyses to the interpretation of results.

The goal of the tissue residue program is to obtain representative samples of the agreed biological tissues by collecting at least one composite sample per site. Ideally, the variability within- and between-sites should be minimal. Field QA will be assessed through the use of replicate and “field split” sample collections, as previously noted.

In Canada, laboratories may seek voluntary accreditations of their ability to conduct specific test methods according to ISO 17025 standards. The major Canadian providers of laboratory accreditation services are the Canadian Association for Laboratory Accreditation (CALA), and the Standards Council of Canada (SCC). Both of these organizations promote high standards of defensibility and scientific excellence through programs that incorporate blind proficiency testing and regular on-site audits of the laboratory’s management system. The advantage to the proponent of using an accredited laboratory is being confident that the results of analytical measurements are accurate and precise. All samples must be tested by a laboratory that is accredited to ISO 17025 standards for the relevant test methods.

The use of appropriate tissue standards, inserted randomly into field sample batches, should also be considered. These could include a project standard, prepared in-lab from a bulk sample taken in the project area and distributed to a number of laboratories for comparative analysis to evaluate the precision of project data. The second standard can be purchased from several sources including the National Research Council Canada’s Certified Reference Material (CRM) Program and contains certified values, allowing estimation of data accuracy. These CRM standards should be of similar matrix to the project tissues, and reference values should be obtained by the same analytical method used on the project tissues.

A more in-depth description of sampling methods recommended for the mining industry is provided below.

Biological Tissue Collection, Preparation, and Handling Prior to Chemical Analysis

Tissue collection methods vary considerably depending on the purpose of collection, organism, and habitat type. Proponents are strongly encouraged to contact regional MOE representatives early in their baseline planning process to supplement the following information as necessary:

- Prior to sample collection, contact the analyzing laboratory to confirm the necessary tissue volume for all planned chemical tests. For fish, tests usually include full metals scans and percent moisture. For other tissues, tests may be full metals scans and percent moisture, if possible and requested.
- Consult the analyzing laboratory about recommended containers, preservatives, holding times and conditions for samples. Recommended tissue preservation, storage conditions, and holding times are given in the latest version of the BC Environmental Laboratory Manual (MOE, 2009a or later) and are included in Appendix 6 of this guidance document.
- For metals analysis, collect samples using plastic equipment that has been washed in nitric acid. For organics analysis, collect samples with stainless steel equipment washed in acetone. For either types of analysis, cutting equipment may need to be acetone-washed stainless steel. Appropriate cleaning of equipment with acetone and de-ionized water (for organics) or nitric acid and de-ionized water (for metals) is required between sites to avoid cross contamination.
- Ensure that periphyton and benthos samples are collected from instream locations that have not recently been dry or exposed to air due to a change in water level.
- Sample in an upstream direction within each site.
- Do not disturb organisms at the site before deploying the sampling device.
- Collect the agreed number of replicates for each organism type.
- For periphyton, macrophytes, and benthic invertebrates, ensure that each sample is a composite taken from several (minimum of three) submerged locations at the site. Use equipment appropriate to the organism and habitat.
- Confirm with the analyzing laboratory the sample weight required for each tissue type collected. The general minimum requirement per sample is approximately 8 grams wet weight. Smaller sample weights may be acceptable but must be confirmed by the laboratory.
- Have tissues analyzed with laboratory detection limits that are less than or equal to $1/5^{th}$ of the respective tissue quality (aquatic or consumption) guidelines, or when guidelines are lacking, less than or equal to $1/5^{th}$ of the lowest background levels measured by the laboratory in typical samples.
- Representative taxonomic sampling and analysis should be conducted to define the makeup of the community being sampled. Taxonomy samples should be identified to the lowest possible taxonomic level in the laboratory..

Organism-specific tissue collection, preparation, and handling methods are discussed below.

Periphyton/Macrophytes

- Use equipment that is appropriate for collecting material quickly but that minimizes the amount of entrained sediments.
- These are bulk samples intended to collect a maximum practical mass. Sampling is not quantitative, so the density of the sample (per area) is not required. Use tools such as razor blades, brushes, tweezers, scissors, etc. to collect the samples. General statements about organism density should be recorded.
- Periphyton sites may typically be covered by only a sparse diatom community that may be difficult to sample in bulk. If the site contains heavy filamentous periphyton cover, consider collecting the filamentous periphyton for contaminant analyses.
- At all but one site (see next bullet), collect one composite periphyton sample (minimum of three scrapings), with the actual number of scrapings dependent on the availability of periphyton.
- At one representative site, collect up to five replicates, if possible, to assess within-site variability. The data from these replicates indicate the suitability of the "one sample per site method" normally applied with the basic program.
- At every third site, collect split samples using two containers. Alternate the loading of periphyton or macrophyte tissue into each container until full. Select split sample locations that contain sufficient tissue quantities.
- Measure and record sampling depth and near-bottom velocity.
- Within each site, collect one representative composite sample for taxonomic analysis from each of the observed communities sampled for chemistry.
- Where macrophytes exist (assumed more common in lentic environments), selected structures of these plants should be composite sampled as per other biota, for selenium, metals and percent moisture, as required. Sample macrophytes by structure or collect the entire plant. Sample storage would be as per laboratory direction.
- Store samples in the field with minimal water at 4°C, but not frozen. Periphyton samples must be filtered in the laboratory prior to analysis and may then be frozen, if necessary. Macrophyte samples may also be frozen following removal of attached water.
- To avoid excessive error, samples with moisture content >90% should be dried at ≤60°C to constant weight, so that parameter concentrations may be measured directly in dry-weight units.

Benthic Invertebrates

- Use equipment that is appropriate to collecting material quickly but that minimizes the amount of entrained sediments.

- These are bulk samples intended to collect a maximum practical mass. Sampling is not quantitative, so the density of the sample (per area) is not required. Kick netting (lotic) or dredging (lentic) are preferred collection methods. General statements about organism density should be recorded.
- At all but one site (see next bullet), collect one composite sample (minimum of three nettings or dredgings), with the actual number dependent on the availability of invertebrates.
- At one representative site, collect up to five replicates, if possible, to assess within-site variability. Data from these replicates indicate the suitability of the "one sample per site method" normally applied with the basic program.
- At every third site, collect split samples, as described for periphyton.
- Measure and record sample depth and near-bottom velocity.
- Within each site, collect one representative composite sample of benthic invertebrates for taxonomic analysis.
- Store samples as per laboratory direction.
- To avoid excessive error, samples with moisture content >90% should be dried at ≤60°C to constant weight, so that parameter concentrations may be measured directly in dry-weight units..

Fish

The tissues collected from fish for chemical analysis depend on the contaminant of concern. For selenium analysis, tissues may include the dorso-lateral muscle, whole body, and egg/ovary tissues. For mercury analysis, tissues may include muscle and liver. The specific tissues collected also depend on the size of the fish being sampled. In most cases, muscle samples can be obtained from individual fish. However, liver samples may need to be obtained as a composite of tissues from several fish, depending on the species, fish size, and sample requirements. For small species (e.g., sculpin), analyses of the whole fish or multiple-fish composites may be the only practical means. Also, depending on the parameter of interest, tissue guidelines may dictate which tissues are analyzed. For example, selenium guidelines are currently established for whole-body concentrations..

Target species

- Monitor contaminants such as selenium primarily by using non-migratory slimy sculpin (or other common sculpin species) and/or rainbow trout, westslope cutthroat trout, longnose suckers, or if necessary, juvenile mountain whitefish as surrogates. If sampling mountain whitefish, only juveniles should be collected to reduce the influence of migration on the uptake/depuration of selenium by older members of this species. Reference sites may need to be established farther afield due to the mobility of whitefish relative to sculpin. The sampling program should anticipate the need to assess a regional fish distribution but should be discussed with MOE staff prior to implementation.

- Monitor mercury on muscle plugs taken using biopsy tools and collected from larger predatory fish, particularly those sport or sustenance species of human dietary interest. See Guidance for Fish Tissue Analysis for Mercury (Environment Canada, 2005).
    - Collect small numbers of sport fish one time during the baseline study for metals and moisture analysis. These tissue concentrations may be of more regional than mine-specific interest. Sample numbers will need to be determined with regional MOE or FLNRO staff. If larger fish are targeted (particularly bull trout), strongly consider using non-destructive sampling techniques such as the collection of dorso-lateral muscle plugs using biopsy tools.
    - In cases where muscle plugs cannot be used, consider reducing the sampling of species that are protected under provincial legislation (e.g., bull trout).
- To account for both the mobile nature of bull trout and their protected status, collections should be restricted to those fish less than 10 cm length, for the following reasons:
    1) Assuming that only a limited number of these fish will be collected, it's necessary to reduce size variability.
    2) Migration effects on contaminant accumulation/depuration should be less in younger fish with greater site fidelity.
    3) A 10-cm length is large enough to provide the minimum 8 g sample size for metals and % moisture analysis.
    4) Under normal circumstances, smaller members of a population should be more abundant.

MOE recognizes that limiting the bull trout baseline to juveniles may overlook the more appropriate adult age class. However, 10-cm fish may be two years old, should be consuming benthos, and may be accumulating selenium. If future assessment is required on larger bull trout, muscle plugs could be taken from fish over larger watershed areas.

Sample collection

- Collect eight replicates per site, or enough to attain an agreed limit on variability. They may be individual or composite samples depending on fish size.
- Confirm sample weight requirements with the analyzing laboratory. The general minimum requirement per sample is approximately 8 g wet weight. Smaller samples may be acceptable after confirming with the laboratory. In particular, try to reduce sample weight for sculpin, where, due to the small size of this species, collecting 8 g per sample usually requires increased numbers of fish to be killed.
- Remove the skin from dorso-lateral muscle tissue samples or muscle plugs prior to analysis.

    - Collect samples for aging from a representative number of each size class of each fish species. Reading otoliths is the preferred method for aging, but because this technique requires fish to be sacrificed, the less-accurate scale analysis may be more practical for some species. Otoliths are used for aging sculpin and bull trout; scales can be used for aging rainbow trout and mountain whitefish.
    - Measure and record species, size, weight, age, and sex (when distinguishable) and submit these data along with other monitoring data.
- If necessary, collect the full fish tissue baseline over a two-year period. Doing so assumes environmental stability over the baseline period and also assumes limited variability in tissue concentrations within and between years. High variability may indicate the need for additional baseline sampling.

Laboratory analyses

- Throughout all mine phases, have fish tissues analyzed for all default parameters listed in Table 5, unless otherwise negotiated.
- Ensure that the laboratory assesses its precision by homogenizing, splitting, and analyzing every eighth fish tissue replicate. The laboratory should select split samples that contain sufficient tissue quantity
- Have tissues analyzed and reported on a wet-weight basis. The level of detection (for selenium) should be reported as 0.02 µg/g wet weight.
- Have moisture content analyzed for every sample due to the variability inherent in this parameter.
- Develop a fish tissue database identifying metals for each watercourse in the mine site area.

8.7 Data Storage and Reporting

The format for tissue data storage may vary among regions. Proponents are advised to contact the regional MOE office for recommended data storage formatting. Data should be assembled in a database by type of biota and/or fish species, site, sample date, fish metrics, and parameter. The database should include basic statistical summaries such as sample size; maximum, minimum, mean, and median values; standard deviation, standard error, etc. (refer to Appendix 9 for table formatting). The method detection limit and the appropriate (fish tissue) guidelines for aquatic life should be tabulated along with the data. Whether data are reported as wet-weight or dry-weight or as normalized values must be clearly indicated. Data may be presented in graphs and/or on maps showing areas with elevated concentrations of parameters, if any are detected. Site data should also be entered into the provincial database system (EMS) by the proponent or their laboratory, following discussion with MOE representatives.

9. WATER QUALITY: AQUATIC LIFE

9.1 Purpose and Objectives of Aquatic Life Monitoring

While physical and chemical parameters provide a foundation in any water quality monitoring program, biological measures provide insight into the health of the aquatic ecosystem. A primary objective of monitoring water quality and ecosystem health is to ensure the protection of water users including humans and both aquatic and terrestrial organisms.

Common aquatic assemblages or populations studied in baseline monitoring include invertebrates (e.g., benthic or planktonic), algae (e.g., periphytic or planktonic), macrophytes, and fish.

This chapter focuses on sampling benthic macroinvertebrates and periphyton in lotic (flowing) water bodies, with some discussion of sampling lentic (calm, such as lakes) water bodies. While many of the concepts presented are relevant to monitoring the marine environment, marine-specific protocols are not discussed. Baseline sampling requirements for fish populations and habitat are discussed in Chapter 10 and tissue sampling is covered in Chapter 8.

The design of a baseline study for aquatic life requires considerable effort and depends on the study's objectives and the desired level of precision. Developing a conceptual model of the ecosystem to be studied is a crucial first step. A model provides a context from which to pose and refine questions to be investigated in the study (Lindenmayer and Likens, 2009). Once clear questions are set, the proponent can design a monitoring program to gather the necessary data. Clear objectives and well-defined questions assist in determining location and number of sampling sites, number of replicates, frequency of sampling, types of organisms to be monitored, approaches to data analysis, budget, level of taxonomic identification, and storage and reporting of data (Biggs and Kilroy, 2000).

9.2 Review of Existing Aquatic Life Information

For a given study area, existing information on aquatic life or ecosystems may be available from a number of the following sources:

- Consultants
- Local industry
- Local libraries
- Colleges / universities
- Ministry of Environment regional offices
- Provincial government libraries including the MFLNRO/MOE library in Victoria
- Cross-Linked Information Resources database
- Data from mines operating in the vicinity of the proposed project area

- Historical environmental assessment or monitoring work conducted by past mineral tenure holders
- Federal government offices and libraries
- Environment Canada's Canadian Aquatic Biomonitoring Network (CABIN) database[16]

The availability and acceptability of these data should be discussed with regional MOE Environmental Impact Assessment Biologists.

Relevant B.C. government documents to be reviewed prior to developing a monitoring program for aquatic life include the following:

- Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (Cavanagh et al., 1998)
- BC Field Sampling Manual (MWLAP, 2003)
- Bioassessment of Streams in North-central British Columbia Using the Reference Condition Approach (Perrin et al., 2007)
- CABIN Field Manual (RISC, 2009a)[17]
- Guidelines for Interpreting Water Quality Data (MWLAP, 1998)

The 2011 Metal Mining Environmental Effects Monitoring (EEM) Technical Guidance Document (Environment Canada, 2011) provides detailed information for sampling benthic invertebrates.

Additional literature related to the fundamentals of monitoring and experimental design include Bailey et al. (2004), Biggs and Kilroy (2000), Green (1979), Hurlbert (1984), Legg and Nagy (2006), Lindenmayer and Likens (2009), and Underwood (1991, 1992, 1993, 1994).

9.3 Site Selection

In selecting sampling sites, consider the following:

- General study design
- Study objectives and questions to be investigated
- Location of historic and current monitoring sites in the area
- Resources at risk from the proposed development
- Consistency of physical habitats among sites
- Degree to which the sites (including reference sites) are representative of the study area

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[16] Check under "Current CABIN sites" (http://cabin.cciw.ca/cabin_current_activities.asp?lang=en-ca) on the website to determine if existing CABIN sites are located in the area of interest. A password is required to access the data in CABIN and can be obtained by contacting the regional MOE Environmental Impact Assessment Biologist (CABIN training is required to obtain a password).

[17] This document is the B.C. Ministry of Environment RISC standard for reference condition approach sampling using CABIN protocols.

- Other development in the area (i.e., confounding sources of contamination)
- Land ownership (e.g., private land)
- Access
- Safety

Biological sampling sites should correspond with water chemistry (Chapter 6), sediment (Chapter 7), and tissue residue (Chapter 8) sites where possible to assist with data interpretation.

Sampling sites should be selected with long-term monitoring in mind to maintain consistency before, during, and after development. While baseline study sites located under the proposed mine footprint (e.g., under the proposed tailings pond) should generally be avoided, they may be necessary if pre-impact information is required to characterize unique habitats or to provide information for compensation or reclamation.

The types of water bodies in a study area will also influence selection of sampling locations. Monitoring programs must include rivers, streams, lakes, and wetlands that may be impacted by mine development.

All sampling sites are to be geo-referenced, mapped, and photographed from different angles. Because sites are commonly added, moved, or renamed during baseline studies, proponents must develop, distribute, and update a table identifying sampling site locations and details of the sampling program (see Table 3 in Chapter 6). This type of table presents a concise summary of the sampling program and provides a systematic way to locate, track, and evaluate each sampling site.

9.3.1 Benthic Macroinvertebrates

Streams and Rivers (Lotic Environments)

The selection of sampling sites in rivers and streams depends on the design of the monitoring and assessment program. The MOE recommends that the reference condition approach (RCA) sampling design through the Canadian Aquatic Biomonitoring Network (CABIN) be used for benthic macroinvertebrate monitoring. However, under certain circumstances (as approved by regional MOE representatives), more traditional designs such as before-after-control-impact (BACI) with multiple reference sites may be appropriate.

RCA is a bioassessment tool that the MOE has adopted. This approach uses a multivariate statistical model to compare benthic macroinvertebrate communities at “test” sites (i.e., exposure sites) with communities found at reference sites that have similar natural characteristics. Rather than relying solely on upstream reference sites (and the inherent statistical problems associated with such designs), the RCA model draws upon an existing database of geographically diverse, undisturbed reference sites. The results from the model are used to determine the degree to which the benthic macroinvertebrate community at a test site differs from the reference (i.e., natural) condition, if at all (Bailey et al., 2004).

With a BACI design, sites must be established prior to disturbance both upstream (and in similar nearby water bodies) and downstream from proposed developments. Upstream (reference) and downstream (impact/exposure) sites should share similar physical habitat features (e.g., slope, substrate, velocity, depth, shade, riparian vegetation, etc.). A set of reference sites (i.e., a minimum of three) is vital to interpreting results of a monitoring program (Underwood 1991, 1994). A larger number of reference sites improves understanding of natural variability of the area and allows more powerful statistical comparisons with sites downstream of development. Thus, multiple reference sites are strongly encouraged in any monitoring program using a BACI design.

With both RCA and BACI designs, test/exposure and reference sites should be sampled within the vicinity of a proposed mining development. Test/exposure sites must be established immediately downstream on watercourses that could be affected by mine development activities, and farther downstream to confirm that negative effects do not extend beyond the initial dilution zone[18]. A gradient design, in which exposure sites are distributed at increasing distances downstream from a proposed development, is used to determine the spatial extent of any effects.

Where suitable reference sites exist, RCA and BACI designs can be combined, provided CABIN field protocols are followed (RISC, 2009a). Combining these designs provides a weight-of-evidence approach to assessment, allows upstream/downstream and before/after comparisons, and uses an array of suitable reference sites. Furthermore, the CABIN database facilitates the calculation of a large number of metrics that can aid with data interpretation.

Lakes, Wetlands, and Oxbows (Lentic Environments)

For some developments, monitoring sites will be required in lentic ecosystems, which include still or slow-moving aquatic habitats found in lakes, wetlands, and oxbows. The location and number of sites in each habitat type depends on the size and depth of the water body, the number of possible alternatives for point or non-point discharges, and the risks posed by the proposed development. Several sampling sites should be established at varying distances from discharges or areas of potential influence. Depending on the size of the water body, sampling is also recommended at the deepest point and at the outlet. Monitoring design options include before–after radial, transect, and gradient designs. Reference sites must be established within the same water body, if it is large, or in similar nearby water bodies. Generally, multiple reference sites are required depending on sampling design, the availability of suitable sites, and the quality assurance/quality control (QA/QC) program.

[18] An initial dilution zone is the initial portion of the larger effluent mixing zone. The extent of an initial dilution zone is defined on a site-specific basis and considers water uses, aquatic life including migratory fish, and other waste discharges. Initial dilution zones are normally relatively small (e.g., up to 100 m from the point of effluent discharge, but not exceeding 25–50% of the width of the water body) and are essential to allow for the initial mixing between effluents and the receiving water.

9.3.2 Periphyton

When selecting sites for periphyton sampling, a suite of factors needs to be considered including the impact assessment design and the habitat features in the study area. At each site, sampling points (replicates and field subsamples) can be randomly chosen as described in MWLAP (2003) or selected at equidistant points along a transect (Biggs and Kilroy, 2000). If similar habitats cannot be captured among sites using transects, sampling a sub-set of common depths, velocities, and substrates is an option (Biggs and Kilroy, 2000). Biggs and Kilroy (2000) recommend sampling runs, while others recommend sampling riffles. The habitat type sampled will be site dependant. It is important, however, to remain consistent among sites, trying to standardize depths, gradients, velocities, exposure to sunlight, etc.

9.4 What to Measure

9.4.1 Benthic Macroinvertebrates

Numerous techniques and protocols exist for sampling benthic macroinvertebrates. Various sampling equipment can be used for both natural and artificial substrates. However, because the RCA is the tool recommended by the MOE, the following section focuses on CABIN protocols used within an RCA framework.

Regardless of the sampling technique, macroinvertebrates should be identified and enumerated by a certified taxonomist[19] to the lowest practical taxonomic level (usually genus or species), or as agreed with regional MOE representatives. Although CABIN models generally require family-level taxonomic classification, lower-level identification can provide greater resolution for interpreting results and can provide options to test and develop genus-level models. Furthermore, genus- and species-level identification may be more appropriate for future research related to issues such as biodiversity.

<u>Streams and Rivers</u>

Reference condition approach (RCA)

The MOE has developed RCA bioassessment protocols for rivers and streams using benthic macroinvertebrates (RISC, 2009a). These procedures, adopted from Environment Canada's CABIN protocols (Reynoldson et al., 2003), are provincial standards. Data collected using these methods are to be used with existing RCA models contained in the CABIN database. Background information on the reference condition approach, including designing monitoring programs, developing models, and using the RCA for impact assessment, is contained in Bailey et al. (2004) and Perrin et al. (2007).

[19] e.g., North American Benthological Society taxonomy certification

The proponent should contact regional MOE representatives for additional information including the suitability of existing RCA models for the proposed project area, the benefits of using the RCA for impact assessment and field forms.

While RCA model outputs are used as indicators of aquatic ecosystem health, traditional community descriptors can also be calculated from data collected using CABIN protocols. Individual metrics can assist with data interpretation. For example, metrics include macroinvertebrate density, taxon richness, diversity indices, Bray-Curtis Index, functional groups (e.g., % shredders), % EPT (Ephemeroptera, Plecoptera, Trichoptera), and presence/absence of individual taxa. For convenience, a number of these metrics can be calculated within the CABIN database. For a discussion of the pros and cons of each type of metric, see Taylor and Bailey (1997).

Other sampling designs

Should RCA models not be available or suitable for the proposed project area, the proponent should discuss the use of BACI or alternative designs with regional MOE representatives. When planning a BACI or similar monitoring program, review the Environmental Effects Monitoring Technical Guidance Document for benthic invertebrates under the *Metal Mining Effluent Regulation* (Environment Canada, 2011).

The proponent should determine sample sizes in a rigorous manner, and clearly explain the rationale for the selected sample size.. A sampling program with an insufficient sample size will have both low precision and low statistical power, and may not meet its objectives. The sampling program should be designed to:

- show a significant change in community structure or biomass with a given degree of confidence (e.g., 95% confidence - 19 times out of 20, the measured difference is real) and
- detect a biologically significant change, if one is present, with a power of at least 0.8 (1-β) (where β=0.2; 20% chance of Type II error). The proponent is required to discuss what constitutes a significant and important biological change (i.e., the effect size) to aquatic communities with regional MOE representatives. Values should be selected prior to implementing the monitoring program and should be stated as actual units of response, a fixed percentage change, or as a given number of standard deviations from a mean. Environment Canada (2002) discusses statistical considerations related to sampling effort and study design.

Proponents are responsible for reporting the *a priori* statistical power of their sampling plan to provide reviewers with an understanding of the program's strengths and weaknesses. If pilot study data are not available to determine power *a priori*, MOE requires at least five replicates, each consisting of 3–5 field subsamples per site during the initial year of sampling. This first year of the baseline study then becomes a pilot study and the proponent is expected to conduct a power analysis to advise the next round of baseline sampling. Environment Canada (2002) provides more detailed information related to sampling effort including the use of a "power regression equation." Avoid using a retrospective power analysis to determine the observed power of a test or to determine the detectable effect size (especially in the case of a non-rejected null hypothesis) (Hoenig and Heisey, 2001).

Once in the field, proponents must:

- Standardize habitat features for each replicate and site as much as possible.
- Collect as much habitat data as possible at each site. RISC (2009a) provides guidance on how to collect habitat data. In particular, record stream wetted and channel widths, cover, gradient, dominant and subdominant substrate (or conduct pebble counts), embeddedness, and depth and velocity at each replicate site.
- Consider recent stream stage and do not sample recently dry habitats.
- Record area and mesh size of the sampling device.
- Record depth and duration of substrate disturbance (e.g., 10 cm x 3 minutes) after removal and cleaning of surface rocks.

Lakes, Wetlands, and Oxbows

Accepted protocols and methods for sampling the littoral, pelagic, and benthic environments of lakes for zooplankton, phytoplankton, macrophytes, and benthic fauna are contained in the B.C. Field Sampling Manual (MWLAP, 2003). See information under the Streams and Rivers heading above to assist with determining appropriate sample sizes.

Collecting benthic macroinvertebrates in off-channel stream habitats and wetlands is especially important in regions where selenium is a concern. See Chapter 8 (Tissue Residues) for more details.

9.4.2 Periphyton

Periphyton is commonly measured during baseline studies in rivers and streams (and sometimes in lentic environments) as an indicator of water quality and primary productivity. Community structure (taxonomy) and biomass (chlorophyll-*a* and possibly ash-free dry mass) are generally the parameters of most interest. Periphyton can be collected from either natural or artificial substrates using a number of techniques. The BC Field Sampling Manual (MWLAP, 2003) outlines one set of sampling protocols. Biggs and Kilroy (2000) have created a comprehensive periphyton sampling manual that is recommended reading when designing a periphyton monitoring program. They discuss all aspects of periphyton monitoring including designing a program, conducting field work, and analyzing biomass and taxonomic data.

To enable statistical comparisons among sites, it is critical to sample an appropriate number of replicates to characterize variability at a site (see section 3 in Biggs and Kilroy, 2000). The number of replicates can be determined based on a preliminary assessment of the variability of the periphyton community at each site. If a pilot assessment is not possible, Biggs and Kilroy (2000) recommend collecting 10 replicates as a default. By measuring replicate depth and near-bottom velocity (variation within the group should be less than +/-25% of the mean), variability can be reduced and data interpretation improved (e.g., a replicate from an area of notably slower water could explain differences in species composition or chlorophyll-*a* concentrations).

Periphyton samples must be collected in a consistent manner within and among sites. Protocols vary with substrate size and type, but the most common method for impact assessment is to brush or scrape a sample from a defined area on the top of submerged rocks. The area can be delineated using a circular template pressed against the stone (e.g., modified syringe, toilet plunger, sample bottle lid). With this method, the two options to gather the sample are to extract the periphyton from the inner portion of an open template, or to scrub the entire surface around the template prior to lifting the template and collecting the circular patch of periphyton that remains. Alternatively, the entire upper surface of the rock can be sampled, though determining the area sampled is more difficult. It is important to sample an adequate area and number of replicates to account for natural variability at the sites.

