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AQUATIC ECOLOGICAL RISK ASSESSMENT

Report on the Sequential Analysis of Lines of Evidence for Risk from the Teck Cominco Smelter at Trail, BC

Submitted to:
Teck Metals Ltd.
25 Aldridge Avenue
P.O. Box 1000
Trail, British Columbia
V1R 4L8

REPORT

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Abstract

The Teck Cominco Metals Ltd. (now Teck Metals Ltd. but still referred to as Teck Cominco in this report, as the work reported herein was completed prior to the name change) Ecological Risk Assessment (ERA) was produced under the British Columbia Contaminated Sites Regulation (CSR). Teck Cominco elected to use a landscape perspective and to use the information to develop a risk-based Wide Area Remediation Plan. The aquatic risk assessment component of the ERA used a combination of laboratory and field-based studies of the major groups of aquatic life comprising the local food web. Interpretation of the findings was guided by a Sequential Analysis of Lines of Evidence (SALE) approach to characterize the degree of risk from smelter-related emissions. The overall approach, individual study plans and interim reports were reviewed by a Technical Advisory Committee (TAC), a Public Advisory Committee (PAC) and other external reviewers.

The ERA was guided by the agreed management goal that there will be “no unacceptable residual ecological risk from past or current smelter-related emissions.” Risk management objectives for the aquatic ERA were stated as:

- Minimize, now and in the future, smelter operation-related direct and indirect effects within the Area Of Interest (AOI) on the diversity of aquatic plant and animal communities in the Columbia River and its tributaries.
- Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on fish populations in the Columbia River and its tributaries.
- Prevent, now and in the future, smelter operation-related direct and indirect effects on threatened and endangered aquatic species in the AOI.

The aquatic AOI encompasses a 56-km section of the Columbia River and its tributaries from downstream of the Hugh Keenleyside Dam and Brilliant Dam on the Kootenay River, and Waneta Dam on the Pend d’Oreille River, to the International Boundary. The Hugh Keenleyside, Brilliant and Waneta dams are physical barriers to fish migration, providing natural upstream endpoints for the study. Numerous tributaries ranging from small intermittent first-order streams to fourth-order streams containing important fish habitat occur within the AOI. Five creeks within the AOI (Ryan, Hanna, Murphy, China and Bear creeks) and three reference creeks (Blueberry, Norns and Deer creeks) were chosen for the screening-level assessment.

Assessment Endpoints (AE) were defined for periphyton (attached algae) community composition; benthic invertebrate community composition; growth, condition, reproductive capability and population characteristics of the fish receptor species in the Columbia River; fish habitat quality in the Columbia River; fish habitat quality in the tributaries; presence, survival and reproductive success of white sturgeon in the Columbia River; and habitat quality for white sturgeon in the Columbia River.

The initial list of fish receptors (mountain whitefish, rainbow trout, walleye and white sturgeon, plus groups including suckers, sculpins, dace, chubs and redside shiner) was pared to mountain whitefish, white sturgeon and prickly sculpin. White sturgeon was chosen because it is a red-listed species in British Columbia, is highly valued by residents of the AOI and is the subject of intensive study under the White Sturgeon Recovery Initiative. Mountain whitefish was chosen as the representative large-bodied fish species on the basis of the availability of

historic and current data on fish health, the degree of exposure to metals of this predominately bottom-feeding species, its status as a member of the salmonid family (regarded as among the most sensitive fish species), and its status as the most abundant sport fish in the AOI. Data on metal concentrations in mountain whitefish, walleye, rainbow trout and largescale sucker confirmed that mountain whitefish have higher concentrations than the other two sport fish species (rainbow trout and walleye) and similar concentrations to the bottom-feeding largescale sucker. The only exception to this is mercury, which is present in higher concentrations in walleye. This is to be expected because mercury biomagnifies, unlike any of the other potential chemicals of concern (PCOC); therefore, its concentration increases with successive steps in the food chain. Prickly sculpin was selected because it is a small-bodied fish with a small home range (thus its exposure can be defined within relatively narrow spatial boundaries), and because of its role as a prey item for predatory fish, its abundance along the PCOC exposure gradient from upstream to downstream of the smelter, and the relative ease of collection. Amphibians are not included as they are the subject of a separate report on wetlands.