Taxonomy and biomass samples should be taken independently. Although it is faster to split each sample into a taxonomy and biomass fraction, it can be extremely difficult to homogenize samples and such practice may not result in representative samples.

For taxonomic studies, samples should be identified to the genus level as a minimum, or as agreed with regional MOE representatives.

Habitat information to be collected in the field includes types and amounts of riparian vegetation on right and left banks, degree of shade, stream gradient, water depth, substrate composition, and depth and velocity at which each rock is sampled. Each site should be photographed from a fixed location on each visit (Biggs and Kilroy, 2000). Photographs should document the overall stream community at the time of sampling.

The MOE will accept other scientifically valid sampling protocols, including the use of artificial substrates if water depths or conditions make sampling natural substrates unsafe, or if natural substrates differ significantly between reference and exposure sites. Rapid assessment procedures, in which the colour and thickness of algae are noted at each site, are a useful addition to any program. Selected sampling protocols should be discussed with regional MOE representatives prior to implementation. Some MOE regional staff have significant experience in sampling periphyton and favour locally developed sampling methods.

9.5 Frequency and Period of Record

Benthic macroinvertebrates and periphyton are typically collected once a year in mid-August to mid-September, depending on the objectives of the study. Because high flows and associated bedload movement can dislodge benthic invertebrates and scour periphyton from substrate, collection of benthic invertebrates should be delayed after heavy rains, and periphyton sampling should not occur until at least four weeks following a flood (Biggs and Kilroy, 2000). MOE requires a minimum of one complete survey for the baseline study but prefers data from two or more consecutive years. Two years is the minimum time required to define inter-annual variability. Subsequent surveys will be conducted according to study objectives, site-specific circumstances, and methods used.

9.6 Methods, Instrumentation, and QA/QC

General methods for sampling benthic macroinvertebrates and periphyton are described in Section 9.4. Detailed field methods for sampling benthic macroinvertebrates using CABIN protocols (RCA) are found in the Canadian Aquatic Biomonitoring Network Field Manual (RISC, 2009a). The Metal Mining Guidance Document for Aquatic Environmental Effects Monitoring (Environment Canada, 2002) provides information on techniques used to sample benthic invertebrate assemblages in both lotic and lentic ecosystems. Methods for sampling macrophytes in rivers and streams and phytoplankton and zooplankton in lakes can be found in the BC Field Sampling Manual (MWLAP, 2003). Variances from suggested procedures and standards should be discussed with regional MOE representatives prior to sampling. The proponent must **fully describe** the methods used in subsequent reports.

Consistent and rigorous quality assurance and quality control (QA/QC) practices enable collection of meaningful and scientifically credible data. QA/QC is crucial in every aspect of a sampling program including program design, field work, laboratory/taxonomic analyses, and data interpretation. QA/QC guidelines are described in detail in the BC Field Sampling Manual (MWLAP, 2003) and by Environment Canada (2002). General QA/QC guidelines are located in 'Part A' of MWLAP (2003) while QA/QC specific to biological sample collection is contained in 'Part C.' To use CABIN protocols, formal training is required for study design, field sampling, sample processing, and data entry to ensure data entered into the database meets standards set by Environment Canada. In addition, CABIN QA/QC protocols must be adhered to.

Results and conclusions based on data and practices that do not meet accepted QA/QC guidelines may be rejected by MOE representatives, jeopardizing the environmental certification of a proposed project or the granting of a discharge permit.

9.7 Data Storage and Reporting

When presenting data, the proponent should refer to Guidelines for Interpreting Water Quality Data (MELP, 1998) as a starting point. Graphical and tabular displays of data are strongly encouraged to supplement text. Maps showing monitoring locations are required.

Where appropriate, summary statistics should include means, medians, standard errors, standard deviations, and 95% confidence intervals. In graphs, tables and text, estimates of means should be accompanied by a measure of precision (e.g., standard error or confidence interval). Always indicate which measure of precision is displayed (e.g., mean ± standard error). Differences in means or medians between reference and exposure sites (for BACI programs) should be compared statistically or using a series of metrics. More elaborate statistics and the selection of appropriate metrics for analyzing macroinvertebrate and periphyton community assemblages will depend on program objectives, and should be discussed with regional MOE representatives in the design phase of the monitoring program prior to initiating field work.

Interpretation of results is required in baseline study reports and in effects assessments. Discussing biological results in the context of water chemistry, sediment chemistry, and contaminant concentrations in tissue is necessary to gain an understanding of the aquatic ecosystem and to predict effects.

9.7.1 Benthic Macroinvertebrates

Proper storage of data is important for all monitoring programs. For RCA studies, all taxonomic, habitat, and water quality data must be stored on the CABIN web-based database. These data must be entered in order to use RCA models contained in CABIN. Training (CABIN certification) and authorization from Environment Canada is required to use CABIN. Contact regional MOE representatives for more information.

The validity of an existing CABIN model for a given mine site can be tested with data collected during the baseline study. To verify the use of the model, enter data from both reference sites and test sites and run the appropriate model. All sites free of upstream disturbance should fall within the 1st band (central green circle in Figure 2). However, it is possible (though less likely) for these sites to fall within the 2nd band (in this situation, speak with your regional MOE representative). If a site falls in the 3rd or 4th band, the site may be either inappropriate for use with the model or impacted by historical land use. Alternatively, the predictive RCA model may not have captured the natural variability associated with the region or streams within your study area. Discuss this possibility with your regional MOE representative.

9.7.2 Periphyton

At a minimum, the proponent should report community composition (e.g., relative abundance of taxonomic groups and discussion of indicator species) and individual metrics including taxa richness, diversity indices, biomass, etc. Chlorophyll-*a* concentrations must be compared with the BC water quality guidelines (see Nordin, 1985).

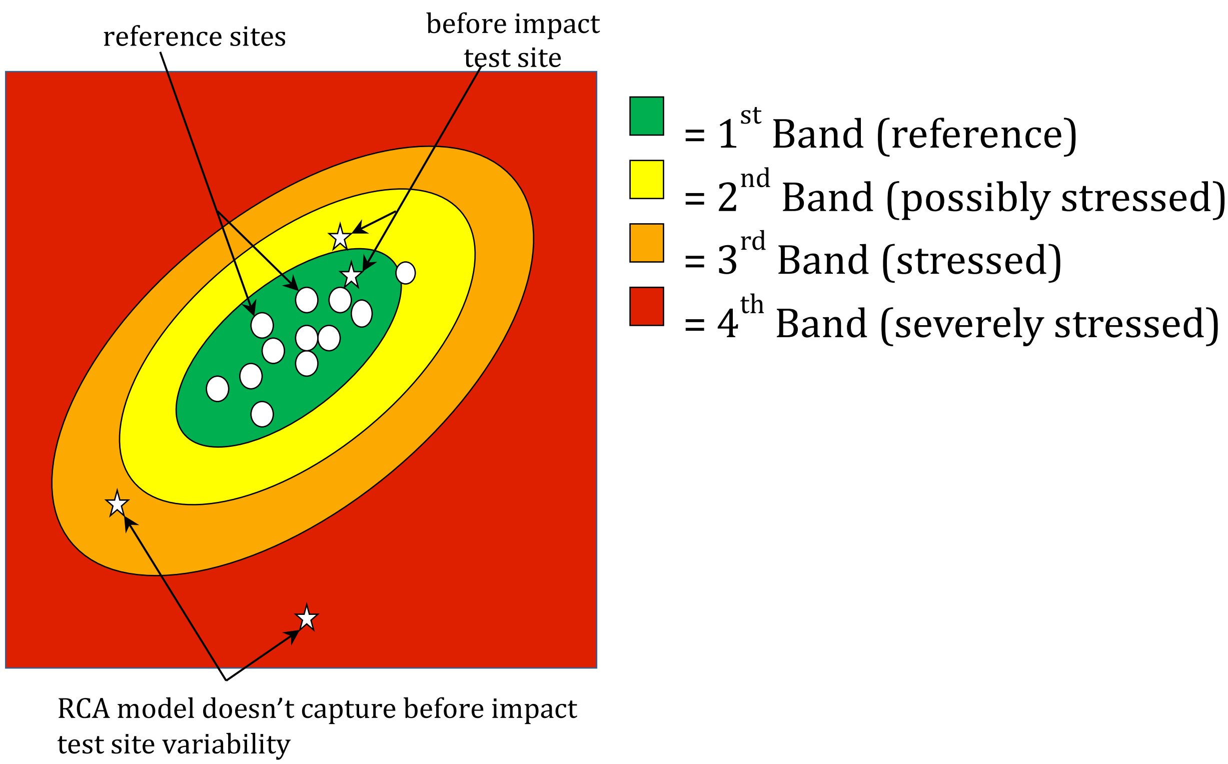


Figure 2: Interpreting the viability of an existing RCA model at a new mine site using baseline data.

10. FISH AND FISH HABITAT

10.1 Purpose and Objectives of Fish and Fish Habitat Monitoring

Baseline data collection must capture detailed information on fish population abundance and distribution by species and life stage and the habitats they use on an annual basis in order for regulatory agencies to evaluate the impacts of mine development on fish and fish habitat. The primary impacts of mine development on fish populations are almost always mediated through impacts to their habitat. These impacts include alteration to sediment deposition and scour processes in streams, sediment accumulation in lakes and wetlands, stream crossings (roads, pipelines, and powerlines), stream diversions, changes to stream flows, effluent discharge, and complete habitat loss under the project footprint. In particular, the impacts of the tailings storage area, waste dumps, and project footprint will require the most detailed studies, as they are likely to pose the most significant risks to fish and fish habitat. Fish populations respond to perturbations in numerous ways, including increased stress, disease, mortality and decreased growth, inability to reproduce, survival, recruitment, and production.

The main objectives of fish and fish habitat monitoring related to mining are to:

- describe the abundance and distribution of fish habitats in the project area;
- determine whether previous land and water uses have affected the habitats;
- determine to what extent the proposed development will affect fish habitat;
- determine to what extent the population is likely to be able to sustain itself through an understanding of population dynamics including sustaining recruitment needs to adult habitats (streams, lakes, reservoirs and rivers);
- determine whether First Nations harvest and angling is likely to be affected by the mining development;
- allow for a robust assessment of how alterations to fish habitats and connectivity between habitats required seasonally and (or) by different life stages will affect fish population processes and productivity;
- identify potential physical and biological bottlenecks to fish productivity and survival, and corroborate them with population data whenever possible (e.g., populations limited by spawning habitat, intrinsic reproductive capacity, and factors affecting growth (e.g., water temperature or trophic regimes) have different characteristics than those that are not); and
- lay the foundation for monitoring programs that will measure project effects during mine construction, operation, and closure.

Overall, the nature and extent of baseline data requirements will depend on the fish population(s) and types in question and the anticipated impacts of the project on aquatic ecosystems. The purpose is to fully understand the fish and fish habitat values to be impacted locally and be able to place these impacts in the context of the wider landscape. As a result, information requirements for review may change in response to initial baseline data. Regular submission of work plans and interim study reports to regulatory agencies during the pre-application stage is an important component of scoping the extent of data requirements for Environmental Assessment.

Fish and fish habitat assessments should be signed off by a Registered Professional Biologist with fisheries expertise that covers knowledge of fish biology, habitat, and population assessment methodologies. Methods for data collection, capture, and presentation of fish and fish habitat data should follow or exceed Resource Information Standards Committee (RISC) standards (RISC, 2000 and 2001a). Any departure from these standards should be discussed prior to the initiation of field assessments with and supported by the appropriate FLNRO fisheries equivalent representative well in advance of field surveys.

In cases where changes to instream flow will impact fish habitat and fish populations, the British Columbia Instream Flow Methodology should be used to assist proponents in collecting the detailed baseline data required according to bioperiod and general flow regime understanding. The approach and requirements of the BC Instream Flow Guidelines are discussed and expanded on in Section 10.4.3.

10.2 Review of Existing Fish and Fish Habitat Information

While many remote areas have had no formal fish sampling, considerable information has been collected on fish distributions, fish abundance at the meso-habitat scale and fish habitat in the province. Much of this information has been stored on databases maintained by the provincial and/or federal governments or has been described and reported on as a meta-analyses. A guide to accessing these databases is available from the Environmental Information Resources System (EIRS), under a search for “Fish and Fish Habitat Information and Inventory.” Most key provincial databases can be searched using the CLIR (Cross-Linked Information Resources), an umbrella search application that queries multiple sources.

A particularly useful tool is the Fisheries Information Summary System (FISS). FISS is a standardized, systematic, province-wide compilation of data that is digital, fully geo-referenced, and linked to the 1:50,000 BC Watershed Atlas. Similarly, Habitat Wizard and iMapBC are useful search engines that provide digital and fully geo-referenced data that can be used to support an initial query. The Ecosystem Information Section of the Ministry of Environment’s Knowledge Management Branch in Victoria can also be contacted to access information in provincial databases and other documented and archived resources. Nonetheless, proponents should note that these tools do not provide sufficient detail for an Environmental Assessment application, because many waterbodies have not been previously sampled and those that have will likely require further sampling for a mine development impact assessment. Proponents should therefore expect to undertake primary and grey literature surveys alongside empirical studies to supplement information available in FISS. They may also canvass experienced biologists that have already undertaken detailed stock assessments integrated with habitat surveys in the Project area.

Regional offices of FLNRO Resource Management Division often have a resource information specialist responsible for managing regional files, databases, maps, and other information. As a last resort, these individuals may be contacted for help locating hard-to-find information however their accessibility may not always be guaranteed.

10.3 Site Selection

The degree and extent of sampling will depend on the nature of the project, the fish habitat in the area, and site-specific conditions that will influence the sensitivity of both populations and habitats to potential impacts. The baseline survey must include all waterbodies to be impacted by the mine footprint and all locations that could impact fish habitat. Therefore, the following locations must be surveyed: the pit, waste dumps, stockpiles, mill, tailings storage area, access road, power lines, and receiving environments. Effluent-receiving environments may require sampling at a significant distance downstream from the project footprint.

The initial survey should follow a RISC standard 1:20,000-level reconnaissance fish and fish habitat inventory (RISC, 2001a). As the proponent gains a basic understanding of the fish populations and habitat distribution, informed decisions can be made regarding more detailed fish and habitat surveys and the extent of sampling required over the landscape. For instance, a RISC survey may be sufficient for access roads and power line crossings, while the pit, waste dumps, stockpiles, mill, and tailings storage area may require more extensive surveys to account for the scale and extent of the impacts. Specifically, areas with more significant impacts should be surveyed using comparable techniques outlined in Johnston and Slaney's (1996) Fish Habitat Assessment Procedure (FHAP). One exception to this requirement is that littoral zones of lakes should be surveyed using RISC standards (2001a).

All habitats that will be permanently affected by the mine footprint should be fully surveyed, documented, measured quantitatively, and mapped by using standardized FHAP techniques (Johnston and Slaney 1996) and Reconnaissance (1:20,000) Fish and Fish Habitat Inventory Standards and Procedures (RISC 2001a). This assessment should include surveys of spawning areas, holding or overwintering pools, resident adult habitats in all seasons, migration corridors, adult production areas (lake, large rivers) or other areas where fish congregate as part of their life history. These surveys provide valuable baseline data and information that indicate the productive capacity of an area's habitat and its importance to population replacement. This information will be used to determine appropriate levels of habitat compensation and subsequently to assess the effectiveness of applied compensation measures. Habitat that will be permanently altered or removed due to the pit, waste dumps, stockpiles, mill, or tailings storage area will require compensation.

The more challenging questions when selecting sites for fish baseline data collection often involve the extent of survey required outside the mine footprint. Knowing whether fish habitat is abundant or rare on the landscape will help evaluate the importance of the habitat in the project area. Whether an impact to spawning habitat represents a loss of 5% or 75% of the total spawning habitat available to a local population is an important distinction. Sampling within the larger watershed is usually necessary to gain this perspective. Therefore, during the reconnaissance inventory, the opportunity should be taken to conduct visual surveys during over-flights of waterbodies of interest. Visual surveys allow opportunities to evaluate overall reach characteristics and to identify barriers, spawning gravels, beaver dams, and other pertinent habitat features. For small streams under closed tree canopies, where visibility for aerial surveys is poor, ground-based stream walks can be conducted with the same goals. These more time-intensive surveys are usually conducted only on systems to be directly impacted which may include specialized radio telemetry studies to better understand population ecology and the relative importance of the impacted sub-basin or tributary network.

The presence of migratory fish populations in the project area can lead to sampling fish and habitat more broadly over the landscape. For species with long migrations (e.g., adfluvial bull trout), the geographical extent of the sampling program may be large, requiring the use of radio telemetry to track fish movements and determine the extent and timing of habitat use in the area expected to be affected by development. For sampling focused specifically on tissue or environmental effects monitoring (EEM), additional considerations that may affect the selection of sites (e.g., species site fidelity, age and size class distributions) are provided in Chapter 8 (Tissue Residues) and Section 10.3.1.

For mine access roads, transmission lines, and other linear developments, habitat data must be collected by the proponent along with fish presence information at the crossing sites (MFLNRO and MOE, 2012). Habitat and fish presence information will establish types of crossing structures that can be used and construction timing windows and to guide Environmental Management Plans. Information regarding landscape-level fish distributions, migration timing and associated passage flows linked to barriers (either partial or complete) can be useful in these assessments.

10.3.1 Site Selection for Monitoring Programs

A key objective of baseline fish data collection is the design and establishment of monitoring programs. Some form of fish monitoring will be required any time there is potential for a population-level impact. Population-level impacts include any loss of habitat, habitat alteration due to sedimentation or effluents, and newly created or improved access that could increase harvest pressure. Also, Fisheries and Oceans Canada (DFO) may require additional monitoring information pertaining to fish or fish habitat to support the development of a federal *Fisheries Act* authorization for the harmful alteration, disruption or destruction (HADD) of fish habitat or an associated fish habitat compensation plan (see section 10.6.1).

Selection of impact and undisturbed reference sites is an important step that relies on quantitative fisheries information gathered during baseline data collection and predicted project impacts. Site location and number should be chosen to provide an experimentally robust design. The search for reference sites in the same Ecosection with similar hydrology, water chemistry, fish population, and habitat characteristics to the impact sites can lead to extensive inventory far upstream of the project footprint or in separate drainages.

Changes to significant mine components (access road routing, tailings and waste rock storage location, water management, effluents) are common during the pre-development stage as baseline data collection and consultation refine the mine plan. These changes may have significant implications for impacts to fish habitat. Therefore, monitoring plans and sampling site selection must reflect these changes.

In addition to any monitoring programs requested by provincial regulators, Environment Canada will likely require EEM under the *Metal Mining Effluent Regulation* (Environment Canada, 2002). In the interest of efficiency, and where possible, the proponent should attempt to seek efficiencies between provincial and federal programs and requirements.

Several years of sampling the reference and impact sites prior to project development with the "before, after, control, impact" (BACI) experimental design (see Section 9.3.1) will provide the best possible experimental and statistical power. More detailed guidance on establishing fish monitoring programs is provided in Appendix A of Hatfield et al. (2007).

The preferred method for monitoring fish populations will depend on objectives, habitat, species, and life phase of interest. Monitoring plans should be discussed with provincial and federal regulators early in the process to assure their information requirements are being met. Statistical and experimental design, proposed analysis, strategies for stratification, and a power analysis will be required components of any proposed monitoring plan.

10.4 What to Measure

10.4.1 Fish Community

Data pertinent to assessing fish and fish habitat must be collected along with data for hydrogeology and hydrology, water quality (Chapters 6, 7, and 8), lower trophic levels (Chapter 9), and stream and riparian ecology. An assessment of how a proposed water use will affect fish and fish habitat can only occur if a sufficient amount of biological information is collected. Baseline biological information for fish must therefore include:

1. Fish presence and absence throughout the project area;
2. Fish species and life stages present;
3. Indicators of fish abundance that can be compared with other studies or models (not CPUE data);
4. Fish distribution (in space and time);
5. Life history timing (fish periodicity chart or bioperiods); and
6. Source and reliability of information.

Baseline biological data collected to support a mine development application should meet or exceed existing inventory and stock assessment standards (e.g., RISC 2001a, Ricker, 1975, Ricker, 1971, Johnson et al. 2007). Any departure from these standards should be discussed with and supported by the appropriate FLNRO representative. Reports pertinent to this assessment should be signed off by a fisheries biologist with a professional designation of R.P. Bio. and demonstrated experience with fish and fish habitat assessments.

10.4.1.1 Fish Presence and Absence

Determining if streams and lakes are fish bearing in the project area is critical. All streams and lakes lacking reliable data are considered to be fish bearing. Therefore, proponents need to search available records to develop appropriate sampling programs and must obtain appropriate sampling permits from DFO and/or MOE or MFLNRO. The Fish Stream Identification Guidebook (BC MOF and BC MELP, 1998) describes the procedure used to determine fish-bearing status for forestry. Many of the same procedures are recommended for supporting mine development applications, but more exact sampling including when necessary, replicated surveys over time, is recommended because mining activities can have different and more direct influences on fish populations and habitat than forest practises.

In the past, the limits of fish distribution in streams have often been established based on the location of barriers. However, this characterization is only accurate for migratory species. Fish are often present upstream of barriers, possibly because they were present in a watershed before a barrier formed or they were transplanted into the watershed by humans. Therefore, all stream reaches and tributaries upstream of barriers must be sampled to demonstrate fish-bearing status. Where waterbodies upstream of barriers are rated as non-fish bearing, proponents must be able to provide a rationale justifying the 'complete' barrier status. Proponents should be able to demonstrate whether a single factor (e.g., fish sampling alone) or the cumulative effects of several factors (e.g., fish sampling, water velocity, barrier height, pool depth at outfall, etc.) were considered in the barrier determination. The assessment of fish barriers should integrate methodologies and data requirements described in Parker (2000).

Fish distribution in lakes should also be determined by using standardized methods. Appropriate methods for collecting data in lakes can be found in the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory Standards and Procedures (RISC, 2001a). The establishment of a lake as fish bearing or non-fish bearing and the degree of impact anticipated may determine the level of Environmental Assessment review required of a project. For instance, a mine that proposes to drain a fish-bearing lake for an open pit and that requires a separate fish-bearing lake as a tailing storage facility will require a more exhaustive study than a mine that is situated on a mountain top with several non fish-bearing headwater streams draining the land. In general, fish community sampling in lakes should be conducted by using gill nets, although other methods should be applied to adequately sample different species and age classes that may be present (e.g., minnow traps, seines, sonar, etc.). As the identification of fish habitat can be a useful guide to determining fish presence or absence, fish habitat in lakes should be identified alongside fish community sampling. Methods and further details are provided in Section 10.4.2.

It is ultimately the proponent's responsibility to ensure that inventory capture methods are appropriate for the waterbody, time of year, flow stage, and water temperature. These procedures should follow methods described in RISC Fish Collection Methods and Standards (RISC, 1997a). Electrofishing is the preferred method for fish inventory sampling in streams. supplement Stream segments must be sampled using electrofishing if the following conditions can be met: conductivity >10 μS/cm; temperature >7° C; and water visibility >25 cm at time of sampling. If these conditions cannot be met at any time of year, alternate methods may be considered, but there may not be any methods that will work effectively in some conditions. Acceptable alternate methods include the use of any two of the following sampling methods: seine netting, gee trapping, angling, and snorkelling. Conditions such as temperature must be suitable if an alternative to electrofishing is used (e.g., because juveniles may be concealed during the day or hiding in the substrate, particularly at cooler water temperatures). Collection permits must be obtained from regulatory agencies regardless of which methods are proposed.

Other important considerations and conditions pertinent to determining fish presence or absence are expanded on in Lewis *et al.* (2004) and RISC (2001a), including habitat connectivity, appropriate sampling times (e.g., season) and locations (e.g., preferred habitat locations), and minimum sampling requirements. In specific reference to streams, sampling must occur when the stream is wetted and fish are most likely to be present. Where stream reaches are considered too dangerous to sample (e.g., due to the presence of chutes or falls), the reach shall be deemed fish bearing, unless a rigorous assessment of the factors influencing fish presence in a "Non-Fish-Bearing Status Report" (BC MOF and BC MELP 1998) is accepted by the Fish and Wildlife Branch of MFLNRO.

Non-fish-bearing status should be established over two consecutive years. The sampling location(s) must be appropriate and sampling effort must be intense enough to support any determination of non-fish-bearing status. By repeating the measurements in two consecutive years during periods when fish are most likely to be present, the probability of error is reduced. Although fish absence is difficult to prove, a level of certainty must be established by considering the probability and consequences of error (i.e., the risk to fish). Sampling with acceptable methods in appropriate locations and during appropriate seasons over this period of two years is beneficial to project proponents, as the data will provide an acceptable level of certainty to the regulators.

Results from presence and absence sampling should be documented using formats described in the Fish Stream Identification Guidebook (BC MOF and BC MELP, 1998) and entered into the provincial database using the Field Data Information System (FDIS), which is a data entry and management tool that includes quality assurance (QA) procedures). Determination of fish absence should be made through the submission of a "Non-Fish Bearing Status Report" and must include a detailed justification and rationale.

The status of fish species present in the area of impact must be defined based on provincial criteria (i.e., Are red-, blue- or yellow-listed fish species present? Are any of the species present of special management concern? Are other listed species (non-fish) present that are dependent on aquatic or riparian habitat?). The BC Conservation Data Centre systematically collects and disseminates information on the rare and endangered plants, animals, and plant communities of British Columbia. Project proponents who have species at risk in their project area should seek advice from regulators (DFO and MOE Ecosystems Branch) with respect to how management actions (e.g., those that may be required under the *Species at Risk Act*) may affect their proposed project.

10.4.1.2 Species, Life Stages, and Fish Population Status

For all project streams where fish-bearing status is established, additional species specific data are required on life stages (age groups) of the fish populations present, as well as absolute abundance and distribution information using appropriate benchmarks for interpretation. This additional information is often collected during fish habitat inventories that are conducted to establish fish presence. All fish capture information summarized in standard length frequency form must be accompanied by detailed habitat data collected at the site of capture.

Fish species, life stages, and their relative abundances are determined in a stream by using the same methods as those used to establish fish-bearing status: electrofishing, snorkelling, minnow trapping, angling, and seining. However, more systematic and intense sampling will be required to provide catch per unit area information that can be used to compare abundance between meso-habitats and make inferences about habitat quality especially when survey effort generates habitat specific fish distribution data. Where it is determined that a stream has exceptional fish value, mark–recapture estimates and radio tagging may be used to gain precise information on abundance and movement patterns. Another cost effective option is rigorously conducted multi-pass catch depletion, potentially more accurate than mark-recapture and radio tagging for abundance estimates that can be generated with tight standard error and confidence limits if catch efficiency is high for electrofishing, seining, or both when used in combination6

Detailed biological information should be collected from captured fish, including species, life stage, length and weight, maturity, and age (through analysis of scales, otoliths, or fin rays). Length-frequency data should be provided through use of standard LF forms to assist in initial field appraisal of size classes for scale sampling and the analysis of age composition and size-at-age. Refer to Chapter 8 (Section 8.3.3) for details pertaining to the collection of tissue residues from fish species in the stream of interest.

10.4.1.3 Fish Abundance

The productive capacity of fish habitat is usually measured by the areal density at mean size by age and species of fish it supports. Assuming no mortality caused directly by the project and a robust experimental design, changes in abundance at impact sites therefore suggest effects on habitat quality. As a result, some monitoring of fish abundance is usually part of a mine's environmental effects monitoring program.

Abundance in different sections of the stream of interest will be calculated based on the number of fish captured or observed by Species-Age per unit area sampled. Abundance indicators should be expressed as a number and biomass of fish caught per unit area. This analysis should be done on a species and life stage basis, with the sample size and appropriate measure of central tendency (mean or median or quantile) given, including the variation in density at size observed at the site and reach or stream within and among sampling periods. More detailed stock assessments may be warranted in streams with exceptional fish habitats.

In streams, fish abundance data collection is usually focused on rearing juveniles or spawning adults. Juveniles are usually measured on the basis of habitat or reach area using multiple pass removal by electrofishing sometimes in combination with seining where the area of interest is isolated with stop nets. This method is described in Hatfield et al. (2007) and references therein. Spawning adults can be counted directly sometimes in a seasonal series of counts employing mark-recapture techniques, or inferred redd counts conducted after the spawning period. Specific guidance on these and other field sampling methods is provided in Johnson et al. (2007).

In lakes, mark–recapture studies are often suggested to obtain abundance estimates. In practice, the amount of sampling effort that must be applied in order to achieve precise estimates is rarely practical or possible. Sonar can be used for pelagic fish populations, but expertise with this technology is relatively rare (see Johnson et al. (2007) for guidance) and usually needs to be accompanied by seining to determine the relative abundances of species detected by sonar. For lake populations, it is often more effective to measure changes in yield, harvest or instantaneous survival, growth, or health (liver somatic or gonad somatic indices). The Environmental Effects Monitoring (EEM) guidelines for fish under the *Metal Mining Effluent Regulation* (Environment Canada, 2002) provide excellent guidance on monitoring changes in fish populations in lakes.

10.4.1.4 Fish Collection Permit Requirements

Sampling must be conducted to classify fish-bearing status and to identify a full species assemblage for each waterbody. Sampling requirements for non-fish bearing stream classification are contained in the *Fish-Stream Identification Guidebook* (FPCBC, 1998). Collection of resident fish and anadromous trout (steelhead) for mine EA baseline data requires a provincial scientific fish collection permit, which is available from the Permit and Authorization Services Bureau. During planning, proponents will need to discuss with regulators how much lethal sampling will be allowed. The key aspects of lethal sampling that require consideration are detailed in Chapter 8 (Section 8.3.3). In particular, all efforts should be made to minimize lethal sampling by planning for all data requirements, federal and provincial, and using as few fish as possible to meet these needs. A power analysis should be submitted with the collection permit applications in order to justify lethal sample sizes.

It is a requirement of provincial fish collection permits that collected data are submitted to MOE. In addition to baseline reports, submission of data captured digitally (mapping, FDIS) is also required. Instructions for data submission will be included with the permit.

The collection and sampling of anadromous salmon for mine EA baseline data collection require a federal scientific collection license issued by Fisheries and Oceans Canada. For projects located in northeastern, central or southern BC, please contact the Fisheries and Oceans Canada Pacific Region office in Vancouver at 604-666-0384. For projects located in northwestern BC, please contact the Fisheries and Oceans Canada Yukon/Transboundary Rivers Area licensing office at 866-676-6722 or via the internet at http://www.pac.dfo-mpo.gc.ca/yukon/index-eng.html.

10.4.1.5 Life History and Migrations

Life history information is necessary in order to understand the wider implications of site-specific impacts. Small trout in a stream may be mature fish with a stream-resident life history, or they may be juveniles rearing for several years before recruiting into a downstream population of larger fish. Methods for inferring life history include spawning and migration surveys, and analysis of growth and age-at-maturity data. Some lethal sampling may be acceptable to collect gonadal maturity data. Biologists attempting to observe spawning and migration may need to conduct regular surveys throughout a protracted period during the initial years of study in order to establish timing.

Fish migrations are associated with specific size and life history classes (e.g., moving from juvenile-rearing to adult-rearing habitat) and seasonality (moving among overwintering, rearing, and spawning habitats). If the fish population under review is migratory, some understanding of the migrations and habitat use will be required. Key habitats used throughout the life history are to be identified and the timing of movements understood. Collecting this information may require spawning surveys, snorkel surveys, counting fences, and radio-telemetry. Field protocols for these and other survey methods can be found in Johnson et al. 2007.

Installing counting fences or traps and conducting radio-telemetry studies have the potential to negatively impact fish populations if poorly executed. Ensuring careful design and experienced personnel will be key aspects of MFLNRO's Fish and Wildlife Branch review when determining whether or not to issue a permit for such a study.

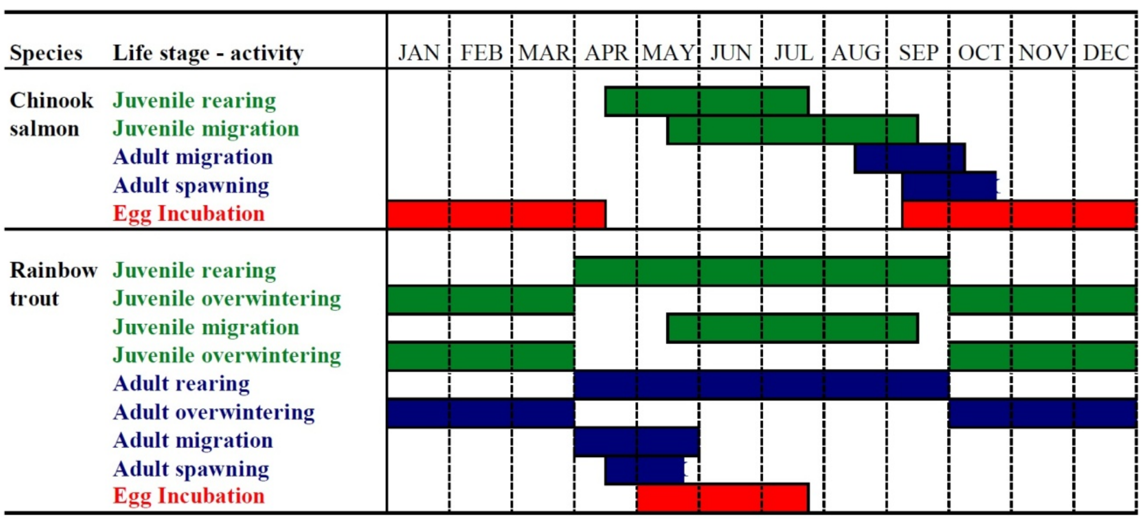
10.4.1.6 Timing of Habitat Use

Seasonal timing of habitat use describes when and where fish are present in the project area. This critical information helps to refine the annual pattern of permissible water uses. Key biological activities such as spawning, incubation, migration, active rearing, and overwintering must be defined throughout the project's area of impact. The seasonal timing of habitat use by fish in a particular stream is also related to the timing and magnitude of instream flows.

Salmonid smolt migrations are additionally affected by water temperature changes and photoperiod.

Reliable information on life history timing and use of specific habitats in streams typically requires considerable effort over several years and can be assisted by existing inferences from neighbouring streams in the same EcoRegion. For this reason, it will likely be necessary to use existing data from nearby streams and watersheds and to supplement it with site-specific data. General sources (e.g., Scott and Crossman, 1973, McPhail, 2007) and instream work windows may provide guidance but are not sufficient for this purpose. Life history timing should be summarized in a species periodicity chart listing the species and life stages present and the timing of key biological activities. Other flow-related ecological needs (e.g., geomorphic needs, riparian and floodplain maintenance, etc.) can also be entered into periodicity charts. In the absence of detailed information, habitat use may be inferred from the species periodicity tables for other streams in the region. Ideally, however, proponents will collect the appropriate site-specific information.

Figure 3: An example of a species periodicity chart detailing life stage timing by activity for each species of interest.



Various methods have been used historically to characterize and quantify fish habitat use. For instance, direct observation through creel surveys, foot surveys, boat and aerial surveys, and snorkel surveys can provide high-quality information quickly in streams with good visibility. A more detailed, quantitative snapshot of fish distribution can be obtained through capture methods such as electrofishing, beach or pole seining, downstream trapping, gee trapping, tangle netting, and fence operation. If employed in a seasonal sequence, these methods can define the relative abundance of fish by species and life stage over time at different locations. Rare and endangered species may require more detailed investigations. For species at risk listed under SARA, proponents must assess whether the proposed project affects critical habitat needs of the species and determine whether the project is in conflict with the recovery strategy for the species. Specific guidance for species at risk should be sought from DFO.

Further information on recognized fish capture techniques are presented in Fish Collection Methods and Standards - Version 4.0 (RISC, 1999). The Nechako Fisheries Conservation Program (NFCP) is a joint monitoring program being implemented by Rio Tinto Alcan, DFO, and MOE. The NFCP has published numerous reports covering a variety of fisheries assessments that provide examples of the types of studies that can be undertaken to identify habitat use (http://www.nfcp.org/Reports.html).

10.4.2 Fish Habitat

Subsection 35(1) of the federal *Fisheries Act* prohibits a harmful alteration, disruption, or destruction (HADD) of fish habitat unless it is specifically authorized by DFO under subsection 35(2) of the Act. In addition, Subsection 36(3) of the *Fisheries Act*, which is administered by Environment Canada, prohibits the deposition of a deleterious substance such as mine tailings or potentially acid generating (PAG) waste in a fish-bearing waterbody. Placement of mining waste on or in a fish-bearing waterbody requires that the waterbody be on Schedule 2 of the federal *Metal Mining Effluent Regulations* before these deleterious substances are deposited.

In determining fish habitat assessment methodologies and standards, proponents should consider which level of habitat assessment is required. Hatfield et al. (2007) outlines three spatial scales for habitat classification and assessment:

1. *Macrohabitats* are lengths of stream with similar channel characteristics, referred to as "reaches" in RISC (2001a), in the Fish-Stream Identification Guidebook (BC MOF and BC MELP, 1998), and Johnston and Slaney (1996). They are used as the basic unit of assessment for 1:20,000-scale reconnaissance-level fish and fish habitat inventory, which includes quantitative measurement and qualitative assessment of channel habitat.
2. *Mesohabitats* are smaller habitat units defined by hydraulic characteristics. They typically include riffles, pools, glides, etc., as defined in Johnston and Slaney (1996), which also outlines standard methods for habitat surveys at this scale. These habitat units are characterized and measured quantitatively.
3. *Microhabitats* are habitat conditions at a specific vertical position on a cross-section. Variables measured quantitatively typically include depth, velocity, substrate, and cover. Microhabitats are measured when assessing habitat suitability for specific life stages of a fish species. Lewis et al. (2004) outline a methodology for measuring microhabitat data for instream flows. Surveys at this scale may be required for other reasons, including stock assessment interpretation (percent habitat saturation), habitat characterization compensation purposes or as part of a habitat monitoring program.

For mining environmental assessment, habitat surveys begin at the macrohabitat scale and move to finer scales, where appropriate, depending on the nature of the impacts and the fish values in question. Typically, details for microhabitats will only be required if an instream flow study is required (see Section 7.4.3.2).

Inventories of fish habitat are compiled so that an assessment of existing conditions can be performed in addition to an assessment of the extent to which the proposed water uses will affect fish habitat. RISC (2001a) describes the requirements for RISC standard fish habitat inventory at stream and lake sites. Overall, the assessment should follow a sequence of six office and field tasks:

1. Identify and code all waterbodies (office task);
2. Identify and characterize all reaches (e.g., confinement, order, pattern, gradient), and record site characteristics at a sample of reaches stratified by reach type (office task);
3. Determine channel morphology, locate and identify obstructions, describe riparian area properties (e.g., vegetation, presence of fisheries sensitive zones), and map habitat locations (Site Card – field task);
4. Identify all lakes; determine lake surface area, elevation, and biogeoclimatic zone; characterize lake riparian area (e.g., vegetation, land use, access); and assess fish production potential (office task);
5. Measure maximum lake depth, water quality (dissolved oxygen, pH, temperature, Secchi depth), and tributary presence (field task); and
6. Determine fish production potential for any lakes to be impacted by mine development, and measure lake bathymetry, lake water quality, littoral areas (classify and identify critical littoral areas for spawning), and lake tributary water quality (field task).

The information should be presented as per the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures" (RISC, 2001a) and entered into the provincial database using the Field Data Information System (FDIS). The reconnaissance-level information will be used in the preliminary screening review of the Environmental Assessment process to assess effects of a project on habitat capability by defining habitat quantity and type. This information, combined with fish presence and absence data, allows reviewers to assess project effects. Where more detailed studies are deemed necessary by regulatory agencies, the reconnaissance-level information will serve as a foundation for additional studies.

For streams, fish habitat inventory includes quantitative measures of the channel, bank, substrate, discharge, and water chemistry, as well as qualitative assessments of cover, riparian vegetation, channel features, and fish habitat quality and quantity. The site must also be photo-documented. For lakes, quantitative measures include water chemistry, limnology including a temperature–oxygen profile, and bathymetry. Qualitative assessments are made of aquatic vegetation, cover, access, shoreline types, and surrounding terrain. Survey crews should include professional biologists or fisheries technicians with experience in quantitative fish and fish habitat survey. Generally, higher resolution quantitative surveys of fish habitat should follow similar methods in Johnston and Slaney (1996), though the Sensitive Habitat Inventory Mapping (SHIM) protocol can also been used with success (Mason and Knight, 2001). The SHIM protocol involves a channel walk, documenting the size and characteristics of all mesohabitat and channel features, width to mean depth ratios as qualified by meso-habitat class names and taking photographs at known flows.

10.4.3 Instream Flow

A wide range of ecosystem components require that a minimum instream flow be maintained. Groundwater recharge, nutrient transport and recycling, pollution attenuation, biological productivity, and recreational opportunities such as fishing, boating, and swimming are a few of the benefits and services a river system provides that are dependent on instream flows. As such, projects that may impact instream flow through the diversion or extraction of water must be assessed through the standardized instream flow assessment methods detailed in Lewis et al. (2004) and Hatfield et al. (2007). Projects that do not propose to divert or extract water are not exempt from fish and fish habitat assessments, because impacts may still occur as a result of other project activities (e.g., effluent discharges impact on water quality).

10.4.4 Streamflow and Fish Production

The flow of water in a stream (annual regime pattern), defines fish habitat and limits the stream's overall productive capacity. For instance, low water flows can impact fish survival and reproductive success by increasing temperatures, lowering oxygen concentrations, and hindering spawning and migratory behaviour. Similarly, flow modification and alteration influences the productive capacity of aquatic habitat. This relationship between flow and fish productivity (i.e., factors influencing fish and fish habitat) is illustrated in Figure 3. Low flow regimes have been mapped for the entire Province that conclude certain landscape units or EcoRegions are more likely to be flow limiting in summer or winter or perhaps both seasons. Landscape maps showing flow sensitivity are useful for a variety of reasons such as conditions likely to occur that restrict sampling methods or clues that form bases of potential impact (MOE files, iMap BC).

The term "flow" is often referred to simplistically, which is problematic as it is the fundamental abiotic factor controlling ecological processes in streams (Poff et al., 1997; Hart and Finelli, 1999). Flow can be interpreted readily by ratio measures such as mean daily discharge, or monthly flows into long-term mean annual discharge (Tennant ratios), yet these measures obscure some of the highly variable nature of flow (Nowell and Jumars, 1984; Heede and Rinne, 1990; Whitfield, 1998; Hart and Finelli, 1999; Kondolf et al., 2000). Flow characteristics vary over a broad range of space and time scales, and the scale of organism–flow interactions can span more than six orders of magnitude (Hart and Finelli, 1999). Determining which scale(s) is (are) the most important to organismal distribution and abundance is a central challenge for stream ecologists. Thus, it is better to refer to "flow regimes" for conceptual purposes and to underscore that organisms are often exposed to a suite of flow characteristics over reasonably large spatial and temporal scales (see Figure 4).

There are thus many reasons to sustain minimum instream flows and mitigate the adverse effects that may occur as a result of a project's activities. As such, an Instream Flow Study (IFS) must be conducted for mining projects that propose to divert a significant amount of water from a river or stream on a year-round basis, as determined using guidance provided in Hatfield et al. (2003) (e.g., timing of withdrawal, volume of withdrawal, etc.). Changes in flow have a wide range of direct and indirect impacts on fish and fish habitat, which may lead to a HADD and consequently a violation of the *Fisheries Act*. The BC Instream Flow Guidelines for Aquatic Habitat (Lewis et al., 2004) were designed to ensure that instream flow levels are maintained throughout the year at a quantity that protects fish and fish habitat. These guidelines are described in the next section.

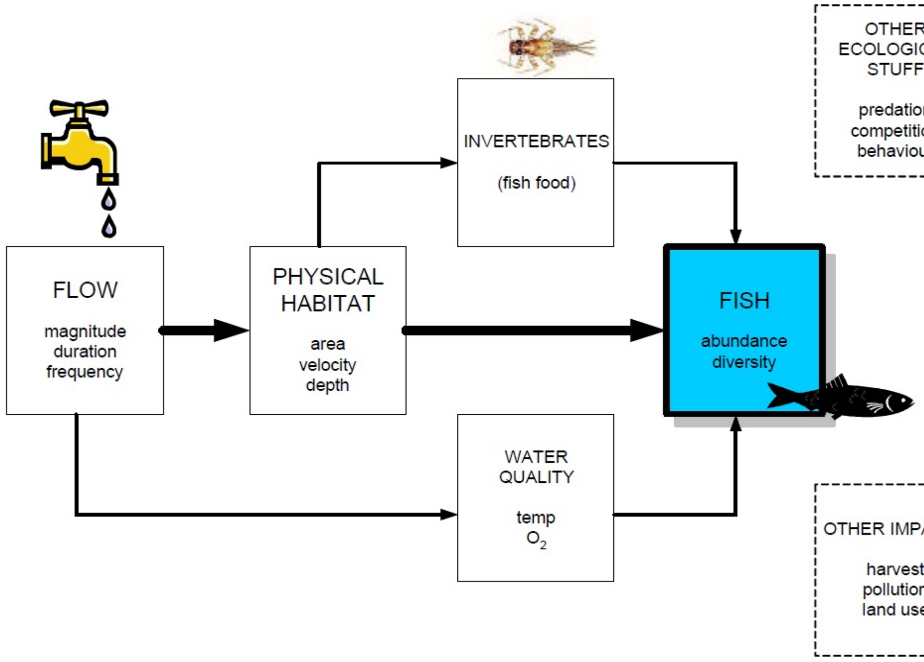


Figure 4: Influence diagram showing how fish production is a function of flow (Hatfield et al., 2003).

In this diagram, fish abundance and diversity are driven primarily by physical habitat availability, which is directly related to flow. Water quality and invertebrate production, also directly related to flow, may have a lesser impact on fish. Other influences may be acknowledged but are seldom treated explicitly in instream flow assessments.

10.4.4.1 Instream Flow Assessment Methods

Mining projects that propose to divert large quantities of water to and from streams will be required to perform an IFS, as described in the BC Instream Flow Guidelines for Aquatic Habitat (Lewis et al., 2004), which contain two key methodologies:

1. Instream Flow Thresholds are guidelines designed to protect aquatic habitat in BC streams from excessive water withdrawal (see Hatfield et al., 2003 for full details).
2. Instream Flow Assessment Methods are methodology guidelines designed to identify impacts from water withdrawal (see Lewis et al., 2004 for full details).

Although the BC Instream Flow Guidelines were designed for small hydro water licence applications, they describe a generic process assessing the potential impacts of mining construction, operation, and deconstruction activities. By following these methods, proponents can streamline the application process, as regulators can readily and accurately assess the projects in a timely manner.

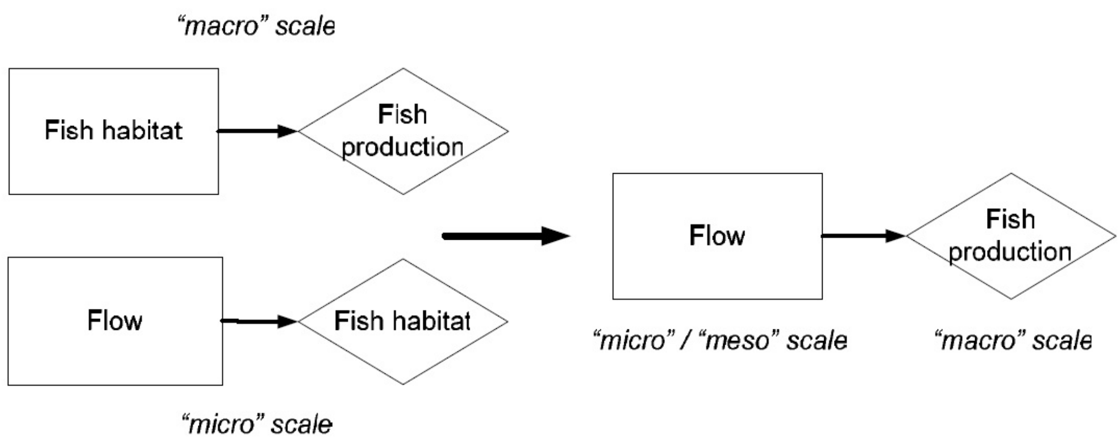


Figure 5: Conceptual illustration of relationships between different spatial and temporal scales interlinking stream flow and fish production (Hatfield et al., 2003).
The link between stream flow and fish production often implies two underlying logical relationships. The different physical and temporal scales of these underlying relationships may make the link between flow and fish production difficult to measure.

Under the BC Instream Flow Guidelines, proponents and reviewers are guided through a two-tiered assessment of fisheries concerns related to instream flows: (1) a coarse screening filter and (2) a detailed assessment level. Preliminary data and information pertinent to fish and fish habitat must be provided by applications that hope to meet these guidelines' Flow Thresholds. Preliminary information includes a project description, daily hydrological data estimated from regional stations or collected from the stream of interest, biological data including fish presence determined through existing records or direct sampling, and reconnaissance-level fish habitat information. Applications that move to the detailed level will have to provide information at both the screening and detailed levels. Detailed information needs must include geomorphology, water quality, fish biology, fish habitat, lower trophic levels, ecological function, and cumulative effects.

In cases where the coarse filter indicates that fish-flow issues are not of concern, regulatory agencies may approve the application subject to a review of other fisheries concerns (e.g., footprint issues, habitat continuity and connectivity, tailings storage area, waste dumps, etc.). In contrast, if the coarse filter indicates a potential fish-flow concern, then the proponent is presented with three options: (1) abandon the project, (2) redesign to meet the flow thresholds, or (3) collect and present additional information to demonstrate that aquatic habitat concerns are adequately addressed.

The information that is considered essential to detailed assessments is only partly described in the BC Instream Flow Guidelines, because the “best” method will vary, particularly among complex projects. The methods provided are considered to be adequate for most, but not all, projects. Where exceptional aquatic habitat values are present, regulators in MOE and DFO may require studies different to those described here in order to characterize habitat values and potential impacts. Streams and lakes with greater fisheries values and sensitivity to development can expect more rigorous analysis and are likely to require even more detailed assessment than that identified in the BC Instream Flow Guidelines. It must be emphasized that there remains no BC standard for detailed stock assessment that integrates with detailed habitat surveys.

The data requirements for both tiers of assessment are based on existing environmental legislation. Accordingly, the information presented by proponents to regulators must be relevant in the context of these existing regulations. These data requirements are intended to meet the requirements of the *Fisheries Act*, specifically the assessment of HADD. DFO has guidelines for determination and authorization of HADD (DFO, 1998a) and for determination of mitigation and compensation (DFO, 1998b). The assessment methods summarized here are meant to complement these and other existing guidelines. Although the assessment methods are detailed here, the responsibility to meet the information requirements of the DFO and other agencies ultimately lies with the proponent and their qualified professional experts.

Fish habitat assessments for water use projects must predict the effect of changes in water flow on fish habitat and ecological function. A number of methods for assessing fish habitat have been used to define instream flow needs, as described and reviewed in Hatfield et al. (2003). Admittedly, there is controversy over instream flow methods and the ‘state of the art’ does not provide the scientific certainty desired by all instream flow practitioners (Castleberry et al., 1996). Despite this limitation, decisions on instream flow use have been made for decades in BC in the absence of good information or any concerns over aquatic ecosystem health.

10.4.4.2 Assumptions and Limitations

Flow has been described as a ‘master variable’ (Poff et al., 1997) that controls a suite of physical variables that in turn influence fish production through a number of direct and indirect pathways. Most instream flow assessments, regardless of method, are based on the implicit acceptance of this hypothesis (and indeed this assumption is the foundation of key features of the *Fisheries Act*). As such, irrespective of the model used for analysis of fish habitat, the key assumption made when predicting the response of habitat to water withdrawal is that habitat or some proxy of habitat such as fish food supply limits fish production. Regulators reviewing proposed projects will assume that aquatic habitat is strongly linked to productive capacity, the crucial performance measure in the *Fisheries Act*. Lewis et al. (2004) provides a review of the literature supporting the hypothesis that stream flow determines fish production. Although only a few examples are found that demonstrate a strong link, a number of factors can affect fish productive capacity, making it difficult to detect fish–flow relationships. Another major assumption is that the area of physical habitat is proportional to the productive capacity of fish habitat. These assumptions cannot be tested when predicting the effects of a proposed project, although they can be evaluated through monitoring the effects of a project.

A limitation of predictions of habitat quantity and quality made in the proposed method (as well as in other habitat models) is that fish habitat preference is independent of flow. Although this assumption is typical of instream flow studies, it has rarely been tested. Beecher et al. (1993) found that preference remained constant over a range of flows and that habitat use could be predicted with habitat suitability index (HSI) curves developed at a single flow. This finding was criticized (Jager and Pert, 1997) and contradicted by Holm et al. (2001), who measured fish use of habitat over an 18-fold range in flow in an experimental flume to estimate habitat preferences at different flows. Holm et al. (2001) found that habitat area predicted with preference curves calculated at different flows varied by up to 200%, creating potentially large errors in modelled estimates of habitat loss. These findings bring into question the validity of using a single set of HSI scores across all flows and seasons, but the question is unresolved, though the underlying assumption is a cornerstone to our confidence in habitat predictions. Further details and discussion of the underlying assumptions and limitations of different types of HSI curves are provided in Lewis et al. (2004).

The approach promoted here is to use a standard set of HSI curves across BC for each species/life stage for a fixed season. These curves will be available on the MOE website for most species and life stages. HSI scores for depth and velocity are recommended for use on all streams; the inclusion of substrate and cover scores may increase the accuracy of estimates of usable area in some situations. The advantage of using common curves is that habitat will be quantified in a consistent manner across all streams in BC, which in turn allows proponents and regulators to use the same benchmarks when comparing habitat quantity. Furthermore, reviewers will be more confident when comparing studies, because the assumptions within the models have been standardized. There are risks in using a single HSI curve: stream and flow-specific behaviour may be adaptive and the use of standard HSI curves may not reflect the quality of habitat at a given flow. We judge this risk to be smaller and more predictable than the error introduced by allowing investigators to select HSI curves from the existing large number of curves available in the literature. Where bias from general HSI curves are of concern, studies to develop river-specific curves can be undertaken, or other curves can be used if a defensible rationale is provided.