PCOC common to water and sediment in the mainstem of the Columbia River and its tributaries were: arsenic, cadmium, chromium, copper, lead, thallium and zinc. Mercury was identified as an additional PCOC for water; cobalt, iron and selenium were included as PCOC for tributaries; nickel and silver were included as PCOC for sediments. The PCOC list was derived using data from 1995 to 2001. Water quality data collected since 2001 have shown that cadmium, chromium, thallium and zinc concentrations continued to occasionally exceed water quality objectives.

Exposure pathways, including atmospheric deposition from smelter emissions in the waterway and historic slag discharge into the Columbia River, were represented in two site-specific conceptual models. These models addressed direct and indirect effect of PCOC as well as physical stresses related to slag deposits. Direct effects included toxicity related reductions in growth or survival of the different receptors. Indirect effects pertain to changes in habitat quality either through loss of or changes in the relative abundance of food resources or changes in the physical environment.

The Teck Cominco smelter is not the only source of stress to the aquatic environment in the AOI. A variety of land uses in the AOI produce point and non-point sources of chemical stressors (surface and groundwater flow as well as atmospheric deposition). In addition, physical stressors caused by habitat alteration or destruction occur as part of some land uses. Other sources include the Zellstoff Celgar pulp mill, flow regulation by the Hugh Keenleyside, Brilliant and Waneta dams, recreational fishing, fish management programs, linear developments (transmission corridors, roads and railroads), urban development, and agricultural land use.

Assessment of Risk to Aquatic Biota in the Tributaries of the Columbia River

Evaluations of water quality, sediment quality, periphyton, benthic invertebrates and fish habitat were completed as part of SALE. None of these lines provide strong evidence for metal-related risks to tributary systems. Because each of these lines indicates similar evidence of low risk from metals, there is confidence in the overall assessment of low risk from smelter-related emissions to tributary systems. Natural habitat variables are likely to be the primary determinant of periphyton and benthic invertebrate communities. Natural habitat features and anthropogenic barriers to fish movement appear to be primary factors influencing fish presence in the tributaries.

Assessment of Risk to Aquatic Biota in the Mainstem Columbia River

The SALE analysis indicated that the risk management objectives are being met for mountain whitefish and prickly sculpin in the AOI. Therefore, an evaluation of risk management options is not required for these receptors. Periodic evaluation of prickly sculpin health measures as well as population characteristics such as age/size distribution, catch-rate and population size upstream and downstream of the smelter would provide further assurance that the prickly sculpin population in the area immediately downstream of the smelter is not being affected by exposure to smelter-related stressors. There is no compelling argument for further monitoring or evaluation of large-bodied fish species in the AOI relative to direct risks from smelter-related stressors.

The SALE analysis indicated that the risk management objectives were not being met for periphyton in the near-field (New Bridge site) and the benthic invertebrate community at the Maglios and Waneta sites. Therefore, evaluation of risk management options is required for these sites. There are non smelter-related stressors in the vicinity of the New Bridge and Maglios sites. Additional data would help increase the understanding of the role of the non-smelter stressors. The role of slag in the sediment as a physical stressor versus the role of PCOC as chemical stressors may also require clarification at both sites in order to refine risk management options. The additional data could be obtained both from laboratory tests and field investigations. The temporal framework would be better understood with a quantitative evaluation of sediment transport and deposition mechanisms in the AOI; this evaluation would assist in the prediction of the length of time for the current slag deposits to be further transported and/or buried with natural sediment materials.

The risk management objective for white sturgeon is not being met; however, the causal link to the Teck Cominco smelter is weak. The current status of the white sturgeon in the AOI is likely to be due to cumulative effects from multiple stressors. The relative role of PCOC and slag deposition appears to be minor; however, there is uncertainty regarding this conclusion because of limited data. Continuing participation by Teck Cominco in the White Sturgeon Recovery Initiative appears to be the appropriate response to the current understanding of the situation.