10.5 Cumulative Effects: Setting the Environmental Context

The ways in which land and water are used and impacted (i.e., both past and present) can affect fish and fish habitat. Multiple types of resource use in the same area can increase the severity of the impacts to fish and fish habitat. For example, mining activities can affect water temperature and runoff rates, mining effluents can adversely affect water quality, and dykes can affect flow patterns and sediment movement in a stream channel. Harvest pressure can affect the resilience of fish stocks to additional perturbations, increasing the importance of small incremental effects on habitat caused by water withdrawal and/or effluent releases. A fish population at low numbers may be particular vulnerable to potential impacts, while a robust population has more resilience when faced with environmental pressures that may cause mortality.

Proponents must consider potential interactions between existing resource uses and the proposed project, including existing and requested water licences and water licence applications (both upstream and downstream) and land uses that may significantly affect instream processes (forestry, mining, linear development, agriculture, urbanization, recreation). Mortality from recreational and commercial fishing should also be considered. The potential interactions between resource uses are frequently described as cumulative effects.

The term 'cumulative effects' has been used in different ways. As a result, it is important to define cumulative effects for the purposes of this document so that ambiguity surrounding the term can be minimized. The Canadian Environmental Assessment Agency defines cumulative effects as:

> "The effect on the environment which results from effects of a project when combined with those of other past, existing, and imminent projects and activities. These may occur over a certain period of time and distance."

In this document, cumulative effects refer specifically to the combined effects on the environment from separate activities, including activities that are not associated with the proposed mine. The focus of a cumulative effects assessment (CEA) is the interaction of multiple activities to produce an environmental impact. CEA has been promoted as a necessary part of impact assessments. The CEA process is important as the individual environmental effect of one activity may be significantly less than the cumulative environmental effect of multiple activities on the same river.

Note that any project that is proposed for a stream or watershed with other licensed users must consider the cumulative effect of impacts such as water withdrawal, effluent release, and permanent habitat loss under the CEA. Assessment of cumulative effects is now required by federal legislation when a project is subject to a federal environmental assessment under the *Canadian Environmental Assessment Act*. Despite the importance of cumulative effects, current assessment and management techniques are not fully developed with respect to these, and as a result they are not always effective. Proponents should consult the reference guides provided by the Canadian Environmental Assessment Agency to obtain recent guidance on the appropriate methods for analysis (CEAA 2002).

A provincial approach to cumulative effects assessment is also in development. Work is underway exploring options for a Cumulative Effects Assessment and Management Framework for British Columbia's natural resource sector. The framework is intended to bring consistency to the assessment and monitoring of a commonly defined set of environmental, social, and economic values; and to improve the consistency, efficiency, and transparency of decision-making. A coordinated cumulative effects assessment framework will streamline decision-making, reduce demands on government staff, and support a shift to results-based management. Ultimately, resulting in reduced uncertainty and costs for project proponents, and improved environmental, social and economic values for all British Columbians.

Further details and guidance for cumulative effects assessments are available at the Canadian Environmental Assessment Agency's website (http://www.ceaa-acee.gc.ca/default.asp?lang=En), such as the Cumulative Effects Assessment Practitioners' Guide (1999).

10.6 Fish Habitat Compensation Planning

Mining projects and associated works such as tailings or potentially acid generating (PAG) storage facilities may result in a harmful alteration, disruption or destruction (HADD) of fish habitat. A HADD is any change in fish habitat that reduces its capacity to support one or more life processes of fish. This includes: 1) harmful alteration, an indefinite reduction in capacity while maintaining some of the habitat; 2) disruption, a short term reduction in capacity; and 3) destruction, permanent loss of capacity.

There are federal and provincial programs that consider the authorization of a HADD of fish habitat and corresponding fish habitat compensation planning. The subsequent sections provide details and descriptions of the current programs that have been established at each level of government to account for impacts to fish habitat.

10.6.1 Federal Program and Requirements

To consider the authorization of a HADD of fish habitat, DFO will require that a detailed fish habitat compensation plan be prepared by the proponent and submitted for approval. Fish habitat compensation planning is guided by DFO's principle of No Net Loss (see the Habitat Conservation and Protection Guidelines for further details and key aspects of the No Net Loss Principle (DFO, 1998b). Preferably, productive fish habitat is preserved under this principle; however, unavoidable habitat losses are balanced with compensatory habitat replacement or offsets on a project-by-project basis to prevent a net habitat loss. The principle applies to proposed work and undertakings, and is not applied retroactively to approved or completed projects.

Authorization of a HADD is considered a last resort by DFO. As a general rule, in order for DFO to consider the authorization of HADD of fish habitat, at a minimum the proponent will need to complete three steps to support the submission of a proposal to DFO for review:

(i) Alternatives assessment
(ii) Habitat quantification and accounting, and
(iii) Compensation planning.

It is important to note that opportunities for fish habitat compensation are often constrained or dictated by past utility and success/failure of a given treatment, local conditions and constraints of the landscape. Offsets involving simplistic measures of square metres of "lost" habitat may miss the mark if the impacted stream is a 2^{nd} order stream that cannot be replicated on the landscape by creating the same area (for example) in an off-channel site. First Nations and community groups will be consulted during the review process. Potential conflicts can be identified early on by seeking advice from these groups in the initial stages of planning. Local groups or individuals are often aware of historic damage or degraded fish habitat from past developments. In some cases, restoration of this habitat can be accepted as compensation.

If deemed acceptable by DFO, the fish habitat compensation plan will become a condition of the subsequent federal authorization. If the fish population in question falls under provincial jurisdiction (resident population, or anadromous trout such as steelheads), then MoE may provide advice to DFO.

10.6.2 Provincial Environmental Mitigation Policy

The BC MOE, along with the Environmental Assessment Office (EAO), and other natural resource management agencies, is developing a new environmental policy to support a consistent approach to mitigating adverse impacts on environmental values and their associated components from development projects and activities. The Environmental Mitigation Policy is intended to help provincial staff give consistent advice to statutory decision makers when authorizing development projects and activities. The policy will help staff make recommendations about ways to conserve and protect environmental components when these environmental components might be adversely affected by development projects and activities.

The policy will provide internal policy guidance that supports existing provincial natural resource legislation, as well as existing federal laws. This policy does not create new legal requirements for industry practices as they plan and carry out their activities and operations. The ultimate decision as to which mitigation measures (i.e., avoid, minimize and/or offset) will apply, where these mitigation measures will apply, and the amount of mitigation, rests with the statutory decision-maker. The intent of this policy is to convey clear provincial expectations concerning environmental components. In addition, the policy is intended to provide guidance on environmental mitigation that will result in better environmental outcomes.

The Environmental Mitigation Policy will provide a consistent provincial approach to:

1. Identification of environmental values and components of concern

This policy is intended to provide a provincially consistent, efficient, and relevant approach to the identification of environmental values and components for the purpose of project-level environmental mitigation. Identification of project level environmental components is expected to be completed by proponents or their qualified professionals based on a core set of provincial/regional environmental values and their components and guidance.

2. Environmental impact assessment

   The policy will provide a standard environmental impact assessment process. An environmental impact assessment is conducted to determine the nature and extent of expected adverse impacts on environmental components from a proposed development project or activity, and the potential impacts on these components that would result from the proposed development project or activity in order to be able to select appropriate environmental mitigation measures. This information provides the decision-maker with clear evidence to support an informed and durable natural resource decision.

3. Consideration and application of mitigation

   The basis of the Environmental Mitigation Policy is the application of the Environmental Mitigation Hierarchy, a concept that forms the basis of mitigation policies across the globe.

   The Environmental Mitigation Hierarchy contains the following three steps:
   - Avoid impacting environmental values and components;
   - Minimize adverse impacts to values and components; and then
   - Offset residual adverse impacts to values and components.

Further information on the development of BC's Environmental Mitigation Policy is available on the policy website (http://www.env.gov.bc.ca/emop/).

10.7 Frequency and Period of Return

Aside from seasonal variation in habitat suitability due to variations in flow, fish habitat values can change due to the dynamic processes associated with stream morphology. For example, construction or breaching of beaver dams, major channel re-structuring flow events, and avulsions can all result in significant changes to habitat values. As the pre-construction phase of a mine can last several years, and in some cases many years, these events can render obsolete the results of earlier habitat surveys.

We recommend conducting overview habitat surveys in the event of high flow events (e.g., 20–50 year flood), and if significant channel impacts are observed, the proponent may need to repeat detailed habitat surveys. In addition, reaches where beaver dams impact habitat should be checked annually for changes. Breached dams will impact habitat conditions within the reach and fish passage to upstream reaches.

Sampling repetition on both seasonal and annual bases may be required in order to provide sufficient evidence of non-fish-bearing status. Monitoring sites for programs that will continue after mine construction should be sampled several times prior to construction. While proponents often highlight the cost of these samples, increased pre-construction monitoring will improve statistical power of post-construction analysis, decreasing the likelihood of type I error (a "false positive" or detecting an impact when there isn't one). At a minimum, two years of monitoring prior to construction is recommended.

10.7.1 Methods, Instrumentation, and QA/QC

Consistent and rigorous quality control and quality assurance (QA/QC) practices will enable collection of meaningful and scientifically credible data. Results and conclusions resulting from data and practices that do not meet accepted QA/QC guidelines may be rejected by regional MOE representatives, jeopardizing the environmental certification of a proposed project or the granting of a discharge permit. QA/QC is important in every aspect of a sampling program from program design through the field work and laboratory analyses and finally to interpretations of results.

In Canada, the major provider of such services is the Canadian Association for Laboratory Accreditation (CALA). The goal of CALA is to help laboratories achieve and demonstrate the highest levels of scientific and management excellence through the combined principles of competence, consistency, credibility, and communication. The advantage to the proponent of using an accredited laboratory is being confident that the results of analytical measurements are accurate and precise. All samples should be tested at a certified CALA laboratory.

The RISC standards for QA/QC are applicable to basic inventory data collected for mining EA baseline data. These are outlined in RISC (2000) and RISC (2004). Specialists working on aging structures or labs analysing DNA samples should be queried as to their QA/QC procedures.

10.7.2 Data Storage and Reporting

Field inventory data should be captured and stored using the Field Data Information System, which is designed to work with RISC field cards and reconnaissance inventory standards. Other related data including stock assessment length frequency and stream transect forms that are not compatible with FDIS should be digitally captured using spreadsheet or database software.

Baseline reports should contain an appendix of data that include FDIS printouts, site photographs, and printouts from software used to digitally capture other non-FDIS compatible data. Mapping products should meet or exceed RISC mapping standards for reconnaissance fish and fish habitat inventory (RISC, 2001b). Critical habitats such as spawning grounds or key holding habitat should also be included on the maps.

Some attention is warranted when presenting habitat data in reports. Graphs showing average channel characteristics (gradient, width, pattern, etc.) from all sites sampled during baseline sampling, while easily extracted from databases and spreadsheet, are rarely useful. The writer should decide if a graph or chart is demonstrating an aspect or pattern of the data that will aid the reviewer in understanding fish habitat in the area. If not, then there is little point in including it. Reviews of habitat inventory data tend to be best accomplished when organized by watershed, with some brief text outlining key channel characteristics, features, and habitat values, and illustrated with representative photographs.

Presentation of fish population data generally includes length-frequency and length-at-age histograms and regressions of weight vs. length (condition) and length vs. age (growth). Allen Plot figures should also be used to show the measured range in density-size by Species-Age code and biomass envelope. Comparisons of biomass, size, growth, or condition between watersheds can be useful, but only if there is sufficient precision to discern a real difference. Standard error bars or other expressions of variance (e.g., $\pm$ 95% confidence limits) should be included on any graph that shows a calculated mean, and an appropriate statistical test should be used to determine the significance of the difference.

11. ENVIRONMENTAL IMPACT PREDICTION — CONSIDERATIONS FOR PERMITTING

The previous chapters of this guidance document have identified the data requirements for various environmental resources of concern. The goal of this chapter is to provide general guidance on MOE's and MFLNR's expectations for environmental impact assessment/prediction for mine projects.

If they are not managed properly, mining and related activities release contaminants that may impair environmental quality. These activities also have the potential to alter the hydrologic flow regime at and around the site of operation. It is necessary to understand the concentration and movement of contaminants and their effect on the ecosystem in order to assess the impact of mining-related activities on the receiving environment. The type of information required for the purpose of the environmental impact and risk assessment in mine certification and permitting is summarized below:

1. **Characterize the resources at risk**: To do this, identify and designate the environmental values. Environmental values include all aquatic ecosystem values, traditional uses, fisheries, groundwater, etc. Identify areas of human exposure to air quality exceeding the criteria. Determine all designated water uses in the area likely affected by the proposed operation.
2. **Describe the ecosystem – baseline and information**: To determine impacts on the environment from mining-related activities, the ecosystem in its natural state must first be described. To do this, consider the existing baseline information on air quality, hydrology, hydrogeology, water quality, sediment, and biota. The sensitivity of the environment (e.g., biota) should include an analysis of the dose-response relationships, which can be done by comparing with existing water quality guidelines (consider the BC Water Quality Guidelines first). Interpret this information to develop benchmarks/indicators of ecosystem health and ecosystem resilience to changes due to the development.
3. **Identify potential hazardous conditions and predict impacts**: Create an inventory of all project-related potential physical and chemical hazards. This information is needed in order to predict impacts. The actual impact prediction phase usually involves modelling the probability and severity of impacts from the proposed operation for each environmental resource or VEC. Once this phase is completed, weigh the options to mitigate the impacts before construction of the project begins and also address how the impacts of mining could be mitigated during the life of the mine and after closure. When assessing potential hazards, consider all potential impacts on VECs and focus on sensitive areas that will require attention on a priority basis for risk assessment and management. Determine the significance of any residual effects by considering data collected during the baseline studies. The identification of any "significant residual effects" may have an impact on whether the EAO can grant an Environmental Assessment Certificate. Finally, address different types of contingencies or mitigation measures to avert potential impacts. It may be possible to

mitigate project effects that cannot be avoided, and a commitment for mitigation may be a condition of EA certification.

4. **Design an Environmental Effects Monitoring (EEM) program**: Metal mines are required to conduct an EEM program under the *Metal Mine Effluent Regulation* of the federal *Fisheries Act*. The results of an EEM program help to support adaptive management activities. Follow the guidance of Environment Canada when setting up an EEM program for a metal mine. Design an EEM program capable of detecting impacts to air and aquatic resources, should they occur. Monitor all environmental components, including air, surface and groundwater quality and quantity, sediment chemistry and loading, flow rates, and the aquatic life present in the environment. Develop a database that will serve as a baseline for the EEM program.
5. **Propose a safe-discharge plan** with concentration and volume limits that are protective of the air and aquatic environment by considering the ambient air and water quality guidelines and (if existing) water quality objectives or science-based environmental benchmarks; initial dilution zones; no acute lethality to aquatic organisms at the point of discharge; and no acute or chronic impacts to aquatic life downstream.

More detailed discussion on the above points and some aspects of the following text can be found in Sharpe (1998).

11.1 Hydrology

The proponent should identify potential impacts of the proposed development on hydraulic processes and estimate the significance of impacts from modified flow regimes. The potential effects from all operations, dewatering, and any other sources associated with ***all phases of the project life cycle*** must be included. In particular, the proponent should document (model) the long-term, post-closure, groundwater flow regime at the site, with particular emphasis on changes in base flow (quantity and quality) to streams. In addition, the proponent should demonstrate the ability of the tailings impoundment to retain sufficient water cover in perpetuity, under variable climatic conditions, if required.

Impact assessments should be reasonable but conservative so as not to underestimate residual impacts from the project. Numerical models may be appropriate; however, MOE does not have a list of approved modelling software, so proponents must demonstrate that their chosen approach is appropriate, well documented, and sufficiently calibrated such that surface discharge predictions are valid for other related impact predictions such as impacts to water quality. The choice of model dimensionality should also be documented and justified. We recommend that the proponent discuss the proposed modelling approaches and the respective calibration method with regional MOE and MFLNRO representatives at the onset of a project (i.e., prior to submitting results or using modelled results for subsequent predictions).

The proponent should also consider the contribution of project impacts to (regional) cumulative effects. Critical information gaps that still exist at the end of the study should be explicitly identified and methods of rectifying the gaps discussed.

11.2 Hydrogeology

The proponent should identify potential impacts of the proposed development on the quantity and quality of the groundwater resource and related surface water resources and assess the significance of these impacts in terms of human and aquatic habitat. The potential effects from operations, dewatering, blasting, and contaminant sources[20] associated with all phases of the project life cycle must be included. In particular, the proponent should document (model) the long-term, post-closure, groundwater flow regime at the site, with particular emphasis on changes in base flow (quantity and quality) to streams. If modelling is required, the proponent should:

- provide enough field evidence to ensure that a model is appropriate (for example, if a continuum model is used to model groundwater flow in fractured bedrock environments, there should be sufficient field evidence that this approach is valid);
- if the assumption of isotropy is made, provide field evidence supporting this assumption, especially in determining direction of groundwater flow in a fractured bedrock environment;
- support modelled travelling times with actual field measurements of porosity or specific yield, especially when modelling travel times in a fractured bedrock environment;
- for modelling of groundwater flow in the post-closure period, include an analysis of seepage flows from the tailings impoundment; and
- for underground mines in mountainous terrain, include an analysis of the potential for post-closure portal discharge and any mitigation measures.

Impact assessments should be reasonable but conservative so as not to underestimate residual impacts from the project. Numerical models of groundwater flow and contaminant transport to adjacent receptors may be appropriate, especially if potential impacts are significant. The MOE does not have a list of approved modelling software, so proponents must demonstrate that their chosen approach is appropriate. The choice of model dimensionality, parameters, and boundary conditions should also be documented and justified. Proponents should discuss the proposed modelling approach with regional MOE and MFLNRO representatives. Where numerical models are used in impact prediction, the code selection, model development, calibration, and verification of the model should be documented in a separate technical report included as an appendix to the EA application. The electronic files required to run the model simulations should be readily available to government representatives, on request, for review and verification. The calibrated model should be used in a sensitivity study to identify key parameters influencing system behaviour and to provide an early evaluation of prediction uncertainty. This is important, since data are typically not available everywhere to complete meaningful model verification.

[20] including pits/shafts, sedimentation/tailings ponds, sewage disposal, waste dumps, landfills, material stockpiles, processing operations

The proponent should also consider the contribution of project impacts to (regional) cumulative effects. Critical information gaps that still exist at the end of the study should be explicitly identified and methods of rectifying the gaps discussed.

11.3 Water Quality

To predict impacts of mining-related activities on water quality, one needs to know the nature and extent of the contamination that may result from these activities compared with the current condition and safe thresholds for water users, such as provincial Water Quality Guidelines (WQGs) and/or site-specific Water Quality Objectives (WQOs). Impact predictions should:

- identify whether the mining project will potentially have a significant effect on the environment and designated water users, and
- discern the influence of the mine and its related activities from other sources of contamination in the watershed.

The key considerations required to assess the impact of a mining activity on water quality are as follows:

- Identify all existing and potential designated water uses that must be protected.
- Identify the existing water quality, including concentrations of constituents that may be influenced by the proposed operation (see Chapter 6).
- Identify potential effluent and non-point discharges from the proposed operation and predict the quality and quantity of contaminants that will be released.
- Identify the contaminants of concern from the above prediction.
- Document the flow and circulation pattern of the water body and their relation to the quality of water, sediments, and aquatic life.

Inventory existing BC-approved or working WQGs or site-specific WQOs for the contaminants of concern associated with the proposed operation. The development of site-specific SBEBs or WQOs is recommended if generic WQGs for a substance are lower than the upper background limit at the site under investigation. In these cases, site-specific SBEBs or WQOs provide the safe thresholds that WQGs provide at most other sides.

Reasons to develop site-specific SBEBs or WQOs may include the following:

- Background concentrations for a specific contaminant exceed generic WQGs.
- The generic WQGs for a substance are below the analytical limit of quantification that is achievable using the best available analytical methods for that substance.
- It can be demonstrated that the toxicity of a substance is dependent on an environmental factor (e.g., water hardness, pH, etc.) that was not considered in the derivation of the generic WQG.

- It can be demonstrated that the species represented in the toxicological data set used to derive the generic guidelines are not representative of the species that occur at the site under investigation.

Elevated background concentrations of specific contaminants may have many reasons, which include:

- High suspended sediment load in streams and rivers to which contaminants (e.g., metals) preferentially attach.
- Natural mineralization in the area that can sometimes result in naturally elevated levels of metals, sulphate, and trace elements, as well as possible pH depression.
- Presence of suboxic waters (e.g., bottom waters of stratified lakes) that may sustain elevated levels of ferrous iron, reduced manganese, ammonia and hydrogen sulphide, and
- Alkaline conditions resulting from the dissolution of sodic rocks, leading to elevated salinity, hardness, and pH.

The procedures to develop site-specific SBEBs, and a flow chart to help determine when to use WQGs, WQOs, SBEBs, or another approach, are found in "A Framework for the Development and Use of Freshwater Science-Based Environmental Benchmarks for Aquatic Life in Environmental Management Act Permitting for Mines" (MOE, 2016).

The procedures to develop site-specific WQOs are outlined in "Guidance for the Derivation and Application of Water Quality Objectives in British Columbia" (MOE, 2012). Other WQO-related publications are:

- Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and Yukon (MacDonald Environmental Sciences Ltd., 1997)
- Principles for Preparing Water Quality Objectives in British Columbia (MOE, 2001)
- Water Quality Objectives Reports.

Once all information from the ambient environment and the predicted loadings is available, the proponent has to predict effects to the receiving environment. This is accomplished by modelling contaminant loadings from various sources and mine related activities. The modelled loadings and the baseline ambient water conditions are used to calculate predicted receiving water conditions (e.g. using a mass balance approach) throughout the year for the various phases of the mine life. Impacts are then assessed by comparing these predicted values with WQGs and WQOs. WQGs and WQOs can also be used to set safe limits for contaminants in mine effluents by back-calculation using a mass balance approach that takes into account effluent quality, stream quality, flow characteristics, and dilution. The efficacy of these predictive tools can be enhanced by considering such factors as timing, location, and types of discharges; pre- and post-discharge water quality conditions; dilution and attenuation of contaminants in the environment (initial dilution zone); and the sensitivity of the receiving environment.

The mine site load may originate from several areas of the mine and can be subdivided into several different components:

- Sediment pond
- Tailings pond

} effluent

- Waste rock dumps
- Ore stockpiles (low and high grade)
- Pits
- Underground workings
- Facilities
- Roads and ditches

} contact areas

- Undisturbed (non-contact) areas

For some of these components (e.g., tailings ponds), it is important to distinguish between surface water discharges and groundwater discharges. The exact form of the mass balance equation will vary on a case-by-case basis, but the form will be similar. For the example case of controlled effluents and uncontrolled contact/non-contact areas, the equation would be:

$$[Q \cdot C]_{\text{downstream}} = [Q \cdot C]_{\text{upstream}} + [Q \cdot C]_{\text{effluent}} + [Q \cdot C]_{\text{contact}} + [Q \cdot C]_{\text{non-contact}}$$

Where Q = flow and C = concentration.

The mass balance applies instantaneously (at all times). For protection of aquatic ecosystems, at least two flow situations are particularly critical:

1. Minimum flow (the lowest annual and lowest summer stream flow for 7 consecutive days that would be expected to occur once in 10 years (7Q10 and 7Q10summer). For receiving waters that provide low dilution, a less frequent low flow may be required (e.g., 7Q20).
2. Maximum flow (10-year or more return period).

The method for predicting the inputs to the water quality mass balance model will vary widely depending on the specific circumstances applicable to a given mine. Whatever approach is adopted, the proponent needs to:

- explain and justify the chosen method;
- make reasonably conservative estimates of input parameters; and
- make the data available for government review.

A “reasonably conservative” statistical interpretation is the 90% confidence bound (the upper or lower bound, as appropriate) on a particular parameter. The general comparator for downstream water quality is the WQG for the most sensitive downstream use or in some cases the site-specific WQO:

$$C_{downstream} \leq \min\{WQG\}_{all\ uses}$$

This requirement normally applies to all chemical parameters, so if the downstream concentration of any single parameter is predicted to exceed the applicable objective at any time, that exceedance may be deemed to have the potential to cause environmental impact.

Groundwater will not be expected to meet aquatic life guidelines, but the effect of groundwater on surface water must be evaluated through modelling.

In the case of contaminants that bioaccumulate and biomagnify, MOE considered the bioaccumulation/biomagnification potential for only some substances (e.g., Hg, PCB, PAH, and Se) when the provincial WQGs were developed. The WQGs for these substances thus provide protection at the ecosystem level. It should be noted that all CCME water quality guidelines are toxicity-based and do not factor in the bioaccumulation potential. Therefore, to assess the true impact on the ecosystem as a whole, it is important to use appropriate objectives/guidelines that also consider the bioaccumulation potential of the contaminant. The CCME environmental quality guidelines offer the option of using tissue residue and sediment guidelines, in conjunction with WQGs, to address the issue of environmental protection at the ecosystem level.

Monitoring for attainment of the WQGs/WQOs during construction, operation, and closure of the project should be an integral part of the impact assessment. Care must be exercised in designing a monitoring program. The monitoring program should include effluent discharges, initial dilution zones (IDZ), and ambient environments (upstream (or reference) from the IDZ, downstream (or outside) the IDZ, near field, and far field). If after a number of years, it has been established that some parameters exceed the detection limit and approach the guideline/objective threshold only during the most sensitive flow periods, monitoring outside and within the IDZ may be required only during these critical periods.

To ensure that guidelines and objectives are attained, it is necessary to understand how the guidelines or objectives are initially set. Guidelines or objectives may be set to protect the ambient environment from chronic and/or acute toxic effects. A single exceedance does not suggest that objectives are not met and the environment is impaired. Statistical analyses can ensure credibility of the results. If the objectives are specified as the 95th percentile of the background, then sufficient samples at appropriate frequency must be collected to ensure that the measured results are statistically sound and worthy for rendering a decision. Appropriate statistical techniques should be employed to reduce uncertainty in the decision process. Quality assurance and quality control (QA/QC) is essential for the monitoring program.

11.4 Sediment and Invertebrates

An important component of aquatic ecosystems, sediment provides habitat for many benthic and epibenthic organisms. Many contaminants are sorbed by suspended matter that is eventually incorporated into bottom sediments. Because sediments tend to integrate contaminant inputs over time, they represent potentially significant hazards to the health of aquatic organisms and to the overall health of aquatic ecosystems.

A wide range of contaminant effects associated with sediments have been documented for floral and faunal assemblages. Both acute and chronic toxicity of sediment-associated contaminants have been reported from laboratory toxicity tests on algae, invertebrates, fish, and other organisms. Field surveys have identified the subtler effects of environmental contaminants, such as the development of tumours and other abnormalities in bottom-feeding fish. Sediment-associated contaminants also have the potential to accumulate in the tissues of aquatic organisms. Elevated tissue concentrations of certain substances in benthic or other aquatic organisms can biomagnify though the aquatic food web, thus presenting a potential hazard to sensitive wildlife species, birds, and humans that rely on these organisms for food.