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1.0 INTRODUCTION

1.1 Purpose

The Teck Cominco Metals Ltd. (now Teck Metals Ltd. but still referred to as Teck Cominco in this report, as the work reported herein was completed prior to the name change) Ecological Risk Assessment (ERA) is a landscape-perspective risk assessment conducted by Teck Cominco under the British Columbia Contaminated Sites Regulation (CSR) (B.C. Reg. 375/96, including amendments up to B.C. reg. 76/2005). Teck Cominco is aware that metal concentrations in environmental media (e.g., soil, sediment, water) surrounding its Trail smelter operations can exceed B.C. CSR standards. Because of the large area potentially affected by elevated metal concentrations, Teck Cominco has chosen to use a risk-based approach to develop a Wide Area Remediation Plan.

The purpose of the risk assessment is to determine the smelter-related risks to terrestrial and aquatic life in order to guide remediation that will achieve risk reduction. In order to achieve this purpose, the risk assessment addressed the following questions:

- are there, or could there be, ecological effects attributable to Teck Cominco's smelter operations?
- what is the magnitude of observed or predicted effects?
- how sure are we about our assessment? and
- how do we know when risks are acceptable?

Once the answers to these questions are developed, the risks are characterized and the assessment can then be used to help evaluate options for remediation. This is done by identifying the reduction in ecological risk achieved by each remediation option.