To assess the impact of a mining project, the following information is required. This information is in addition to that collected for water quality impact assessment and must be collected before the proposed project begins.

- A survey of benthic macroinvertebrates (e.g., number, diversity, structure) such as mayflies, freshwater shrimps, stoneflies, caddis flies, and worms. The survey must be conducted at sites upstream, downstream, and near to the mine sites. Upstream (ambient) reference sites should be selected to be representative of the site(s) that may be impacted. Reference condition approach (RCA) methodology may be used to establish sites that represent ambient or background conditions.
- A survey of physical characteristics (e.g., grain size distribution, texture, organic carbon content, etc.) and sediment chemistry upstream, downstream, and near to the mine site.
- A survey of sediment physical characteristics (e.g., grain size), sediment chemistry, and benthic macroinvertebrates downstream at potentially impacted sites.
- The development of sediment guidelines/objectives for the protection of aquatic life.

All sampling procedures and analysis of sediment and benthic macroinvertebrates should follow procedures outlined in earlier sections of this report.

The MOE has developed sediment quality guidelines (SQG) for a limited number of parameters (e.g., PCB and PAH). SQGs are toxicity-based and should be used in assessing the potential for environmental impacts. These guidelines, along with the CCME sediment guidelines, provide a screening tool for predicting the impact of mine-related activities on the sediment environment. Site-specific sediment quality objectives have been set on rare occasions, especially for those contaminants that naturally exceed their SQG or in situations where guidelines did not exist.

The CCME's interim SQGs (given as threshold effect level, TEL, and probable effect level, PEL)[21] are not based on clear cause-and-effect relationships. In this regard, these guidelines may not adequately predict the environmental impact of contaminants released from a mine site, especially if the sediment contaminant levels exceed threshold levels. There are four reasons for this limitation of the CCME SQGs:

1. They were derived by comparing biological effects with contaminant concentrations in field-collected sediments. Exceeding an assessment value indicates an increased likelihood of toxic effects, but correlation is not proof of cause, so it cannot be assumed that the contaminant exceeding the assessment value is necessarily responsible for the observed effects.
2. They do not consider the modifying factors that may alter the toxicity of contaminants present in the sediments. For instance, organic carbon, acid volatile sulphides, sediment texture (clay content), and mineralogy can all affect the bioavailability and hence toxicity of contaminants in sediments.
3. The background concentration of contaminants may be naturally higher than the recommended sediment guidelines.
4. Variations in environmental conditions across a landscape will affect sediment quality in different ways, and many of the sediment guidelines may need to be modified according to local conditions.

Since sediment quality analysis alone may not be sufficient, the analysis of data collected simultaneously for biological organisms will yield better prediction of the environmental impact of the mining activity. The Freshwater Biological Sampling Manual (RISC, 1997b) and the CABIN Field Manual (RISC, 2009a) outline the approaches that the proponent should use for data gathering and interpretation to assess impacts on biota. Statistical tools should be employed to reduce uncertainty in the predictive results.

11.5 Aquatic Biological Data and Tissue Residues

A number of wildlife species, such as bald eagles, osprey, many colonial nesting birds, and semi-aquatic mammals (e.g., mink, otter, and polar bear) depend on aquatic species like fish, shellfish, and aquatic plants as their primary food source. Biomagnification of certain organic substances and metals through the food web (e.g., from suspended solids to fish) can affect these species.

The Canadian Tissue Residue Guidelines (TRG) for the protection of wildlife consumers of aquatic biota are intended to protect wildlife species that depend on aquatic organisms for food. The TRGs are based on the highest concentration of a chemical in the prey's body tissues that is not expected to result in adverse effects to the predator. MOE has recommended TRGs for Se, Hg, PCB, and some PAHs to protect the consumers of fish/shellfish, including human

[21] Type I (false positive) and Type II (false negative) errors for TEL and PEL, have been found to range from 5% to 30% for most sediments contaminants.

consumers. TRGs are also available from CCME for other contaminants that are not dealt with at the provincial level.

TRGs are appropriate predictive tools to protect wildlife in aquatic ecosystems for several reasons:

1. Aquatic food consumption is the main exposure route to persistent, bioaccumulative toxic substances.
2. CCME's water quality guidelines are toxicity-based and do consider bioaccumulation potential of contaminants.
3. These bioaccumulative and persistent substances are more likely to partition into the tissues of aquatic organisms or sediments rather than stay in the water column.

Any impact from consuming the water as well as the combined impact of water and food consumption must also be considered.

The proper use of the TRGs for the protection of local wildlife species (i.e., those species that the TRGs are not based on) requires an understanding of:

- the various avian and mammalian reference concentration values (i.e., the contaminant level in prey items considered to be acceptable for a particular species;
- the consumption patterns of local species to be protected; and
- the local environment (lotic versus lentic environments; the probability of bioaccumulation in lakes is higher than in streams).

Assessment of impact at the local level should augment the predictive ability of the TRGs.

Finally, TRGs are not only used to protect consumers of aquatic organisms but also to protect the health of the aquatic organisms themselves. For instance, one of the considerations in devising BC water quality guidelines for the protection of aquatic life from adverse effects of selenium was to prevent excessive accumulation that may directly affect the health (and reproductive success) of the fish exposed to selenium.

12. SUMMARY AND CONCLUSION

This guidance document outlines and defines the baseline study requirements and information considerations necessary to propose a mineral development project in the Province of British Columbia. By providing these requirements to the proponent early in the project evaluation stage (exploration), MOE aims to promote effective study design and duration and to ensure that information collection and data usage/interpretation will assist in the initial project evaluation and be useful throughout the development, operation, and closure of a mine.

The topics covered in this document – geology/geochemistry, meteorology and air quality, surficial hydrology, hydrogeology, water quality (physical and chemical parameters, aquatic sediments, tissue residues, and aquatic life), fish and fish habitat, and initial environmental impact assessment – emphasize the inter-relationships among these varied topic areas and how they must all be considered holistically to provide a comprehensive assessment of the potential impacts a given mineral extraction project may have on the environment. Focusing on the collection, analysis, interpretation, and submission of baseline information allows for characterization of the environmental resources prior to mine development and a preliminary assessment of potential impacts. Monitoring the environmental resources before and throughout the construction and operation phases of the mine development provides information to assess the effectiveness of any proposed mitigation measures and implementation of adaptive management.

The information contained in this document is meant to provide guidance and does not absolve any proponent from meeting obligations under Acts and Regulations or Codes of Practice for which MOE or other regulatory bodies may have authority. It also does not preclude MOE from requesting additional information or clarification of information that may be provided as a result of this guidance document. Additional information may be required by federal government departments involved with the issuance of regulatory approvals for mining works, activities, or operations. Proponents are advised to contact relevant federal agencies before applying for regulatory approvals for mine development or operations. Proponents are also advised to consult with the Environmental Assessment Office, the Ministry of Energy and Mines, the Ministry of Forests, Lands and Natural Resource Operations, the Ministry of Environment, and other Ministries as appropriate to ensure their respective requirements are being addressed.

13. REFERENCES

Allen, D. 1999. An assessment of the methodologies used for analyzing hydraulic test data from bedrock wells in British Columbia. Victoria, BC: Groundwater Section, Water Management Branch, BC Ministry of Environment, Lands and Parks, Earth Sciences, Simon Fraser University.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements.

Bailey, R.C., R.H. Norris, and T.B Reynoldson. 2004. Bioassessment of Freshwater Ecosystems Using the Reference Condition Approach. Kluwer Academic Publishers, Massachusetts, USA.

Barrow, E.M. and R. J. Lee. 2000. Climate Change and Environmental Assessment: Part 2: Climate Change Guidance for Environmental Assessments, for the Research and Development Monograph Series.

B.C. Ministry of Forests (BC MOF) and B.C. Ministry of Environment, Lands, and Parks (BC MELP). 1998. Fish-stream identification guidebook. Second edition, Version 2.1. Forest Practices Code of British Columbia, Victoria, B.C. Guidebook. http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/fish/FishStream.pdf

Beecher, H.A., T.H. Johnson and J.P. Carleton. 1993. Predicting microdistributions of steelhead (*Oncorhynchus mykiss*) parr from depth and velocity preference criteria: test of an assumption of the instream flow incremental methodology. Can. J. Fish. Aquat. Sci. 50:2380-2387.

Biggs, B.J.F. and C. Kilroy. 2000. Stream Periphyton Monitoring Manual. National Institute of Water and Atmospheric Research, Christchurch, New Zealand. 224 pp. www.niwa.co.nz/sites/default/files/import/attachments/peri_complete.pdf

Butler, J.J. 1996. Slug tests in site characterization: Some practical considerations, Environmental Geoscience, 3(3), 154.

Butler, J.J. 1998. The Design, Performance and Analysis of Slug Tests, Lewis Publishers, CRC Press LLC, Boca Raton, Florida.

Canadian Council of Ministers of the Environment (CCME). 1994. Subsurface Assessment Handbook for Contaminated Sites, CCME-EPC-NCSRP-48E, March 1994. http://www.ccme.ca/files/Resources/csm/pn_1144_e.pdf

Canadian Council of Ministers of the Environment (CCME). 2007. Guidance Document on Continuous Improvement (CI) and Keeping-clean-areas-clean (KCAC), PN 1389.

Canadian Dam Association (CDA). 2007. Hydrotechnical Considerations for Dam Safety.

Canadian Environmental Assessment Agency (CEAA). 2002. Reference Guide: Addressing Cumulative Environmental Effects. Available on the internet:

https://www.ceaa-acee.gc.ca/default.asp?lang=En&n=9742C481-1 Carmichael, V.E., S. Kenny, D.M. Allen, and C. Gellein. 2009. Compendium of Aquifer Hydraulic Properties from Reevaluated Pumping Tests in the Okanagan Basin, British Columbia. Water Stewardship Division, Ministry of Environment, Victoria.

a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=16377

Castleberry, D.T., J.J. Cech Jr., D.C. Erman, D. Hankin, M. Healey, G.M. Kondolf, M. Mangel, M. Mohr, P.B. Moyle, J. Nielsen, T.P. Speed and J.G. Williams. 1996. Uncertainty and instream flow standards. Fisheries. 21:20-21

Cavanagh, N., R.N Nordin, L.W. Pommen, and L.G. Swain. 1998. Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia. Field Test Edition. Resource Information Standards Committee, Province of B.C.

Coulson, C.H. and W. Obedkoff. 1998. British Columbia Streamflow Inventory. Water Inventory Section, Resources Inventory Branch, Ministry of Environment, Lands and Parks.

Department of Fisheries and Oceans Canada (DFO). 1998a. Decision framework for the determination and authorization of harmful alteration, disruption or destruction of fish habitat. Minister of Public Works and Government Services Canada. Available on the internet: http://www.dfo-mpo.gc.ca/Library/231028.pdf

Department of Fisheries and Oceans Canada (DFO). 1998b. Habitat conservation and protection guidelines. Minister of Public Works and Government Services Canada. Available on the internet: http://www.dfo-mpo.gc.ca/Library/241041.pdf

Environment Canada. 2002. Metal Mining Guidance Document for Aquatic Environmental Effects Monitoring.

Environment Canada. 2004. National Air Pollution Surveillance Network Quality Assurance and Quality Control Guidelines. Environment Technology Centre, Ottawa, Ontario, AAQD 2004-1.

Environment Canada. 2005. Guidance for Fish Tissue Analysis for Mercury using Non-Lethal Methods for the Metal Mining Environmental Effects Monitoring Program. www.ec.gc.ca/eem/pdf_publications/English/mm_fish_tissue.pdf

Environment Canada. 2011. 2011 Metal Mining Environmental Effects Monitoring (EEM) Technical Guidance Document.

http://www.ec.gc.ca/esee-eem/default.asp?lang=En&n=AEC7C481-1

Forest Practices Code of British Columbia (FPCBC). 1998. Fish-Stream identification guidebook. Second Edition. Vers. 2.1. BC Ministry of Environment and BC Ministry of Forests. www.for.gov.bc.ca/hfd/library/ffip/BCMoF1998.pdf

FORREX. 2010. Compendium of forest hydrology and geomorphology in British Columbia. www.forrex.org/program/water/compendium.asp

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons. Toronto.

Hatfield, T., A. Lewis, D. Ohlson, and M. Bradford. 2003. British Columbia Instream Flow Standards for Fish, Phase II: Development of instream flow thresholds as guidelines for reviewing proposed water uses. Developed for the BC Ministry of Sustainable Resource Management and the BC Ministry of Water, Land and Air Protection. March 2003.

Hatfield, T., A. Lewis, and S. Babakaiff. 2007. Guidelines for the collection and analysis of fish and fish habitat data for the purpose of assessing impacts from small hydropower projects in British Columbia. www.env.gov.bc.ca/wld/documents/bmp/guidelinesIFRv5_2.pdf

Hart, D. D., and C. M. Finelli. 1999. Physical-biological coupling in streams: the pervasive effects of flow on benthic organisms. Annual Review of Ecology and Systematics 30: 363-395.

Heede, B. H., and J. N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research. North American Journal of Fisheries Management 10: 249-268.

Helsel, D.R. and R.M. Hirsch. 2002. Statistical Methods in Water Resources. U.S. Geological Survey, Techniques of Water-Resources Investigations Book 4, Chapter A3. http://pubs.usgs.gov/twri/twri4a3/

Hoenig, J.M. and D.M. Heisey, 2001. The Abuse of Power: The Pervasive Fallacy of Power Calculations for Data Analysis, The American Statistician, February 2001, Vol. 55, No. 1. www.vims.edu/people/hoenig_jm/pubs/hoenig2.pdf

Holm, C.F., J.D. Armstrong and D.J. Gilvear. 2001. Investigating a major assumption of predictive instream habitat models: is water velocity preference of juvenile Atlantic salmon independent of discharge? J. Fish Biol. 59:1653-1666.

Hurlbert S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54:187-211.

Huston, C. and E. Juarez-Colunga. 2009. Guidelines for computing summary statistics for data-sets containing non-detects, Department of Statistics and Actuarial Science, Simon Fraser University; Written for the Bulkley Valley Research Center with assistance from the B.C. Ministry of Environment.

Jager, H.I. and E.J. Pert. 1997. Comment: testing the independence of microhabitat preferences and flow (Part 2). T. Am. Fish. Soc. 126:536-542.

Johnson, D.H., B.M. Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O'Neil and T.N. Pearsons. 2007. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Johnston T.S. and P.A. Slaney. 1996. Fish Habitat Assessment Procedures. Watershed Restoration Technical Circular No. 8. Revised April 1996. Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests. www.for.gov.bc.ca/hfd/library/ffip/Johnston_NT1996.pdf

Kondolf, G. M., E. W. Larsen, and J. G. Williams. 2000. Measuring and modeling the hydraulic environment for assessing instream flows. North American Journal of Fisheries Management 20: 1016-1028.

Lawrence, R.W. and Wang, Y., 1996. Determination of Neutralization Potential for Acid Rock Drainage Prediction, MEND Report 1.16.3, Ottawa, ON, 149 pp.

Lawrence, R.W. and Wang, Y., 1997. Determination of Neutralization Potential in the Prediction of Acid Rock Drainage, Proceedings of the Fourth International Conference on Acid Rock Drainage, Vancouver, BC, pp. 15-30.

Legg, C.J. and L. Nagy. 2006. Why most conservation monitoring is, but need not be, a waste of time. J. Environ. Manage. 78: 194-199.

Lewis, A., T. Hatfield, B. Chilibeck, and C. Roberts. 2004. Assessment methods for aquatic habitat and instream flow characteristics in support of applications to dam, divert, or extract water from streams in British Columbia.

Lindenmayer, D.B. and E.G. Likens. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring, Trends in Ecology and Evolution Vol.24 No.9.

MacDonald Environmental Sciences Ltd. 1997. Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and Yukon, Ministry of Environment. www.env.gov.bc.ca/wat/wq/BCguidelines/effects_ratio/effectsratio.html

Maidment, D.R. 1992. Grid-based computation of runoff: a preliminary assessment. Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

Mason, B. and R. Knight. 2001. Sensitive Habitat Inventory and Mapping. Community Mapping Network, Vancouver, British Columbia. 315pp + viii. M. Johannes, Editor.
http://www.cmnbc.ca/atlas_gallery/shim-sensitive-habitat-inventory-and-mapping McPhail, J.D. 2007. The freshwater fishes of British Columbia. University of Alberta Press, Edmonton, Alberta.

Ministry of Energy and Mines (MEM) and Ministry of Environment, Lands and Parks (MELP), 1998. Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia. http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/permitting/ml-ard_policy.pdf

Ministry of Environment (MOE). 1996. Developing Water Quality Objectives in British Columbia: A User's Guide. www.env.gov.bc.ca/wat/wq/BCguidelines/wq_ob_user_guide/usersguide.html

Ministry of Environment (MOE). 2001. Principles for Preparing Water Quality Objectives in British Columbia, Province of B.C. www.env.gov.bc.ca/wat/wq/BCguidelines/principles.html

Ministry of Environment (MOE). 2006a. Continuous Water-Quality Sampling Programs: Operating Procedures. Watershed and Aquifer Science Section.

Ministry of Environment (MOE). 2015. Guidelines for air quality dispersion modelling in British Columbia, Environmental Protection Division, Environmental Quality Branch, Air Protection Section, Victoria, B.C.

http://www.bcairquality.ca/pdf/bc-dispersion-modelling-guideline-2015.pdf Ministry of Environment (MOE). 2009a. British Columbia Environmental Laboratory Manual, Environmental Quality Branch, Water and Air Monitoring and Reporting Section. www.env.gov.bc.ca/epd/wamr/labsys/lab-man-09/index.htm

Ministry of Environment (MOE), 2009b. Groundwater Investigation and Characterization. Technical Guidance on Contaminated Sites, Version 1, Draft 6. www.env.gov.bc.ca/epd/remediation/guidance/technical/pdf/tg08-draft.pdf

Ministry of Environment (MOE). 2010. Approved Water Quality Guidelines. www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved

Ministry of Environment (MOE). 2012. Guidance for the Derivation and Application of Water Quality Objectives in British Columbia (draft).

Ministry of Environment (MOE). 2016. A Framework for the Development and Use of Freshwater Science-Based Environmental Benchmarks for Aquatic Life in Environmental Management Act Permitting for Mines.

Ministry of Environment, Lands and Parks (MELP). 1992. Metal Concentrations in Bottom Sediments from Uncontaminated B.C. lakes. www.env.gov.bc.ca/wat/wq/reference/metalsediment.pdf

Ministry of Environment, Lands and Parks (MELP). 1998. Guidelines for Interpreting Water Quality Data. Resource Information Standards Committee, Province of B.C.

Ministry of Water, Land and Air Protection (MWLAP). 2003. British Columbia Field Sampling Manual - For Continuous Monitoring and the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment and Biological Samples. Province of B.C. www.env.gov.bc.ca/epd/wamr/labsys/field_man_03.html.

Ministry of Forest, Lands and Resource Operations (MFLNRO) and Ministry of Environment (MOE). 2012. Fish-stream Crossing Guidebook, Revised Edition. Victoria, B.C.

Mudroch, A. and J.M. Azcue. 1995. Manual of aquatic sediment sampling. CRC Press. (ISBN 1-56670-0299)

National Research Council of Canada (NRCC). 1989. Hydrology of Floods in Canada: A Guide to Planning and Design.

Nordin, R.N. 1985. Water quality criteria for nutrients and algae. British Columbia Ministry of Environment, Water Management Branch, Resource Quality Section.

Nowell, A. R. M., and P. A. Jumars. 1984. Flow environments of aquatic benthos. Annual Review of Ecology and Systematics 15: 303-328.

Parker, M.A. 2000. Fish passage-culvert inspection procedures. British Columbia Ministry of Environment, Lands and Parks and British Columbia Ministry of Forests, Victoria B.C. WRP Technical Circular No.11. 47 p.

Perrin, C.J., S. Bennett, S. Linke, A. Downie, G. Tamblyn, G. Ells, I. Sharpe, and R.C. Bailey. 2007. Bioassessment of streams in north-central British Columbia using the reference condition approach. Report prepared by Limnotek Research and Development Inc. and the B.C. Ministry of Environment for the B.C. Forest Sciences Program. 121p.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime. BioScience 47:769-784.

Puls, R.W. and M.J. Barcelona. 1996. Low-flow (minimal drawdown) groundwater sampling procedures, Ground Water Issue, U.S. Environmental Protection Agency, Report EPA Pub. EPA/540/S-95/504. April.

Reilly, T.E. and A.W. Harbaugh. 2004. Guidelines for evaluating ground-water flow models, U.S. Geological Survey Scientific Investigations Report 2004-5038, 30 p. pubs.usgs.gov/sir/2004/5038/

Renard, P., D. Glenz, and M. Mejius. 2009. Understanding diagnostic plots for well-test interpretation. Hydrogeology Journal 17: 589-600, 2009. doc.rero.ch/lm.php?url=1000,43,4,20090909155547-RD/Renard_Philippe_-_Understanding_diagnostic_plots_for_well-test_20090909.pdf

Reynoldson, T.B., C. Logan, T. Pascoe, and S.P. Thompson. 2003. CABIN (Canadian Aquatic Biomonitoring Network) Invertebrate Biomonitoring Field and Laboratory Manual. National Water Research Institute, Environment Canada.

Resources Information Standards Committee (RISC). 1997a. Fish Collection Methods and Standards version 4.0. Province of British Columbia.

Resource Inventory Standards Committee (RISC). 1997b. Freshwater Biological Sampling Manual.

Resources Information Standards Committee (RISC). 1999. Fish Collection Methods and Standards version 4.0: Errata No.1. Province of British Columbia

Resource Inventory Standards Committee (RISC). 2000. Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Quality Assurance Procedures - Version 1.0. Prepared by BC Fisheries Information Services Branch for the Resources Inventory Committee.

Resource Inventory Standards Committee (RISC). 2001a. Reconnaissance (1:20 000) Fish and Fish Habitat Inventory Standards and Procedures, Version 2.0. Prepared by BC Fisheries Information Services Branch for the Resources Inventory Committee.

Resource Inventory Standards Committee (RISC). 2001b. Standards for Fish and Fish Habitat Maps Version 3.0. Prepared by BC Fisheries Information Services Branch for the Resources Inventory Committee.

Resource Inventory Standards Committee (RISC). 2004. Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Quality Assurance Procedures - Version 1.0 Errata No. 1. Prepared by BC Fisheries Information Services Branch for the Resources Inventory Committee.

Resource Inventory Standards Committee (RISC). 2009a. The Canadian Aquatic Biomonitoring Network Field Manual, prepared by Ministry of Environment, Science & Information Branch, Watershed and Aquifer Science Section.

Resource Inventory Standards Committee (RISC). 2009b. Manual of British Columbia Hydrometric Standards, Version 1.0, Prepared by the Ministry of Environment, Science and Information Branch, for the Resources Information Standards Committee.

Ricker, W.E. 1971. Methods for Assessment of Fish Production in Fresh Waters. International Biological Programme (IPB) Handbook No.3.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish. Bull. Fish. Rca. Boani Can. 191:1-382, 1975.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bull. Fish. Res. Board Can. No. 184.

Sharpe, I. 1998. How to Assess and Manage Risk Using Principles of Impact Assessment Biology: A Mine Lifecycle Approach, Ministry of Environment, Skeena Region.

Sobek, A.A., Schuller, W.A., Freeman, J.R., and Smith, R.M., 1978. Field and Laboratory Methods Applicable to Overburden and Minesoils, U.S. Environmental Protection Agency Report EPA-600/2-78-054, 204 pp.

Taylor, B.R. and R.C. Bailey. 1997. Technical Evaluation on Methods for Benthic Invertebrate Data Analysis and Interpretation Final Report. Aquatic Effects Technology Evaluation (AETE) Program Project 2.1.3. Prepared for Canadian Centre of Mineral and Energy Technology. Ottawa, ON.

Underwood, A.J. 1991. Beyond BACI: Experimental Designs for Detecting Human Environmental Impacts on Temporal Variation in Natural Populations. Aust. J. Mar. Freshwater Res. 42: 569-87.

Underwood, A.J. 1992. Beyond BACI – The Detection of Environmental Impacts on Populations in the Real, but Variable, World. J. Exp. Mar. Biol. Ecol. 161: 145-178.

Underwood, A.J. 1993. The Mechanics of Spatially Replicated Sampling Programs to Detect Environmental Impacts in a Variable World. Aus. J. Ecol. 18: 99-116.

Underwood, A.J. 1994. On Beyond BACI – Sampling Designs that Might Reliably Detect Environmental Disturbances. Ecol. Appl. 4: 3-15.

U.S. Environmental Protection Agency (USEPA). 1997. Federal Register, Part II, National Ambient Air Quality Standards for Particulate Matter; Final Rule. 40 CFR Part 50, Vol. 62, No. 138, July 18, 1997.

U.S. Environmental Protection Agency (USEPA). 1998. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part I, Ambient Air Quality Monitoring

Program Quality System Development, August 1998. Research Triangle Park, NC, EPA-454/R-98-004. www.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf

U.S. Environmental Protection Agency (USEPA). 2006a. Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4. www.epa.gov/quality/qs-docs/g4-final.pdf

U.S. Environmental Protection Agency (USEPA). 2006b. Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements Version 2.0 (Final).

Wels, C., Mackie, D. And Scibek J. 2012. BC MOE Groundwater Modelling Guidelines, BC Ministry of Environment.

Whitfield, P. H. 1998. Reporting scale and the information content of streamflow data. Northwest Science 72: 42-51.

World Meteorological Organization (WMO). 2008 and 2009. Guide to Hydrological Practices. WMO-No. 168. Volume 1 (2008) and Volume II (2009).
http://hydrology.nl/images/docs/hwrp/WMO_Guide_168_Vol_I_en.pdf;
http://hydrology.nl/images/docs/hwrp/WMO_Guide_168_Vol_II_en.pdf

14. SUMMARY OF WEB SITES

SUMMARY OF WEB SITES:	
Acts and Regulations (Provincial):	
• *Environmental Assessment Act*:	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/00_02043_01
o Reviewable Project Regulation	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/13_370_2002
o Concurrent Approval Regulation	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/10_371_2002
o Prescribed Time Limits Regulation	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/11_372_2002
• *Environmental Management Act*	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/03053_00
• *Water Sustainability Act*	• www.bclaws.ca/civix/document/id/complete/statreg/14015
o Groundwater Protection Regulation	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/11_299_2004
• *Mines Act*	• www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/00_96293_01
Acts and Regulations (Federal):	
• *Fisheries Act*	• laws-lois.justice.gc.ca/eng/acts/F-14/
o Metal Mining Effluent Regulation	• laws-lois.justice.gc.ca/eng/regulations/SOR-2002-222/page-1.html
Canada-BC Agreement for Environmental Assessment Cooperation (2004):	• http://www.ceaa.gc.ca/default.asp?lang=En&n=EA76AACC-1
Canadian Aquatic Biomonitoring Network (CABIN):	• http://ec.gc.ca/rcba-cabin/
Canadian Council of Ministers of the Environment (CCME) documents:	• Canadian Tissue Residue Guidelines for the Protection of Wildlife Consumers of Aquatic Biota • Continuous Improvement and Keeping Clean Areas Clean • Subsurface Assessment Handbook for Contaminated Sites • Water Quality Guidelines • Sediment Quality Guidelines
Canadian Council of Professional Geoscientists:	• http://geoscientistscanada.ca/
Canadian Environmental Assessment Agency:	• http://www.ceaa-acee.gc.ca/default.asp?lang=En&n=D75FB358-1 • Incorporating Climate Change Considerations in Environmental Assessments • Preparing Project Descriptions under the Canadian Environment Assessment Act

Community Mapping Network:	• www.cmnbc.ca
Environmental Assessment Office: • EAO User Guide: • Electronic Project Information Centre (e-PIC): • Guidance documents:	• http://www.eao.gov.bc.ca/ • http://www.eao.gov.bc.ca/pdf/EAO_User_Guide_20150629.pdf • http://a100.gov.bc.ca/appsdata/epic/html/deploy/epic_home.html • http://www.eao.gov.bc.ca/guidance.html
Environment Canada: • Access to Regional Data: • Archived Hydrometric Data (stream flow records: • Discharge Measurements from Ice Cover: • Environmental Indicators: • Freshwater Maps: • Water Survey of Canada: • National Air Pollution Surveillance Network Quality Assurance & Quality Control Guidelines: • National Climate Data and Information Archive: • Water Quality:	• www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=9018B5EC-1 • http://wateroffice.ec.gc.ca/search/search_e.html?sType=h2oArc • http://publications.gc.ca/site/archivee-archived.html?url=http://publications.gc.ca/collections/collection_2014/ec/En56-245-1999-eng.pdf • http://www.ec.gc.ca/indicateurs-indicators/ • http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=130FFF78-1 • http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1 • National Air Pollution Surveillance Network Quality Assurance & Quality Control Guidelines • www.climate.weatheroffice.ec.gc.ca/Welcome_e.html • http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=13307B2E-1
Guidance Documents: • Global Acid Rock Drainage (GARD) Guide: • Guidelines for evaluating GW flow models: • Guidelines for Metal Leaching & Acid Rock Drainage at Mine sites in BC:	• http://www.gardguide.com • http://pubs.usgs.gov/sir/2004/5038/ • http://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/permitting/ml-ard
Health Canada: Environmental and Workplace Health:	• http://www.hc-sc.gc.ca/ewh-semt/index-eng.php
Natural Resources Canada (Information regarding existing mines):	• http://www.nrcan.gc.ca/home

Provincial databases, guidelines and manuals:	
Data repositories: • B.C. Cross Linked Information Resource (CLIR): • Geo BC: • Water and Air Monitoring and Reporting: • WELLS – Ground Water Wells and Aquifer Database:	• www.env.gov.bc.ca/clir/ • geobc.gov.bc.ca/ • http://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring • http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools
Air:	• Guidelines for Air Quality Dispersion Modelling in British Columbia
Surface Water:	• British Columbia Streamflow Inventory • Water Licences Query
Groundwater:	• Water Well Record Data Entry (e-WELLS) • Glossary of groundwater terms • Groundwater Investigation and Characterization • Guide to Conducting Well Pumping Tests • The Ground Water Reference Library • Water Well Search Application
Water Quality:	• Approved Water Quality Guidelines • Working Water Quality Guidelines (Water Column and Sediments) • Guidance for the Derivation and Application of Water Quality Objectives in British Columbia • Bioassessment of Streams in Northern British Columbia Using the Reference Condition Approach • British Columbia Environmental Laboratory Manual • British Columbia Environmental Field Sampling Manual • Continuous Water-Quality Sampling Programs: Operating Procedures • Glossary of water quality terms • Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia • Guidelines for Interpreting Water Quality Data • Guidelines for Monitoring Fine Sediment Deposition in Streams
Waste Discharge Authorizations:	• http://www.env.gov.bc.ca/epd/waste_discharge_auth/index.htm

Fish:	• Field data information system (FDIS) • Fish and fish habitat inventory and information – products and tools • Fisheries Inventory Data Queries • Scientific fish collection permit
Resource and Inventory Standards Committee (RISC) documents:	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/
• Canadian Aquatic Biomonitoring Network Field Manual:	• http://publications.gc.ca/collections/collection_2012/ec/En84-87-2012-eng.pdf
• Continuous Water-Quality Sampling Programs: Operating Procedures:	• www.env.gov.bc.ca/wat/wq/BCguidelines/risc_reports/wq_sampling_op_proc.pdf
• Freshwater Biological Sampling Manual:	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/freshwaterbio/
• Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia:	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/design/index.htm
• Guidelines for Interpreting Water Quality Data:	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/interp/intrptoc.htm
• Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Quality Assurance Procedures (Version 1.0)	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/quality/assets/quality.pdf
• Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Quality Assurance Procedures (Version 1.0) – Errata March 2004	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/quality/assets/qa_errata01.pdf
• Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Quality Assurance Procedures (Version 2.0)	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/recon/recce2c.pdf
• Manual of British Columbia Hydrometric Standards:	• http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/science-data/man_bc_hydrometric_stand_v10.pdf
• Standards for Fish and Fish Habitat Maps Version 3.0:	• https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/fishmaps2k1/fishmaps_april2001.pdf

U.S.A. Environmental Protection Agency Federal Register, *Part II, Environmental Protection Agency, National Ambient Air Quality Standards for Particulate Matter; Final Rule.* 40 CFR Part 50, Vol. 62, No. 138, July 18, 1997:	• https://www3.epa.gov/ttn/caaa/t1/fr_notices/pmnaaqs.pdf • Guidance on Systematic Planning Using the Data Quality Objectives Process • Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements Version 2.0 (Final) • Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part I, Ambient Air Quality Monitoring Program Quality System Development
"Sub-EA" project application: • To structure a Mine Permit Application (MPA) for permits under the *Mines Act,* refer to: • For guidance on permit applications under the *Environmental Management Act* refer to: • *Environmental Management Act* waste discharge applications:	• http://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/permitting • http://www2.gov.bc.ca/gov/content/environment/waste-management/industrial-waste/mining-smelting/guidance-documents • http://www2.gov.bc.ca/gov/content/environment/waste-management/waste-discharge-authorization

Appendix 1. Environmental Assessment and Regional Permitting Information Needs for Mine Development (Process Trigger Letter)

Background

An environmental assessment (EA) for a proposed mine requires substantial amounts of data/information to be gathered and assessed. The timing and quality of this work is critical in order for the assessment process, and ultimately mine development, to proceed without unnecessary delay.

The Ministry of Environment's Environmental Protection Division (EPD) has a responsibility under the *Environmental Management Act* to ensure that waste discharges from an operation do not harm the environment. For all hard rock and coal mine proposals, whether a newly proposed mine or the expansion of an existing mine, proponents will be expected to perform an appropriate assessment. This assessment must be conducted whether or not the proposal triggers the formal EA process under the *Environmental Assessment Act*.

Purpose

The purpose of this appendix is to provide proponents with an understanding of the EPD's information needs (both general content and timing) during the assessment process. A compilation of EPD's detailed information requirements for mine development has also been provided. These requirements are not meant to replace an active assessment process laid out by the Environmental Assessment Office or a Mine Development Review Committee. Rather, the intention is to provide specific direction that can dovetail with these processes

Environmental Assessment Data/Information Needs

Baseline Collection

Baseline water and air quality data collection and acid rock drainage/metal leach testing are essential so that a proper assessment of potential effects from project discharges may occur. Baseline data collected over a minimum period of one year are expected prior to an EA application or a Mine Permit Application (MPA) if the project does not trigger the EA process. Because of this time period, discussions with EPD staff need to occur as early as possible in the development process. **An appropriate time for a company to initiate discussions is when it suspects that a mineable resource is present that it wishes to develop.** Data collection programs must first determine the objectives that will help answer questions about the geographical areas to be studied. The proponent must determine the parameters to be measured and the sampling locations, frequency, and methods. The proponent must discuss with the EPD and agree on analytical procedures, including appropriate detection limits, and data quality assurance. Without an acceptable data collection program, baseline data could be considered invalid and the resulting impact predictions inaccurate. To avoid delays, a proponent should develop a **Baseline Collection Workplan** for EPD approval prior to beginning field work. This workplan should be submitted a minimum of 18 months prior to submission of an EA application or MPA. Since baseline data collection could be affected by activities such as bulk sampling, a proponent may need to adapt the data collection program in view of these activities and in consultation with EPD.

Project Description

A Project Description, as required under the *Environmental Assessment Act*, provides good general information for EPD staff. The Project Description should identify any obvious environmental challenges or issues (e.g., significant ARD generation, use of processes such as cyanidation or heap leaching, significant amount of fines in the soil that will be disturbed, unusual metallurgy requiring unusual process control technology, lack of available dilution in the receiving environment for discharges, etc.). It is understood that not all of this information may be available at this stage of the EA review.

Application Information Requirements (AIR)

A project AIR describes the items that a proponent will assess and report on and the management plans that a proponent will develop in order to avoid, minimize, or mitigate impacts. The AIR forms the blueprint of information to be presented in an EA application. Guidelines for how to prepare an AIR have been developed by the Environmental Assessment Office and can be found on its website under Procedural Guides and Templates. For an MPA, a proponent should discuss AIR requirements with the Mines Branch of the Ministry of Energy and Mines. EPD is one of many agencies that reviews draft AIR to ensure that all issues of interest are included.

Impact Assessment Workplans

While the AIR will describe the potential project impacts to be assessed, it is not expected to include details of how the assessment work will be done. A proponent must ensure that acceptable assessment methods are being used prior to performing the assessment. For this purpose, it is anticipated that a proponent will develop **Impact Assessment Workplans,** where appropriate, in consultation with EPD staff. These workplans should eliminate disagreement and delays that otherwise may arise later in the assessment process. The workplans should be completed as soon as possible and will not be incorporated in the AIR beyond mentioning that the studies will occur. The review of these workplans should occur outside of the EA process and include the relevant MOE staff. The proponent should first have project-specific meetings with EPD staff and should then develop workplans with reference to EPD's detailed information requirements.

While the number and type of Impact Assessment Workplans may vary from project to project, air and water quality workplans are expected to be the most common. A key component of the plans should be a description of the models to be used to predict potential impacts. Early discussion with EPD staff to determine workplan requirements is key.

Impact Management Plans

Impact Management Plans describe how the proponent will control or treat discharges in order to prevent detrimental impacts to the receiving environment. Examples of these types of plans include a Sediment Control Plan, Flocculent Management Plan, and Dust Management Plan. These plans can be submitted at the EA application or MPA stage; however, more detailed plans may be required when applying for a waste discharge permit under the *Environmental Management Act*.

Environmental Assessment or Mine Permit Applications

EPD will participate in the evaluation or screening of EA applications to ensure that information identified in the approved AIR has been included.

When the Environmental Assessment Office (EAO) or Mines Branch receives an application, EPD staff (as well as other agencies and groups) will review the information to identify any concerns or issues and to assess the adequacy of the information contained within the EA Certificate Application. The EAO assesses the potential for significant adverse impacts based on information gleaned throughout the course of the EA process. The EAO provides an assessment report and recommendations to the relevant Minister(s). This report documents the assessment's findings, including the extent to which concerns have been addressed and whether any issues remain outstanding. Comments will be provided to the Environmental Assessment Office (or to the Chair of the Regional Mine Review Committee in the case of MPAs) as part of its process and clarification may be sought directly from the proponent.

Permits for Discharges of Waste under the Environmental Management Act (EMA)

EMA permits are issued after the EA Certificate or *Mines Act* permits have been issued; however, the application process for an EMA permit can be initiated at any time. While much of the information supplied for the EA or MPA processes can be used for the EMA permitting process, more detailed information is normally required for an EMA permit.

To satisfy the additional information needs, the proponent must submit a Technical Assessment Report (TAR) along with the EMA permit application. Contact the EPD to discuss the required content of this report.

Applications for Concurrent Permitting

Proponents may submit an application to the Executive Director of the Environmental Assessment Office for concurrent review of all permits needed to proceed with construction of a proposed mine. There are certain deadlines for applying for concurrent review and, if the application is accepted, the authority responsible for issuing a permit must proceed expeditiously with its review and consideration of the application and must respond within specified timelines. Proponents wishing to pursue this course should consult with the Environmental Assessment Office.

<u>Summary:</u>

<u>Stage of Mine Development and Proponent Actions Required</u>

1. A proponent suspects that it has identified a mineable resource that it wishes to develop.

   <u>Action</u>: Initiate discussions with EPD about baseline water and air quality data collection requirements.

2. 18 months (minimum) prior to submission of an EA or MPA application

   <u>Action</u>: Submit Baseline Data Collection Workplans to EPD (for air and water quality).

3. 15 months (minimum) prior to submission of an EA or MPA application

   <u>Action</u>: Begin baseline data collection programs.

4. Environmental Assessment Process (Pre-application)

   <u>Actions</u>: Meet with the Environmental Assessment Office.
   Submit Project Description.
   Submit draft Application Information Requirements (what will be assessed).
   Update draft Application Information Requirements based on input from public, First Nations, and Working Group.
   Submit First Nations consultation report and plan.
   Submit Application for evaluation (screening).

5. Environmental Assessment Process (Application)

   <u>Actions</u>: Submit Application in accordance with Application Information Requirements.
   Include Impact Management Workplans as part of the methodology for gathering baseline information and effects analysis.
   Address issues and concerns raised through the Application review and provide appropriate mitigation measures and commitments.

6. *Environmental Management Act* permits

   <u>Actions</u>: Hold a pre-application meeting with EPD staff.
   Submit waste discharge applications for discharges to the air, water, and land. Include a Technical Assessment Report with applications.
   Note: This application process can begin during the assessment processes noted above, when sufficiently detailed information is available.

Appendix 2. Glossary of Terms[22]

Ambient: *With respect to water quality,* refers to a condition of site/watershed/waterbody that is not necessarily associated with episodic perturbations or disturbance caused by a given activity. This term is often used to describe the 'background' condition with respect to water quality, sediment, and biological characteristics. *With respect to air quality,* refers to the condition of the surrounding air.

Anisotropy: The property of being directionally dependent. See also isotropy.

Application: An application for an Environmental Assessment Certificate and a permit to construct/operate or carry on the activity that is filed by the proponent.

Baseline study: Information about relevant, pre-existing environmental, economic, social, heritage, and/or health conditions at the site of, or in the area surrounding, a proposed project to enable a determination of actual project effects through comparisons before and after development.

Benthic macroinvertebrates: The bottom-dwelling animals (without backbones) that are retained in mesh sized 200-500 µm or are visible by the unaided eye. The most diverse group of freshwater benthic macroinvertebrates is aquatic insects. They are also referred to as benthos, infauna, or macrobenthos. Benthic macroinvertebrates are ideal for use in bioassessment because (a) they are sedentary and thus are constantly exposed to the effects of pollution; (b) they are reasonably long-lived (1-3 years in north-temperate waters) to express environmental effects of the stressors; and (c) they occur in high diversity, so many different species can potentially react to many different types of impacts.

Biological assessment/bioassessment: An evaluation of the biological condition of a site or waterbody using surveys of the structure and function of a community of resident biota.

Biological monitoring/biomonitoring: A method of inferring the condition of a site by examining the organisms (e.g., algae, fish, benthic macroinvertebrates) that live there. In a river or stream, biomonitoring can detect effects that traditional water quality tests may not.

Biota: The total fauna and flora of a region; the populations of living organisms in general.

Community structure: Taxonomic and quantitative attributes of a community, including species richness and relative abundance both structurally and functionally.

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[22] A comprehensive glossary of water quality terms can be found at: www.env.gov.bc.ca/wat/wq/reference/glossary.html

Designated water use: A water use that is protected at a specified location and is for one of the following uses: drinking water, public water supply, and food processing; aquatic life and wildlife; agriculture (e.g., livestock watering and/or irrigation); recreation and aesthetics; and industrial water supply.

Discharge: The total amount of solid, liquid, or gaseous waste introduced into the environment from mining-related activities, including effluent and reclaimed water.

Ecosystem: Any complex of living organisms interacting with nonliving chemical and physical components that together form and function as a natural environmental unit.

Environmental Assessment: The process that provides a mechanism for reviewing major projects to assess their potential impacts. In order for a major project to proceed, an Environmental Assessment (EA) must be completed successfully, and the proposed project must be approved by two provincial government Ministers. The EA process addresses a broad range of environmental, economic, social, health, and heritage issues through a single, integrated process. It ensures that the issues and concerns of all interested parties and First Nations are considered together, and that a project, if it is to proceed, will do so in a sustainable manner.

Environmental Assessment Office: The provincial body that manages the assessment of proposed major projects in British Columbia as required by the *Environmental Assessment Act* and regulations.

Environmental Assessment Certificate: If issued at the conclusion of an environmental assessment, allows a proponent to seek any other statutory authorizations needed to proceed with the project.

Fish Habitat: Spawning grounds and nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly in order to carry out their life processes.

Fish Habitat Compensation: The replacement of natural habitat or increase in the productivity of existing habitat where mitigation techniques and other measures are not adequate to maintain habitats for Canada's fisheries resources.

Groundwater: Subsurface water at or below a water table in fully saturated geological materials and formations.

Initial dilution zone: The three-dimensional zone around the point of discharge where mixing of the effluent and the receiving water occurs.

Isotropy: Exhibiting properties with the same values in all directions or uniformity in all directions. See also anisotropy.

Lentic systems: Standing freshwater habitats, environments, or ecosystems. They have no current, are non-moving, may be landlocked, are layered regions, and have greater biodiversity. Lakes and ponds are examples of lentic environments.

Lotic systems: Running freshwater habitats, environments, or ecosystems. They have current, are moving, change in elevation, have constant water supply, can freeze, have no layered regions, and are well oxygenated. Rivers and streams are examples of lotic environments.

Mitigation: Measures implemented to control, reduce, or eliminate a potential adverse impact of a project, including restorative measures.

Non-point source: A combination of a variety of pollution sources that are diffused and difficult or too small to measure on an individual basis. Agriculture and forestry are examples of non-point sources of pollution. From an air quality perspective, emissions from cars, fireplaces, and lawnmowers are combined into the category of non-point sources.

PM_{10} or $PM_{2.5}$: Particulate matter. PM_{10} refers to particles in the air with aerodynamic diameters smaller than 10 µm, and $PM_{2.5}$ are particles with an aerodynamic diameter smaller than 2.5 µm.

Periphyton: A broad assemblage of organisms composed of attached algae, bacteria, their secretions, associated detritus, and various species of microinvertebrates.

Permit: An authorization for introduction of waste into the environment subject to requirements for the protection of the environment that the issuer considers advisable.

Point source: A single, stationary source of pollution that can be well defined. A pipe discharging effluent and a smokestack are examples of point sources. It is easy to measure and define the source of pollutants from a point source. It is also easy to regulate a point source using an effluent/emission permit process.

Proponent: Any person or organization proposing to undertake a reviewable project in British Columbia, including the government of Canada, the government of British Columbia, a First Nation, a company, a municipality, a regional district, another province, or another jurisdiction.

Risk assessment: An estimate of the probability that environmental or health problems will result from a particular activity. Risk assessment plays an important role in determining controls for the toxic contaminants.

Science-based environment benchmark: a quantifiable receiving environment parameter or attribute protective of freshwater aquatic life that is developed by a qualified professional through a rigorous scientific process with the intent to inform management decisions and guide mitigative actions for a regulated mining activity at a specific location.

Specific storage: The amount of water that a portion of an aquifer releases from storage (per unit mass or volume of aquifer or per unit change in hydraulic head) while remaining fully saturated.

Specific yield: The volume of water released by drainage (per unit area) from an aquifer as a result of a unit decline in groundwater level. For non-cohesive sediments or bedrock, the specific yield can be approximated as the effective porosity.

Water quality guideline: A maximum and/or minimum value for a physical, chemical, or biological characteristic of water, biota, or sediment that must not be exceeded. Water quality guidelines are developed in order to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions. The guidelines are applicable province-wide. The term 'water quality guideline' is equivalent to 'water quality criterion,' which the Province used in the past.

Water quality objective: A guideline value adapted or adopted to protect the most sensitive designated water use at a specified location with an adequate degree of safety, taking local circumstances into account. In a given waterbody, each objective may be based on the protection of a different water use, depending on the water uses that are most sensitive to the characteristics of concern in that waterbody.

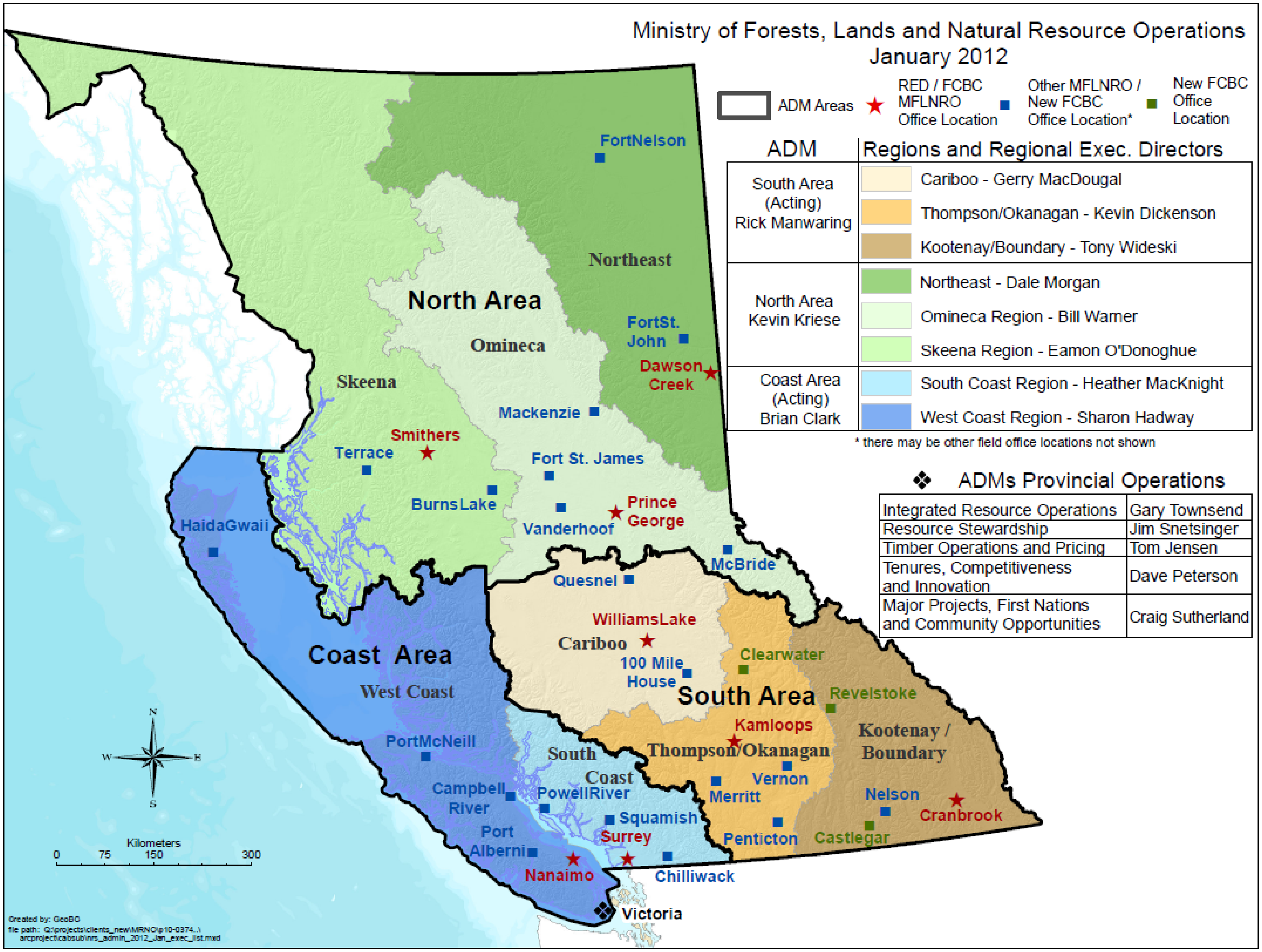
Appendix 3. Contact Information for the Ministry of Environment and the Ministry of Forests, Lands and Natural Resource Operations[23]

Ministry of Environment

Office	Address	Phone
Vancouver Island	2080 Labieux Road, Nanaimo BC V9T 6J9	250-751-3100
Lower Mainland	2nd Floor, 10470-152nd Street Surrey, BC V3R 0Y3	604-582-5200
Thompson Region	1259 Dalhousie Drive, Kamloops, BC V2C 5Z5	250-371-6200
Kootenay Region	401-333 Victoria Street, Nelson, BC V1L 4K3	250-354-6333
Cariboo Region	400-640 Borland Street, Williams Lake, BC V2G 4T1	250-389-4530
Skeena Region	PO Box #5000, 3726 Alfred Avenue, Smithers, BC V0J 2N0	250-847-7260
Omineca Region	325–1011 4th Avenue, Prince George BC V2L 3H9	250-565-6135
Okanagan Region	102 Industrial Place, Penticton, BC V2A 7C8	250-490-8200

[23] Current as of May 2012

Ministry of Forests, Lands and Natural Resource Operations



Appendix 4. Overview of Geological and Geochemical Information Requirements for Environmental Assessment

This appendix includes a list of detailed information requirements that the proponent must evaluate for the proposed project. The list focuses on metal leaching and acid rock drainage (ML/ARD) and includes information about baseline data collection, project design, environmental assessment, permitting, and impact assessment. The list is not considered to be exhaustive. Refer to Chapter 2 for further relevant information links to legislation, policy, guidelines, and best practices documentation.

It is critical that the proponent design a workable mine plan that minimizes disturbances, maximizes use of materials and resources, enhances closure capabilities, and minimizes discharges to the environment both in the short- and long-term.

Geological Information

It is critical to detail the project geology and relate it to the proposed mine development, so the proponent must include the following in the baseline report:

- A comprehensive discussion of the deposit geology and its relationship to ML/ARD potential for all the geologic units that will be disturbed during the mine development. Include information about mineralogy, alteration assemblages, facies changes (e.g., coal, other sedimentary deposits), material volumes, and the relationship between the geology and the mine development. Evaluate the changes to the disturbed materials due to any type of processing, physical or chemical.
- A delineation of the geologic structures (e.g., faults) in the project area and how they may affect the proposed infrastructure (e.g., open pit(s), waste rock dumps, tailings impoundment(s), ore stockpile(s), overburden stockpile(s), sedimentation pond(s), water management structures, plant site, etc.). Assess how these features may influence contaminant flow paths, mitigation proposals, and closure strategies.
- The potential for differential weathering based on alteration, physical and structural characteristics, or other factors and how this information will be used to determine the static and kinetic sample selection (e.g., areas of intense sericitic alteration would likely result in rapid weathering and physical breakdown, and as such, would be sampled as a distinct population from an unaltered portion of the same geologic unit). Include physical information such as how the alteration directly relates to drainage chemistry predictions and water quality impacts.
- The potential for ML/ARD based on variable primary mineralization features (e.g., disseminated pyrite vs. stock work vs. vein as the predominant mode of occurrence). These types of deposit characteristics require consideration when designing kinetic test programs.
- Plan views of the site relating the geology, proposed mine infrastructure, drill-hole locations, and cross-section locations. Include plans and sections of the pit at variable

time intervals throughout the proposed life of the mine (e.g., five-year increments) and at closure for all development options. Illustrate the expected lithologies, alteration, and mineralization to be exposed at each time increment and provide a discussion on how each would materially affect mine drainage and the final closure of the mine site.
- Clear, concise cross-sections that relate the ML/ARD assessment (e.g., static/kinetic sample locations), geology, and mine development plans (e.g., development phases and final pit outline).