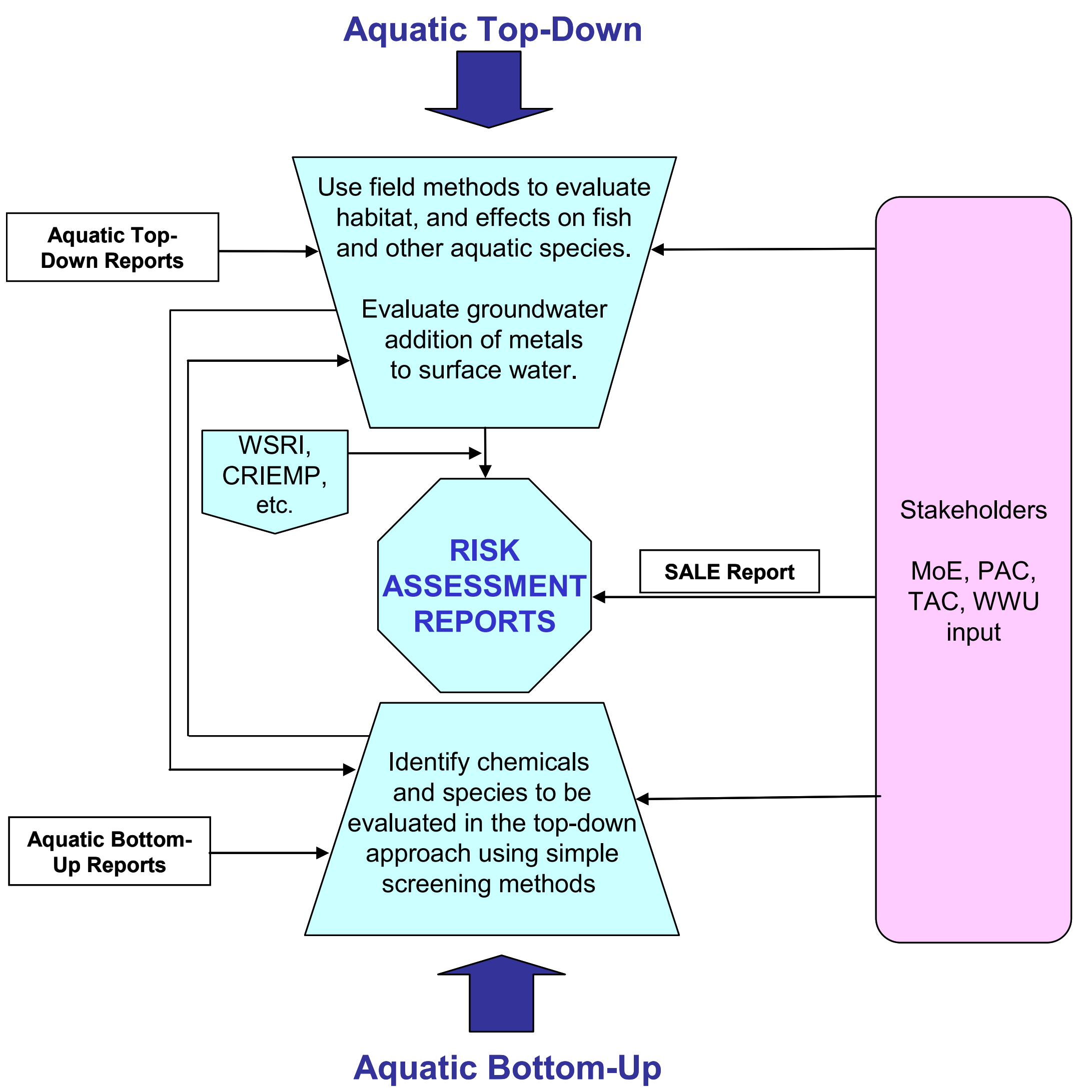
1.2 Overview of Approach

Landscape-perspective ecological risk assessment must consider endpoint-specific spatial and temporal scales. There are few such assessments as traditional chemical-by-chemical risk modelling methods were focused on distribution of chemicals often without regard for the relevant ecological scales defined by the valued ecological components. Therefore, the study team decided to use a weight-of-evidence (WOE) approach and incorporated both top-down and bottom-up lines of evidence (Figure 1.1). The aquatic risk assessment used a combination of laboratory and field-based studies of all major groups of aquatic life, from the bottom to the top of the food web. The details of these studies are presented in supporting documents (Golder 2007a, b, c, d). Studies reported in the supporting documents encompass more than one year of data (e.g., past years of fish survey data conducted for B.C. Hydro; monitoring data collected by Teck Cominco over a number of years; pilot studies conducted to refine the design of the 2003 field surveys). Thus, both the Problem Formulation and the subsequent risk analysis were based on multiple years of data.

A separate series of studies on groundwater was initiated in response to questions specific to the smelter site. The results of these studies to date show that groundwater pathways originating on site may contribute to localized aquatic ecological risks off-site. These studies will further define loads and area of potential local effects to biota. Future groundwater data will be used as input to remediation planning as and if appropriate.

The study team developed a sequential approach to the evaluation of the lines of evidence (called SALE for Sequential Analysis of Lines of Evidence). The SALE process is described below.

Figure 1.1 Overall Approach to the Aquatic Ecological Risk Assessment



WSRI - White Sturgeon Recovery Initiative; CRIEMP - Columbia River Integrated Environmental Monitoring Program; MoE - Ministry of the Environment; PAC - Public Advisory Committee; TAC - Technical Advisory Committee; WWU - Western Washington University.

The aquatic WOE approach addressed spatial issues by using a gradient study design; that is, a design that followed the responses of aquatic life from upstream to downstream in the Columbia River, as metal concentrations changed from upstream of the smelter to immediately below the smelter, to increasing distances downstream. The gradient approach also assisted with distinguishing responses to other stressors in the AOI.

Some of these stressors originate at other points in the system (e.g., the Zellstoff Celgar pulp mill discharge immediately downstream of the Hugh Keenleyside dam); therefore, the spatial pattern of responses of aquatic life to the pulp mill discharge would be expected to be shifted upstream relative to responses to the smelter. Other stressors are present throughout the AOI (e.g., flow regulation due to operation of dams); in this case, the responses of aquatic life would be expected to occur across the gradient of other stressors. Responses to stressors that occur in the same gradient as smelter-related stressors would be more difficult to distinguish. Stressors expected to occur in the same gradient as smelter-related stressors include those associated with treated sewage effluent and storm-water discharge from the City of Trail, as well as stressors present in tributary flow immediately upstream and downstream of the smelter (e.g., metals or nutrients originating from historic landfill areas and past operations of the Teck Cominco fertilizer plant).

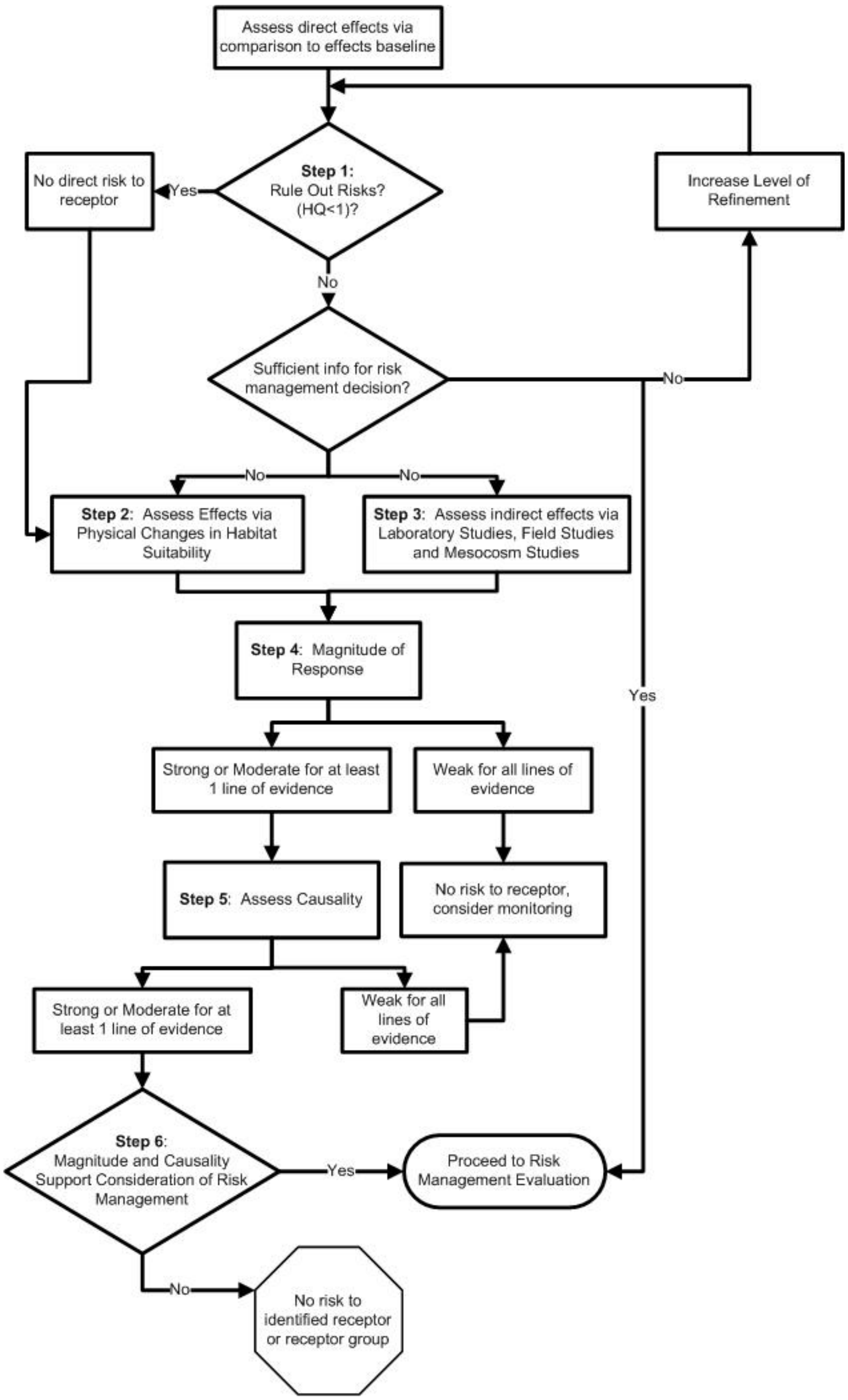
The gradient design in the tributaries to the Columbia River followed metal concentrations from the headwaters (with lower dilution, but also sometimes lower smelter-related atmospheric deposition) to downstream, close to the mouths in the Columbia (with greater dilution but higher smelter-related atmospheric deposition). Most tributaries also had other sources of stressors, e.g., former mining activity, roads, transmission corridors, agricultural land use and logging. These additional sources could confound the interpretation of any gradient in smelter-related metal deposition; therefore, the presence of any additional sources in each tributary watershed was noted and discussed relative to water and sediment quality, or responses observed in aquatic life.