Detailed Acid Rock Drainage and Metal Leaching Assessment Requirements

The baseline report must describe static and kinetic test work conducted and should detail any future programs. Please refer to the Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia *and* Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia. Further guidance and information can be found in Chapter 2 and the references provided below. As part of the baseline studies, it is appropriate for static and kinetic testing to be initiated during early stages of exploration. The characterization of the ML/ARD potential is a critical component of the project assessment and must include the following:

- Rationale for, and description of, sample selection. Linkage to the mine planning and proposed development scenario is a crucial component of this evaluation, as the test work must reflect the ultimate development. Information regarding sampling may be obtained from the following:
    - Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials, Chapter 8, MEND Report 1.20.1.
    - ARD Sampling and Sample Preparation
    - Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State of the Art, Kuipers & Associates, 2005
    - Comparison of Predicted and Actual Water Quality at Hardrock Mines: the Reliability of Predictions in Environmental Impact Statements, Kuipers & Associates, 2006
    - EPA and Hardrock Mining: A Sourcebook for Industry in the Northwest and Alaska
    - Other sampling information sources
- Methodology for all test work performed.
- The raw baseline and predictive data from the ML/ARD assessment programs properly identified and clearly tabulated, with sample calculations and clear interpretations and conclusions for all the collected data. Provide development proposals based on this information, where applicable.
- Sufficient static ML/ARD tests to define the ML/ARD potential of all materials to be disturbed (e.g., waste rock, ore, low-grade ore, overburden, construction materials, etc). Include acid base accounting (ABA samples from variably oriented drill holes to ensure that characterization of the materials reflects all the possible controls (i.e., oriented fracture control). Where one methodology is used such as Sobek (Sobek, et.al, 1978) a

second technique, such as a modified Sobek methodology (after Lawrence and Wang, 1996, 1997), is necessary on a representative sub-set to off-set method biases and provide a more comprehensive assessment of the ARD/ML potential of the materials in question. Using this comparative evaluation, sensitivity assessments may be made to address the potential impacts to the project given the range in characterization. (For example, compare and contrast with other neutralization potential NP methodologies and assess the impacts on material handling/waste balances/mine planning using the range of values attained; e.g., if method 2 yields 30% less NP, what impacts would this have on waste handling and disposal, construction materials, impoundment size, onset to ARD, pit lake characterization, effluent quality, treatment requirements, etc.?). For all test work, the methodology biases, limitations and margin of error must be considered during data interpretation, conclusion determination, and forthcoming recommendations.

- Kinetic characterization of the critical lithologies, alteration assemblages, and long-term exposure surfaces associated with waste rock, tailings, ore, low-grade ore, construction materials, pit walls, and any other material that will be disturbed or exposed during the mining operation. Sample selection must also reflect mine development and be representative of the various mining phases and potential closure scenarios. By assessing the deposit in terms of mining phases, grade and economic considerations are taken into account.
- Kinetic test work that determines the impact of gypsum/anhydrite (if present in the deposit) on ML/ARD reactions and predictions. If possible, collect gypsum-rich and gypsum-barren samples from the same lithological/alteration unit for comparative kinetic test cells.
- Kinetic studies that include leaching under neutral conditions.
- Kinetic programs of sufficient detail to identify reasonable worst-case and median-case scenarios as determined by the ABA, geologic, and proposed development information.
- At a minimum, analyses for pH, total sulphur, percent sulphide sulphur, percent sulphate sulphur, acid potential (AP), neutralization potential (NP), carbonate neutralization potential (CaNP), net neutralization potential (NNP), neutralization potential ratio (NPR), range, average, median, and standard deviation.
- Identification of the mineralogical sources of neutralizing potential within each of the major geological/alteration units. Differentiate between calcium/magnesium carbonate NP and other forms of NP and conduct kinetic test work on proposed NP sources to determine the availability of NP and its rate of production under the expected geochemical conditions.
- Graphical representation of the information collected during the ABA and kinetic test work (e.g., NPR distribution for the sample population from ABA tests, parameter trend assessment for kinetic test results, etc.). Present graphs at a scale and clarity that remove clutter and allow for interpretation of the data points.
- Population assessments such as population distribution within a given geologic and/or alteration unit. Evaluate distinctions between ore, low-grade ore, alteration

assemblages, and various waste rock types as distinct populations in the initial assessment. Assess the various populations in terms of vertical and horizontal distribution and sampling biases (i.e., is the observed population a function of the sampling program?) to ensure that a waste management unit is properly characterized over its range of variability. Bar graphs that have the % population along the y-axis and the characteristic of interest along the x-axis (e.g., % sulphide sulphur) are especially useful. Distinct data set evaluation of sub-populations is necessary, especially during early evaluations, in contrast to property wide "lumping" of data.

- Metal leaching potential of the disturbed or exposed materials, determined by identifying the elemental composition of different materials, providing comparisons with crustal abundances, and identifying elements of possible concern under the expected geochemical conditions. Include an assessment of the soluble constituents.
- Details of any leach pads including pad construction, waste rock identification and geologic correlation, sample characterization, sampling program, results, and assessment.
- Threshold geochemical indices (e.g., segregation NPR) used to evaluate and predict ML/ARD and to determine material handling procedures. Justify these indices by site-specific prediction data. Where indices are used from other geographical areas, provide supporting evidence (i.e., the raw data where possible).

Overburden

- Identify the various overburden layers and their relationship to the deposit, including volumes, distribution, potential usage, and ML/ARD potential. Quantify available NP sources and whether there is a portion chemically and/or physically unavailable under the expected development conditions.

Waste Rock

- Characterize waste rock to be exposed in terms of ML/ARD potential, mineralogy, waste rock generation and mine sequencing, mitigation strategies, disposal options, and the ability for long-term closure of the site. Include the rationale and details for all proposed waste rock disposal options.
- Accurately define the waste units in terms of day-to-day practical management (e.g., bench heights or equipment sizing may be the limiting factors for effective material segregation). The intent is to quantify practical material segregation and handling programs and generate management scenarios that are achievable over both the short- and long-term. During operations, an on-site sampling program may be necessary to assist the day-to-day material handling.
- Describe operational systems to be used for materials handling at the mine site as well as how these systems will be implemented.

Ore Characterization

The characterization of ore and low-grade ore is important for several reasons. These include understanding the requirements for surface stock-piling and the effect economics may have in changing the mine plan, which in turn may impact the material exposed for oxidation on the surface, in the pit, and in the underground developments. It may also have an impact on drainage water quality as well as dusting and spillage. The various on-site ore stockpiles are to be assessed in terms of:

- static and kinetic tests to predict the time to onset and severity of oxidation;
- predictions about the volume and quality of stockpile runoff;
- the impact of stockpile runoff on the tailings supernatant, pit water quality, or other areas of contact, storage, or diversion;
- ability to mill the ore after oxidation processes have occurred;
- the impact on closure planning in the event that milling is not an option;
- operational plans for the collection and containment of the runoff; and
- contingency plans for the permanent disposal of un-milled ore.

Coal

Although there are many similarities between coal and other types of ore, there are also some unique challenges to be considered, especially in regard to mode of deposit formation and capacity for mining or segregating specific coal seams. Some of these unique information requirements include the following:

- Identification of coal seams that will be mined and which seams will be left behind, either in-pit or as waste. Include the volume and ML/ARD characteristics of non-mineable coal seams or remaining coal material along contacts. Evaluate their effects on the ML/ARD characteristics of the waste dump(s), discharge water quality, and possible handling and disposal scenarios.
- Evaluating options for special handling of coal seam cleanings (coal material left at contacts which is often pyritic). Describe the impacts on the tailings facility if the coal seam cleanings are to be separated and disposed of in the tailings impoundment.
- Potential impact on the ML/ARD potential of the waste dumps and discharge water quality of the coal waste unrecovered from the mined coal seams. Address different methods to practically reduce the coal loss (e.g., smooth bucket vs. toothed bucket to clean coal contacts) and identify any benefits that may be achieved regarding the ML/ARD potential of the waste dumps.
- On-site coal stockpiles, which are to be assessed in terms of:
    - static and kinetic tests to determine the time to onset and severity of oxidation and its impacts on drainage chemistry,
    - an assessment of the volume and quality of the runoff,
    - the impact of runoff on the tailings supernatant water quality, pit water quality, or receiving environment,

- the ability to clean the coal after oxidation processes have occurred,
- the impact on the closure plan in the event that coal cannot be processed,
- operational plans for the collection and containment of the drainage, and
- contingency plans for the permanent disposal of any remnant stockpiled coal.

Tailings Management Facility

Tailings management facilities may be solely for the storage of tailings or may be a combined tailings/waste rock repository. If the latter, there are significant potential consequences in terms of impoundment size, water balance requirements, supernatant chemistry, and discharge concerns. Information to be collected for the tailings management facility include the following:

- Design details for the tailings/waste rock impoundment(s) for the range of all possible production rates (storage volume, water cover requirements, etc.). Include preliminary engineering designs for the tailings impoundment's construction, material availability, sourcing, and characterization.
- Tailings characterization in terms of static and kinetic ARD prediction tests, neutral metal leaching, mineralogy, particle size, sulphide content, and other parameters as appropriate based on the milling processes and reagents used.
- Expected location, rates, and quality of seepage from the tailings impoundment as well as proposed mitigation strategies. Groundwater evaluations will also comprise a component of baseline and on-going studies. Note that if a fish-bearing water body is proposed to be part of a tailings management facility, a significant federal process is required.
- Characterization of the expected tailings supernatant quality and how that predicted quality may change over time, both operationally and post-closure.
- A detailed water balance. In this assessment, include inputs (retained water content, precipitation, groundwater sources, etc.) and outputs (overflow, seepage, evaporation, etc.) and consider water cover requirements during operation and post-closure.
- Characterization of cyclone tailing sands material if proposed for dam construction. Include geochemistry, mineralogy, static and kinetic test work, leachability, drainage characteristics, and effluent toxicity. Test results must demonstrate the degree and consistency to which sulphides will be removed from the construction sands.

Backfill Material

Material to be used in backfilling mine workings (underground or open pit) require geochemical characterization and leach tests to assess the potential for contaminant loading from the backfill proper or contribution to increasing leaching from other areas of the mine. For example, in the event that cyanide has been used in the milling process, cyanide destruction may be required prior to the materials' use as backfill.

Dump Construction

- Include construction profiles for each proposed waste dump or stockpile illustrating current topography, construction technique, operational considerations, and final dump height and configuration.
- Provide detailed design specifications (volume, thickness, frequency, source, etc.) for any intermediate and/or final till caps, if proposed.
- Describe dump material composition, predicted drainage quality and quantity, mitigation measures, dump configuration, and dump hydrology. Include drainage collection and the separation of dump surface run-off from dump seepage as a component of the overall mitigation strategy.
- Assess drainage characteristics, cover performance, and dump stability (e.g., hydraulic conductivity, particle size, etc.) where overburden may be either covered by mine waste or conversely used as cover material to reduce in-flow and enable reclamation.
- Include sources, characterization, and economics of any off-site neutralizing materials, if required.

Construction Material

- Mine development material (tailings, waste rock, overburden, etc.) to be used for infrastructure construction (e.g., roads, tailings impoundment, berms, pipe bedding, external dam shells, etc.) must be geochemically characterized (ARD/ML test work) and defined in terms of required volumes, sourcing locations, physical test characterizations, drainage quality, and materials handling/scheduling plans.

Hydrology Considerations

In conjunction with Chapters 3 (Meteorology), 4 (Hydrology), and 5 (Hydrogeology), the following information is required specifically in the context of the proposed mine development:

- Detailed mapping, characterization, and understanding of the local and regional geology in order to understand, define, and quantify flows.
- A detailed water balance for the entire mine site. Include all surface watersheds draining the mine site, especially those watersheds expecting to receive effluent or seepage (e.g., mill, pit, tailings impoundment, and any other associated infrastructure). This assessment must consider the mine development and its impacts on the water balance (e.g., reclaim water, early closure). An evaluation of any large scale or significant withdrawal or diversion of water resources must be made, as reduced flows or groundwater levels may be limiting factors for the proposed project if requirements (i.e., water withdrawals) are significant.
- Seepage rates and predicted water quality as well as control and mitigation strategies for potential seepage sources (e.g., tailings impoundment, waste dumps, pit, etc.).
- The surface run-off rate, quality, control, and mitigation strategies for surface run-off from the various mine components (e.g., pits, waste rock dumps).

- Measures to separate clean and potentially contaminated drainage and to prevent erosion and sediment discharge during the construction, operation, and closure phases.
- Pit profiles illustrating the levels to which flooding may be achieved based on hydrology, backfilling (if applicable), in-pit contours, spill points, and structural considerations (faults). Include seasonal variability of flooding levels.
- An assessment of the likelihood of pit lake water-quality stratification and the possibility of sudden adverse changes to water quality in the event of seasonal turn-over.
- Identification of faults located in the pit and the extent of the faults beyond the confines of the pit. Assess the implications of these faults using information about the discharge of water from these fault zones (rates, quality, etc.), loss of drilling fluids into the faults during exploration, evidence of oxidation, physical characteristics of the fault material, and the size, width, and extent of the faults. Detail the surface extension of the faults as they relate to the completed pit development (e.g., where would the fault be on the pit floor or highwall and how does it relate to the in-pit water levels). Include an assessment of the hydraulic connection between the pit and any adjacent water bodies.
- Details on the additional water requirements necessary to maintain the tailings and waste rock permanently saturated. If exposure is expected, kinetic test results and other information must be used to determine an acceptable exposure period. In addition, identify source(s) of additional water. In situations where there will be long-term submergence of the tailings and waste rock, assess potential seepage and the resultant potential impacts on groundwater.
- A detailed assessment and prediction for all site water discharges. This assessment must include volumes, water quality, discharge structures and location, potential impacts on the receiving environment, and a description of any treatment processes. Describe contingency plans for excessive run-off events and drought conditions.

Collection and Treatment

As described in the *Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (MEM and MELP, 1998), a proposal for collection and treatment must demonstrate the following:

- Collection and treatment is an acceptable and viable long-term land use for the site.
- Preventative methods have been examined and are determined to be technically unachievable.
- The collection system will be capable of collecting all drainage as required from both surficial and groundwater sources.
- Detailed information is provided on collection capability (liners, etc.), treatment system design, sludge handling, sludge storage, sludge stability, lime procurement, and all required maintenance and monitoring. This assessment is to include reasonable median- and worst-case inflow and outflow predictions of water quality and contaminant loadings.

- The treatment system will enable the mine to achieve discharge and receiving environment requirements.
- Material segregation, covers, and diversion systems are used to the degree possible to minimize the amount of contaminated drainage that requires handling.
- Land-based or subaqueous deposition of treatment sludge is both physically and geochemically secure.
- Impacts on post-closure land use objectives from the collection and treatment of contaminated drainage and the creation of treatment sludge have been determined.
- A collection system can be constructed and operated in a manner that ensures there is minimal risk (i.e., likelihood of occurrence and consequences) to the environment, and the system can be maintained for as long as is necessary. The supportive evidence must include detailed engineering and economic analyses, including consideration of relevant biological factors and a comprehensive risk management plan to show that environmental values will not be jeopardized. This analysis must include consideration of possible failure mechanisms and their consequences and back-up protection commensurate to the potential for failure and the risk to the environment.
- The costs and resources required to build and operate collection, treatment, and sludge disposal systems (including post-closure operating, monitoring, and maintenance costs) are included.

General Reporting Requirements

The proponent must submit a mine plan that considers all of the information collected to produce a materials handling plan for the minimal impact on the receiving environment. Differentiate the various lithologies in terms of geology, alteration, ML/ARD predictions, and defined management units (e.g., waste, ore, low grade ore stockpiles, etc.). Define the relationship of mine sequencing with waste rock generation, ARD potential, mitigation strategies, and the ability for long-term closure of the site. Define factors that will determine the various options for the ongoing mine production rate (e.g., cut-off grade, price fluctuations, operating cost variables, etc.). Describe the resulting impacts on the project design from a range of production rates (e.g., ore volume, pit size, waste volume and handling, mine life, infrastructure construction, transport volume, impacts to the area, etc.), and evaluate these changes to potential impacts to the receiving environment.

Proponents must also ensure that submissions address the following:

- Ensure that all maps, figures, graphics, and tables are:
    - properly labelled,
    - provided with appropriate legends and scales, and
    - legible and of the appropriate size to display the information being illustrated.
- Include applicable units of measurement and use them consistently throughout the document.

- Provide raw data from the various monitoring programs, sample calculations showing methodologies, and the rationale for how the data were used to arrive at conclusions and recommendations.
- Interpret data results with comprehensive assessments and conclusions, and provide recommendations where applicable.
- Submit the document in a format that makes it readily reviewable, has information complete and readily accessible, and has full cross-referencing of themes among the main reports, appendices, and supporting technical documentation.
- Provide documentation that has been signed by the appropriate Qualified Professionals for each specific field of study.

Appendix 5. Examples of Formats for Presenting Water Quality Information

Graphical Format

Tabular Format

Total Molybdenum Concentrations (µg/L) - 2008								
	Site 01	Site 02	Site 03	Site 04	Site 05	Site 06	Site 07	Site 08
January								
February								
March								
April								
May								
June								
July								
August								
September								
October								
November								
December								
Data Summary								
No of Values								
No of Values <DL								
Maximum								
Minimum								
Mean								
Standard Deviation								
Median								

Appendix 6. BC MoE Sample Preservation and Holding Time Requirements

BC MOE SAMPLE PRESERVATION & HOLDING TIME REQUIREMENTS[1,2]					Version: 10-Feb-2011
Parameter Name	**Sample Container**	**Storage Temp[3]**	**Preservation**	**Holding Time[4] (days)**	**References**
Water					
Physical & Aggregate Properties					
Acidity	Plastic, Glass	≤6ºC	none	14	APHA
Alkalinity	Plastic, Glass	≤6ºC	none	14	APHA
Colour	Plastic, Glass	≤6ºC	none	3	APHA / BC MOE
pH	Plastic, Glass	≤6ºC	none	15 minutes	APHA
Solids (Total, TSS, DSS)	Plastic, Glass	≤6ºC	none	7	APHA
Conductivity	Plastic, Glass	≤6ºC	none	28	APHA
Turbidity	Plastic, Glass	≤6ºC	store in dark	3	APHA / BC MOE
Inorganic Non-metallics					
Bromide	Plastic, Glass	no requirement	none	28	EPA 300.1
Chloride	Plastic, Glass	no requirement	none	28	APHA / EPA 300.1
Chlorate, Bromate	Plastic, Glass	≤6ºC	50 mg/L EDA	28	EPA 317.0
Chlorine, Total Residual (Free Chlorine)	Plastic, Glass	none	none	15 minutes	APHA
Chlorite	Plastic, Amber Glass	≤6ºC	50 mg/L EDA	14	EPA 317.0
Cyanide (SAD, WAD)	Plastic, Glass	≤6ºC	field NaOH, store in dark	14	APHA
			none	1	APHA
Dissolved Oxygen (Winkler Method)	Glass BOD bottle	≤6ºC	Winkler kit, store in dark	8 hours	APHA
Fluoride	Plastic	no requirement	none	28	APHA / EPA 300.1
Nitrogen, Nitrate + Nitrite	Plastic, Glass	≤6ºC	H2SO4	28	APHA
			none	3	BC MOE
Nitrogen, Ammonia	Plastic, Glass	≤6ºC	H2SO4	28	APHA
			none	3	BC MOE
Nitrogen, Nitrate	Plastic, Glass	≤6ºC, do not freeze	none	3	APHA / BC MOE
Nitrogen, Nitrite	Plastic, Glass	≤6ºC, do not freeze	none	3	APHA / BC MOE
Nitrogen, Total Kjeldahl	Plastic, Glass	≤6ºC	H2SO4	28	APHA
			none	3	BC MOE
Nitrogen, Total, Persulfate Method	Plastic, Glass	≤6ºC	H2SO4	28	APHA
			none	3	BC MOE
Nitrogen, Total, Combustion Method	Plastic, Glass	≤6ºC	HCl	28	APHA
			none	3	BC MOE
Phosphorus, Dissolved (Orthophosphate)	Plastic, Glass	≤6ºC	Filter (field or lab)	3	APHA / BC MOE
Phosphorus, Total Reactive (Orthophosphate)	Plastic, Glass	≤6ºC	none	3	APHA / BC MOE
Phosphorus, Total Dissolved	Plastic, Glass	≤6ºC	Filter, H2SO4	28	APHA
			none	3	BC MOE
Phosphorus, Total	Plastic, Glass	≤6ºC	H2SO4	28	APHA
			none	3	BC MOE
Silica, Reactive	Plastic	≤6ºC, do not freeze	none	28	APHA

Sulfate	Plastic, Glass	≤6ºC	none	28	APHA / SW846 Ch3 2007
Sulfide	Plastic, Glass	≤6ºC	ZnAc / NaOH to pH >9	7	APHA
Metals					
Hexavalent Chromium	Plastic, Glass	≤6ºC	1 mL 50% NaOH per 125 mL	30	EPA 1669
			none	1	APHA
Metals, Total	Plastic, Glass	no requirement	HNO3, field or lab (7)	180	APHA / EPA 200.2
Metals, Dissolved	Plastic, Glass	no requirement	field filter 0.45 um, HNO3 or lab filter & qualify (7)	180	APHA
Mercury, Total	Plastic, Glass	no requirement	HNO3, field or lab (7)	28	APHA
Mercury, Dissolved	Plastic, Glass	no requirement	field filter 0.45 um, HNO3, or lab filter & qualify (7)	28	APHA
Aggregate Organics					
Adsorbable Organic Halides (AOX)	Amber Glass	≤6ºC	HNO3, store in dark, sodium sulfite if chlorinated, collect with no headspace	14	APHA 5320 1997
Biochemical Oxygen Demand (BOD)	Plastic, Glass	≤6ºC, do not freeze	none	3	APHA / BC MOE
Carbonaceous Biochemical Oxygen Demand (CBOD)	Plastic, Glass	≤6ºC, do not freeze	none	3	APHA / BC MOE
Carbon, Dissolved Organic	Plastic, Glass	≤6ºC	Filter, H2SO4 or HCl	28	APHA
			none	3	BC MOE
Carbon, Dissolved Inorganic	Plastic, Glass	≤6ºC	Field Filter	14	APHA (alkalinity)
Carbon, Total Organic	Plastic, Glass	≤6ºC	H2SO4 or HCl	28	APHA
Carbon, Total Inorganic	Plastic, Glass	≤6ºC	none	14	APHA (alkalinity)
Chemical Oxygen Demand (COD)	Plastic, Glass	≤6ºC	H2SO4 (field or lab)	28	APHA
			none	3	BC MOE
Chlorophyll "A"	Filter	Filters: freeze	field filter, store in dark	Filters: 28	APHA
Phaeophytin	Filter	Filters: freeze	field filter, store in dark	Filters: 28	APHA
Surfactants (Methylene Blue Active Substances)	Plastic, Glass	≤6ºC	none	3	APHA / BC MOE
Total Phenols (4AAP)	Plastic, Glass	≤6ºC	H2SO4	28	APHA
Extractable Hydrocarbons					
Extractable Hydrocarbons (LEPH, HEPH, EPH)	Amber Glass	≤6ºC	HCl, H2SO4 or Sodium Bisulfate	14 / 40	EPA 3511
			none	7 / 40	SW846 Ch4 2007
Oil and Grease / Mineral Oil and Grease	Amber Glass	≤6ºC	HCl or H2SO4	28	EPA 40CFR 2007
Waste Oil Content	Amber Glass	≤6ºC	none	28	BC MOE
Individual Organic Compounds					
Carbamate Pesticides	Amber Glass	≤6ºC	Potassium Dihydrogen Citrate (solid), ~pH 3.8, 9.2-9.5 g/L, + 100 mg/L Na2S2O3 if chlorinated	28	EPA 531.2, APHA 6610B 2004

			ChlorAC buffer, ~pH 3, 1.8mL / 60 mL sample, + 100 mg/L Na2S2O3 if chlorinated	28	EPA 531.1
Chlorinated and Non-chlorinated Phenolics	Amber Glass	≤6ºC	0.5g Ascorbic Acid / L + (H2SO4 or Sodium Bisulfate)	14 / 40	Alberta Env AE130
			none	7 / 40	SW846 Ch4 2007
Dioxins / Furans	Amber Glass	≤6ºC	none	unlimited	SW846 Ch4 2007
Glyphosate / AMPA	Amber Glass or Polypropylene	≤6ºC	100 mg/L Na2S2O3 if chlorinated	14	APHA 6651B 2000
Halogenated Hydrocarbons (Semi-Volatile)	Amber Glass	≤6ºC	100 mg/L Na2S2O3 if chlorinated	7 / 40	SW846 Ch4 2007
Herbicides, Acid Extractable	Amber Glass	≤6ºC	HCl (optional), store in dark, 50 mg/L Na2SO3 if chlorinated	14 / 21	APHA 6640A 2001 APHA 6640A 1994
Paraquat / Diquat	Amber Plastic (protect from light)	≤6ºC	100 mg/L Na2S2O3 if chlorinated	7 / 21	EPA 549.2
Pesticides (NP, OP, OC)	Amber Glass	≤6ºC	none	7 / 40	SW846 Ch4 2007
Polychlorinated Biphenyls (PCBs)	Amber Glass	≤6ºC	none	unlimited	SW846 Ch4 2007
Polycyclic Aromatic Hydrocarbons (PAHs)	Amber Glass	≤6ºC	HCl, H2SO4, or Sodium Bisulfate	14 / 40	EPA 3511
			none	7 / 40	SW846 Ch4 2007
Resin Acids, Fatty Acids	Amber Glass	≤6ºC	(0.5g Ascorbic Acid + 0.4g NaOH) / L	14 / 40	Alberta Env AE129
			none	7 / 40	SW846 Ch4 2007
Volatile Organic Compounds (Trihalomethanes)	43mLGlass VOC Vials (2-3)	≤6ºC	3 mg Na2S2O3 (see BC Lab Manual method for more details)	14	BC MOE
Volatile Organic Compounds (VOC, BTEX,VH)	43mL Glass VOC Vials (2-3)	≤6ºC	200 mg NaHSO4, or 3 mg Na2S2O3 if chlorinated (see BC Lab Manual method for other options and details)	14	BC MOE
Microbiological Parameters					
Coliforms, Total, Fecal, and Ecoli	Sterile Glass or Plastic	<8ºC, do not freeze	Na2S2O3	30 hours(5)	BC CDC / APHA 9060B 2006
Cryptosporidium, Giardia	Sterile Glass or Plastic	<8ºC, do not freeze	Na2S2O3	96 hours	EPA 1623 / APHA 9060B 2006
Enterococcus	Sterile Glass or Plastic	<8ºC, do not freeze	Na2S2O3	30 hours(5)	APHA 9060B 2006
Heterotrophic Plate Count	Sterile Glass or Plastic	<8ºC, do not freeze	Na2S2O3	24 hours	APHA 9215 2004
Toxicity					
Daphnia, Chronic 21day / Chronic EC25	Plastic, Glass (non-toxic)	4±2ºC	collect with no headspace	5	EC EPS 1/RM/14 & 11
Daphnia, LC50 / LT50	Plastic, Glass (non-toxic)	4±2ºC	collect with no headspace	5	EC EPS 1/RM/14 & 11
Microtox	Plastic, Glass (non-toxic)	4±2ºC	collect with no headspace	3	EC EPS 1/RM/24
Trout, LC50	Plastic, Glass (non-toxic)	4±2ºC	collect with no headspace	5	EC EPS 1/RM/13 & 9
Trout, LT50	Plastic, Glass (non-toxic)	4±2ºC	collect with no headspace	5	EC EPS 1/RM/13 & 9

Soil and Sediment					
Inorganics					
Bromide / Chloride / Fluoride	Plastic, Glass	≤6ºC	none	unlimited	Carter (Table 4.1)
Cyanide (WAD / SAD)	Plastic, Glass	≤6ºC	store in dark, field moist	14	SW846 Ch3 2007
Hexavalent Chromium	Plastic, Glass	≤6ºC	store field moist	30 / 7	SW846 Ch3 2007 / EPA 3060A
Metals, Total	Plastic, Glass	no requirement	none	180	SW846 Ch3 2007
Mercury, Total	Plastic, Glass	no requirement	none	28	SW846 Ch3 2007
Moisture	Plastic, Glass	≤6ºC	none	14	Puget Sound Protocols
pH	Plastic, Glass	≤6ºC	none	365	Carter
Sulfide	Plastic, Glass	≤6ºC	store field moist	7	Puget Sound Protocols
TCLP - Mercury	Plastic, Glass	no requirement	none	28 / 28	EPA 1311
TCLP - Metals	Plastic, Glass	no requirement	none	180 / 180	EPA 1311
Organics					
Carbons (TC, TOC)	Plastic, Glass	≤6ºC	none	28	SW846 Ch4 2007
	Plastic, Glass	no requirement	dried state	unlimited	Carter (Table 4.1)
Chlorinated and Non-chlorinated phenolics	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
Dioxins / Furans	Glass	≤6ºC	none	unlimited	SW846 Ch4 2007
Extractable Hydrocarbons (LEPH, HEPH, EPH)	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
Glycols	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
Herbicides, Acid Extractable	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
Oil and Grease / Mineral Oil and Grease / Waste Oil Content	Glass	≤6ºC	none	28	SW846 Ch3 2007, Puget Sound Protocols
Pesticides (NP, OP, OC)	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
Polychlorinated Biphenyls (PCBs)	Glass	≤6ºC	none	unlimited	SW846 Ch4 2007
Polycyclic Aromatic Hydrocarbons (PAHs)	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
Resin Acids, Fatty Acids	Glass	≤6ºC	none	14 / 40	SW846 Ch4 2007
TCLP - Volatile Organic Compounds	Glass	≤6ºC	none	14 / 14	EPA 1311
TCLP - Semi-Volatile Organic Compounds	Glass	≤6ºC	none	14 / 40	EPA 1311
Volatile Organic Compounds (VOC, BTEX, VH, THM)	Glass	≤6ºC	none	7(6) / 40	CCME / BC MOE
Biota					
Inorganics					
Metals, Total	Plastic, Glass	freeze (≤ -18C)	none	2 years	Puget Sound Protocols
Mercury, Total	Plastic, Glass	freeze (≤ -18C)	none	180	NOAA 131.01
Organics					
Semi-Volatile Organic Compounds	Glass, Teflon	freeze (≤ -18C)	none	365 / 40	Puget Sound Protocols
Volatile Organic Compounds	Glass, Teflon	freeze (≤ -18C)	none	14	Puget Sound Protocols

Air (Vapours)					
VOCs by Canister Sampling	SS canister	ambient	none	30	EPA TO15
VOCs by Thermal Desorption	thermal desorption tube	≤6ºC	none	30	EPA TO17
VOCs and other Volatile Substances by Charcoal and Miscellaneous Collection Media	see BC Lab Manual Method	≤6ºC (or as specified by applicable reference method)	none	30	see BC Lab Manual Method

[1] A Director or an Environmental Management Act permit may specify alternate requirements.
[2] Refer to applicable BC Environmental Laboratory Manual methods for additional detail. Where differences exist between Lab Manual methods and this table, this table takes precedence.
[3] Storage temperature applies to storage at the laboratory. For all tests where refrigeration at ≤6°C is required at the laboratory, samples should be packed with ice or cold packs to maintain a temperature of ≤10°C during transport to the laboratory. The storage of ≤8°C for microbiological samples applies during storage at the laboratory and during transport to the laboratory. To prevent breakage, water samples stored in glass should not be frozen. Except where indicated by "do not freeze", test results need not be qualified for frozen samples.
[4] Hold Times: Single values refer to hold time from sampling to analysis. Where 2 values are separated by a "/", the first is hold time from sampling to extraction, and the second is hold time from extraction to analysis.

[5] Samples received from remote locations more than 48 hours after collection must not be tested.
[6] Methanol extraction or freezing must be initiated within 48 hours of arrival at lab, to a maximum of 7 days from sample collection. Alternatively, samples may be frozen the field if extracted within 14 days of sampling, or may be methanol extracted in the field.
[7] If not field preserved, water samples for metals analysis must be acidified at the lab in their original containers (within 14 days of sampling), then must equilibrate at least 16 hours prior to sub-sampling or analysis. This approach can also be applied to dissolved metals, but only if field filtered.

Appendix 7. MOE Protocol: Use of Field Turbidity to Assess the Effect of Well Development and Purging for Groundwater Quality Sample Collection

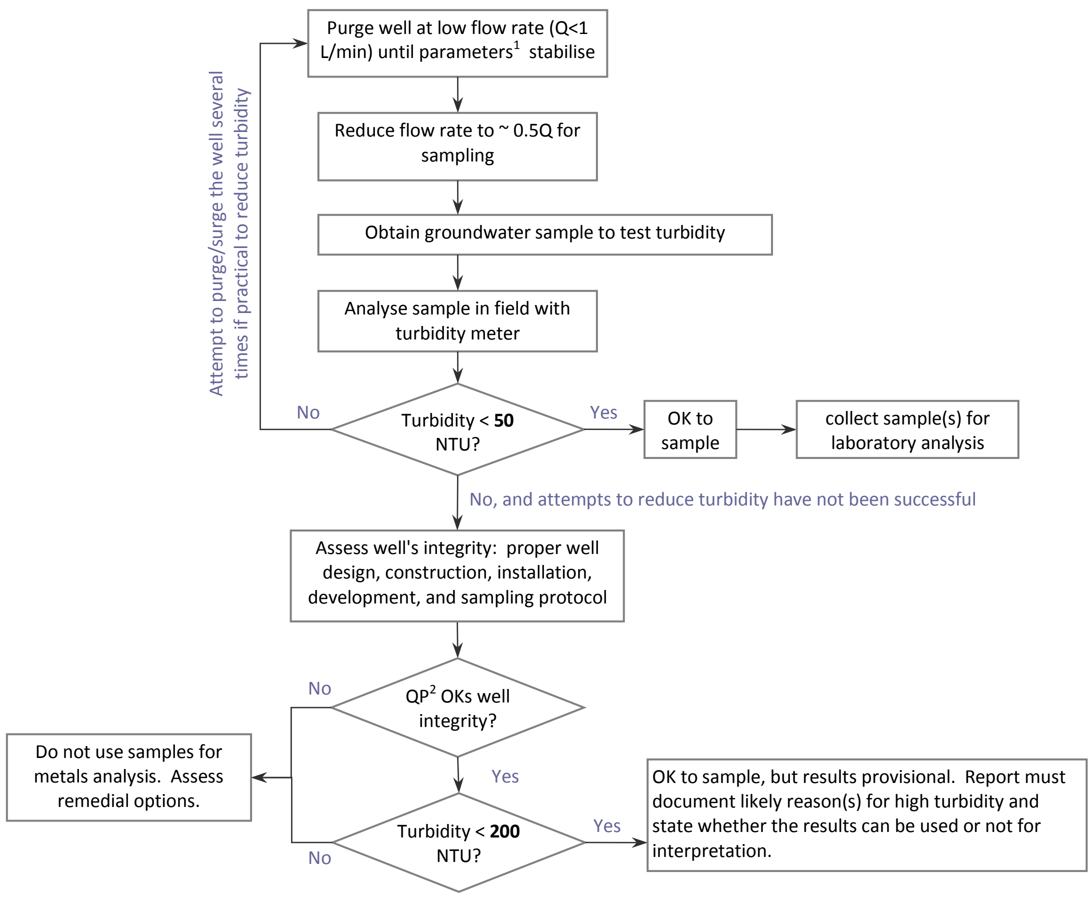
The MOE expects monitoring wells to be designed, constructed, and developed to a sand-free condition. Purging should be carried out at low flow rates to minimize disturbance. The use of a mechanical pump and not a bailer or hand pump is recommended at all times and is mandatory if field turbidity exceeds 50 NTU. Sampling must be carried out at lower flow rates than purging, typically at less than 1 L/min to minimize hydraulic stress and disturbance on the well and adjacent geologic formation. In situations where the well is completed in a low-permeability formation, it may be necessary to purge at very low flow rates (i.e., less than 100 mL/minute), taking care to avoid dewatering the well screen (Puls and Barcelona, 1996).

If sample turbidity as measured in the field is greater than 50 NTU, low-flow sampling techniques should be employed. The purpose of the low-flow sampling technique is the recovery of representative samples of water in the formation adjacent to the well screen. The technique is also called “low-stress” purging and sampling, as it does not cause excessive movement of water from the soil formation into the well. Ideally, the flow rate of water from the pump will approximate or be less than that entering the well from the surrounding formation.

If low-flow sampling techniques are unable to reduce turbidity to below 50 NTU, the well’s integrity should be evaluated by a Qualified Professional with expertise in hydrogeology prior to further sampling. If the turbidity is not due to faulty monitoring well design, construction, or development, but rather to the geology of the saturated zone (e.g., clay-rich glacial deposits and high natural flow rates), the well may be sampled and results submitted. However, the report must specify that groundwater quality data are provisional due to high turbidity, and the report should contain an assessment of the expected mobility of colloid-sized particles within the groundwater system.

The flow chart below summarizes this approach to ensuring that analytical metal concentrations in groundwater are reliable estimates for the purposes of regulatory decision-making.

Decision Flow Chart:
Acceptability of Groundwater Samples Collected for Metals Analysis

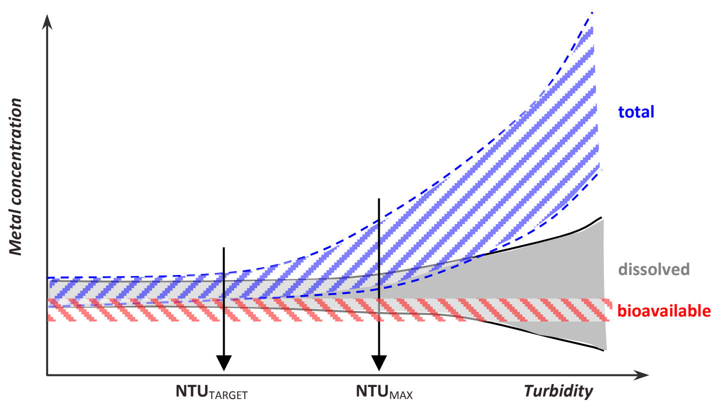


[1] Parameters that could be monitored in the field include specific conductance (electrical conductivity) or redox potential (ORP).
[2] QP = Qualified Professional with competence in hydrogeology

High turbidity in groundwater samples interferes with accurate characterization of the mobile and bioavailable (i.e., the proportion of total metals that are available for incorporation into biota) concentrations of trace metals in groundwater. If field turbidity exceeds the target (50 NTU), then a Qualified Professional (P.Eng. or P.Geo. with competence in hydrogeology) must assess the reasons for excessive turbidity.

At low levels of turbidity, the total concentration is approximately equal to the dissolved concentration, and either concentration will give a reasonable, conservative estimate of the bioavailable portion (i.e., total metal concentrations do not necessarily correspond with metal bioavailability), which is the information of real interest. As turbidity rises, normally due to poor well construction and development or excessive purging force, total and dissolved concentrations diverge. The portion measured as dissolved in the sample may exceed the true dissolved concentration if the constituent partitions from the turbidity-causing particles into solution, or it may underestimate the true dissolved concentration if the constituent partitions from the solution onto turbidity-causing particles. This concept is illustrated on the figure below.

Conceptual relationship between total, dissolved, and bioavailable metals.



The MOE sets a target upper bound of acceptable turbidity (e.g., 50 NTU) such that total and dissolved concentrations give reasonable, conservative estimates of bioavailability. In order to prevent excessive data loss, a maximum upper bound of turbidity may be established (e.g., 200 NTU) to allow provisional data to be collected from wells that may have justifiably high natural turbidity.

Although this protocol has been drafted in consideration of metals analysis only, high turbidity may also interfere with analysis for other parameters, so minimum turbidity is recommended for all analytical parameters.

Appendix 8. Hydrogeology Rationale

Government Mandate

The Government of British Columbia (BC) has primary jurisdiction over the management and protection of water, including groundwater in BC. The Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) and the Ministry of Environment (MOE) are the main agencies that share this provincial responsibility. Both agencies carry out activities that ensure the surface water and groundwater resources of British Columbia are safe, sustainable, and valued by all. MOE leads strategic and policy initiatives related to the groundwater resources, coordinates scientific studies, and through the *Environmental Management Act* works to prevent pollution and promote and restore environmental quality. MFLNRO leads operational functions, which include operating provincial groundwater networks, administering the *Water Act* and the *Ground Water Protection Regulation*, conducting groundwater assessments, and providing technical advice to decision makers.

MFLNRO is responsible for the administration of the *Water Act* in respect of groundwater, including the *Ground Water Protection Regulation* (GWPR). The objective of the GWPR is to protect the quantity and quality of the groundwater resource by:

- setting standards to safeguard and maintain the integrity and efficient use of the groundwater resource, and
- ensuring activities related to wells (including water wells, monitoring wells, geotechnical boreholes and others, but not oil and gas wells) and groundwater are undertaken in an environmentally safe manner.

MOE manages water quality to optimize the benefits and sustainability of the province's water resources for communities, the economy, and the environment. MOE regulates groundwater quality through the *Environmental Management Act* (EMA) and its several regulations, including the *Hazardous Waste Regulation* (HWR), *Waste Discharge Regulation* (WDR), and the *Contaminated Sites Regulation* (CSR). The objectives of EMA and its regulations are to use modern environmental management tools to protect human health and the quality of water in British Columbia and to enable the use of administrative penalties, orders, and legal and economic instruments to assist in achieving compliance.

Guiding Principles

The following principles guide MOE's and MFLNRO's groundwater policy with respect to environmental assessments (EAs) under the BC *Environmental Assessment Act* (EAA), in accordance with the above mandate. The footnotes provide additional clarification of these principles.

1. Status of the Resource

- By statute, the Crown owns all natural waters in the province, including groundwater.
- Groundwater is a valued resource in and of itself, and irrespective of existing use. It is not necessary to show *how* groundwater is *currently used* in order for it to be included

as a valued component[24] in an environmental assessment under the EAA; it is automatically included.

2. *Overall Assessment Methodology*

- **Scientific and in the public interest*:*** MOE supports science-based decision-making. Proponents are expected to meet or exceed current MOE guidelines and generally accepted industry best practices in groundwater assessment. All groundwater assessment programs should be designed, carried out, and reported under direct supervision of a **Qualified Professional** (professional engineer or geoscientist with competency in hydrogeology). This requirement is to uphold the public interest and promote professional accountability by ensuring that a reasonable standard of technical proficiency in groundwater assessments has been met and that the assessment holds paramount the safety, health, and welfare of the public and the protection of the environment.
- **Comprehensive*:*** The proponent must consider all potential impacts. Potential impacts must all be mitigated to an acceptable level and contingency measures must be technically feasible, economically achievable, and acceptable to MOE. The level of detail in the study should be comparable to a technical feasibility assessment or conceptual design. Detailed design for construction is not required, but the design must be sufficiently detailed to constrain uncertain impacts to a range or upper bound that allows reasonable decision-making by regulatory bodies. In particular, it must be possible to mitigate unexpected but possible effects to an acceptable level using technically proven, economically feasible, and socially acceptable technologies.
- **Temporal scope*:*** The assessment must cover all phases of the life cycle of a proposed mining project. In particular, the environmental assessment covers exploration, construction, operations, closure, and post-closure. It may be difficult to accurately predict long-term impacts, but in principle, the proponent is responsible for significant project effects on an indefinite time scale. In practice, the time scale will usually be limited based on the *contaminating lifespan* of the project. The contaminating lifespan continues until the date when the residual project effects (on-site or off-site) are reduced in magnitude to the point where they are no longer judged significant by the permitting agency.
- **Spatial scope*:*** The assessment must cover the entire area that may be adversely affected by impacts to groundwater that arise due to the proposed mining project. There is no minimum threshold for identifying effects. All effects should be identified and their potential significance assessed at least *qualitatively*. It is natural and appropriate that *quantitative* assessment will focus on the most significant anticipated effects.
- **Integrated*:*** Project proponents are encouraged to assess and monitor groundwater and surface water holistically as an integrated resource in relation to activities both on the

[24] EAO guidelines require only Valued Ecosystem Components (VECs) to be included in the summary of project impacts.

land surface and underground. Diversion and use of either groundwater or surface water could affect the quantity and quality of the other. Nearly all surface water features (e.g., streams, lakes, reservoirs, springs, wetlands, estuaries, etc.) interact with groundwater. Effective land and water management requires a clear understanding of the linkages between groundwater and surface water as it applies to any given hydrological or geological setting.

- **Situational**: Regional data may supplement, but not replace, site-specific data. Hydrogeologic systems are often heterogeneous, limiting the usefulness of regional groundwater data.

3. Resource Characterization

- Baseline resource characterization is the responsibility of the project proponent. Groundwater resource characterization includes, but is not limited to, determining hydraulic properties of aquifer units and hydraulic head measurements to support:
  - development of a site water budget,
  - identification and characterization of the groundwater flow system, including flux, time of travel, function, and quality, and
  - identification of surface water–groundwater interaction, including recharge/discharge areas.
- The accuracy and level of detail of the assessment will, in part, be determined by specific site characteristics and the scope and nature of the proposed mining project.

4. Stewardship of Groundwater Quantity[25]

- Groundwater should, in principle, be allocated to beneficial uses. Mining project proponents need to acknowledge that other competing uses of groundwater are legitimate. Groundwater also commonly supplies base flow integral to the proper functioning of freshwater aquatic ecosystems. The project proponent should present evidence that mining is a beneficial use of groundwater in the area and that the use of groundwater for mining will not interfere unduly with other uses of the resource.
- Proponents may divert and use groundwater in compliance with all legislation and in consideration of both existing and reasonably expected future users. A proponent's use of groundwater must be reasonably forecasted and a quantitative assessment made of the impact of this use on the resource itself (aquifer), base flow in streams, users of surface water that is hydraulically connected to the groundwater, and other existing or reasonably expected future users of the resource.

5. Protection of Groundwater Quality

- Resource development should be protective of all existing or reasonably expected future uses of groundwater. Protecting the most sensitive potential use preserves

[25] Quantity includes both water levels and groundwater flow.

options for flexibility in future resource decisions, consistent with the precautionary principle.

- Water quality guidelines depend on water use. Unless other evidence is provided, drinking water use and freshwater aquatic life are assumed to be default uses of groundwater, whether existing or reasonably expected in the future. Drinking water is a default groundwater use wherever human habitation is possible, unless there is no useable aquifer below or downgradient of the mine site. *Freshwater aquatic life* is present in most groundwater discharge areas. Typically, groundwater discharge from a mine site will not be the only source of water in streams or wetlands, and so allowance may be made for naturally occurring processes of mixing, dilution, and aeration as they occur at the project site.
- The mining project must not result in a significant adverse impact to groundwater or surface water quality (i.e., no measurable toxicity in the water column) at any time in areas outside the initial dilution zone (this zone will need to be identified on a site-specific basis). The following will be taken to constitute significant adverse impacts:
    - *Substances in groundwater* exceeding the standards set out in the *Contaminated Sites Regulation* for drinking water use and freshwater and marine aquatic life use. The drinking water standard will not apply to substances for which the background groundwater concentration exceeds the applicable standard.
    - *Substances in surface water* exceeding established water quality concentration guidelines (or site-specific objectives) for protection of aquatic life.
- Reasonable use of groundwater with respect to water quality requires consideration of background water quality and both existing and reasonably expected future contaminant sources. A single facility will not by default be allowed to exploit 100% of the assimilative capacity (i.e., the difference between existing background concentrations and the maximum concentrations suggested by water quality guidelines) of the groundwater resource, as this could unfairly limit opportunities for future development.

6. Uncertainty Analysis

- In the absence of data, MOE takes a conservative approach. Proponents are expected to make reasonably conservative, science-based assumptions regarding all variable hydrogeologic processes and parameters. The use of conservative assumptions supports upper-bound impact predictions.
- The proponent needs to consider and assess seasonal variations and long-term trends in water level and groundwater quality, because water quality objectives must be met at all times, including during summer and winter low flows when dilution is minimal.
- The proponent is responsible for collecting all required data for a thorough groundwater assessment. Particular attention should be paid to identifying and acquiring critical

missing and incomplete data (gaps) that are needed to assess the impact(s) of the proposed mine.

- Range estimates of hydrogeologic parameters and outputs are preferred over point estimates. Where there is sufficient information to define the underlying probability distribution for conventional statistical analysis, a central 90 % confidence interval should be calculated as a definition of the range. Where project data is insufficient to define the probability distribution, Monte Carlo simulation or conservative estimates (e.g., published ranges) may be used with caution. Lack of data can only justify expanding, never contracting, uncertainty bounds.

Appendix 9. Fish Tissue Collection Program

		Collected or Analyzed	Sample Size	Size Mean	Size SD	Reps per Site	(mm)	Mean Length (mm)	SD (mm)	Mean Length (mm)	SD (mm)	(g)	Mean Weight (g)	SD (g)	Mean Weight (g)	SD (g)
CCG	Bill's Ck	2005	8	5.5	1.9	4	48	49.4	4.4	60.2	10.3	0.9	1.1	0.4	2.6	1.7
							50					1.4				
							52					1.2				
							43					0.5				
							51					1.2				
							43					0.7				
							55					1.4				
							53					1.6				
CCG	Bill's Ck	2005	4				67	68.0	0.8			4.0	3.6	0.6		
							68					2.7				
							68					3.8				
							69					3.8				
CCG	Bill's Ck	2005	4				73	74.8	2.9			4.5	5.3	1.2		
							73					4.8				
							74					4.6				
							79					7.1				
CCG	Bill's Ck	2005	6				56	59.8	3.2			1.7	2.3	0.4		
							56					2.4				
							60					2.2				
							63					2.9				
							61					2.1				
							63					2.6				
CCG	Wichcika Ck	2005	2	6	3.0	6	77	78	1.4	60.7	11.7	4.6	5.1	0.7	2.6	1.9
							79					5.6				
CCG	Wichcika Ck	2005	7				61	61.3	1.1			2.5	2.3	0.4		
							60					2.2				
							60					2.1				
							63					2.7				
							61					2.2				
							62					1.7				
							62					2.8				
CCG	Wichcika Ck	2005	8				55	56.8	1.7			1.6	1.9	0.2		
							56					1.7				
							57					2.0				
							57					2.1				
							58					1.8				
							58					2.0				
							59					2.0				
							54					1.6				
CCG	Wichcika Ck	2005	6				70	68	1.7			4.1	3.4	0.7		
							69					4.3				
							68					2.3				
							69					3.4				
							66					3.1				
							66					3.3				
CCG	Wichcika Ck	2005	3				83	86.3	3.1			6.3	7.5	1.3		
							87					7.2				
							89					8.9				
CCG	Wichcika Ck	2005	10				42	47.8	2.7			0.8	1.1	0.2		
							46					0.9				
							47					0.9				

Appendix 10. Sampling Site Tracking Table

GLITTERING MOUNTAIN BASELINE MONITORING PROGRAM ***Date: March 2008***

SAMPLE LOCATION	GEOGRAPHIC CO-ORDINATES & DATUM	MONITORING PARAMETERS	BASELINE FREQUENCY	EXPECTED DURATION	SAMPLING RATIONALE
CREEK 1					
Site 1 - DISCONTINUED	55.54785ºN 127.23456ºW NAD83	Water chemistry			This site is now under the proposed tailings impoundment.
Site 2 - Control site 200 m upstream of proposed tailings pond	55.54872ºN 127.23486ºW NAD83	Water chemistry	1x/m, weekly for 5 wks. during spring run-off, fall run-off, (summer low flows)	Baseline, operation and post-closure	One of several main u/s inputs to Creek 1. Sited u/s of proposed tailings impoundment and u/s of diversion channel. This is a control site.
		Periphyton, Benthic invertebrates	Once per year - late August	Baseline, operation and post-closure	
Site 3 - 100 m downstream of proposed tailings pond at upstream of road crossing.	55.54900ºN 127.24123ºW NAD83	Water chemistry	See site 2	Baseline, operation and post-closure	Initially as a baseline site for Creek 1, this station will assess the immediate d/s impacts of discharges from the tailings/seepage ponds.
CREEK 2					
Site 3 - Located at base of 1m waterfall	55.55900ºN 127.45907ºW NAD83	Metals in fish muscle tissue - sculpins	Once	Baseline, operation and post-closure	Concern about metals building up in fish
LAKE 1					
Site L-1 Deep Station - Surface, 10m and bottom	55.54963ºN 127.45907ºW NAD83	Water chemistry, secchi	Spring turnover, July.	Baseline, operation and post-closure	Lake is located 1.5 km downstream of proposed tailings pond and contains rainbow trout.
		Plankton	Once per year	Baseline, operation and post-closure	
		Metals in fish muscle tissue	Minimum once; depends on variability	Baseline, operation and post-closure	

GLITTERING MOUNTAIN BASELINE MONITORING PROGRAM   Date: March 2008

SAMPLE LOCATION	*GEOGRAPHIC CO-ORDINATES & DATUM*	*MONITORING PARAMETERS*	*BASELINE FREQUENCY*	*EXPECTED DURATION*	*SAMPLING RATIONALE*
CREEK 1					
Site 1 - DISCONTINUED	55.54785ºN 127.23456ºW NAD83	Water chemistry			This site is now under the proposed tailings impoundment.
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		Periphyton, Benthic invertebrates	Once per year - late August	Baseline, operation and post-closure	
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		Metals in fish muscle tissue	Minimum once; depends on variability	Baseline, operation and post-closure	