The current practice of WOE analysis in ecological risk assessment has several important difficulties, including a lack of transparency related to how each line of evidence is weighted or integrated into the overall weight-of-evidence conclusion. Therefore, a SALE approach has been developed for this project (Hull and Swanson 2006; Figure 1.2). The sequential aspect of the SALE process is based upon two primary ideas.

First, risks can be ruled out using certain lines of evidence, including comparisons of water or sediment quality with conservative water or sediment quality guidelines or effects benchmarks. Thus, the SALE process recognizes that comparisons with guidelines or conservatively-derived effects benchmarks are most useful in ruling out risk rather than establishing unacceptable risk to ecological populations or communities. Second, the SALE process requires that each line of evidence where risks are not ruled out is assessed for three attributes: (1) the magnitude of effect; (2) the strength of the cause/effect link with the smelter; and (3) the uncertainty caused by natural variability plus our lack of knowledge about ecological processes. These three criteria are then used in the final characterization of risk from smelter-related emissions.

The SALE approach explicitly includes interaction between assessors and risk managers. It illustrates to risk managers how risk management can go beyond the simple derivation of risk-based concentrations of chemicals of concern in water or sediment to risk management goals based on ecological metrics (e.g., species diversity or fish health indices). It also can be used to stimulate discussion of the limitations of the science of ecological risk assessment, and how scientists deal with uncertainty. It should assist risk managers by allowing their decisions to be based on a sequential, flexible and transparent process that includes direct toxicity risks, indirect risks (via changes in habitat suitability), and the spatial and temporal factors that may influence the interpretation of results.

Figure 1.2 The Sequential Analysis of Lines of Evidence (SALE) Process for the Aquatic Ecological Risk Assessment



Several studies were conducted in the tributaries to evaluate consistency among the results and whether any of the results indicated a strong response to metal concentrations in water or sediment. The tributary assessment was a screening-level assessment designed to produce information for the first step of SALE. In this screening-level assessment, water and sediment samples were screened against water and sediment quality objectives as well as effects thresholds for aquatic biota. Additionally, a screening-level evaluation of the magnitude of responses noted in field-based lines of evidence was conducted for attached algae, benthic invertebrates and fish habitat.

1.3 Consultation and External Review

From the beginning, the Teck Cominco ERA included consultation with regulators and the public through two primary bodies, the Technical Advisory Committee (TAC), and the Public Advisory Committee (PAC). The PAC includes individuals who represent public groups such as regional tribal councils and environmental or wildlife organizations, as well as independent members of the public. The PAC is responsible for reviewing project work plans and reports and providing feedback and suggestions regarding valued ecosystem components, details of the ERA project process and public communication strategies. The PAC is also responsible for communicating information about the project (e.g., public meeting dates, availability of new project reports) to the groups that they may represent. The TAC includes individuals from the B.C. Ministry of the Environment and other agencies who have a stake in the project, in terms of resource management responsibility in the study area, or downstream in the Columbia River watershed. The TAC is responsible for reviewing project work plans and reports, and providing technical recommendations to the Ministry of Environment and thence to the management team of the projects. The TAC is also responsible for communicating project plans and progress with their agencies and their publics as appropriate.

In addition, an external review team on the ERA project, retained by Teck Cominco, is led by Professor Wayne Landis of Western Washington University (WWU). The external review team is responsible for:

- reviewing project work plans and reports and providing technical and process-related recommendations to the Management Team (copied to the Ministry of Environment);
- providing advice at the request of the Ministry of Environment to support the Ministry in its regulatory review role; and
- providing a summary assessment of the validity of the ERA project at public meetings.

Other methods for public participation and information sharing include an interim overall summary report, newspaper and electronic media articles, and the Teck Cominco web site.

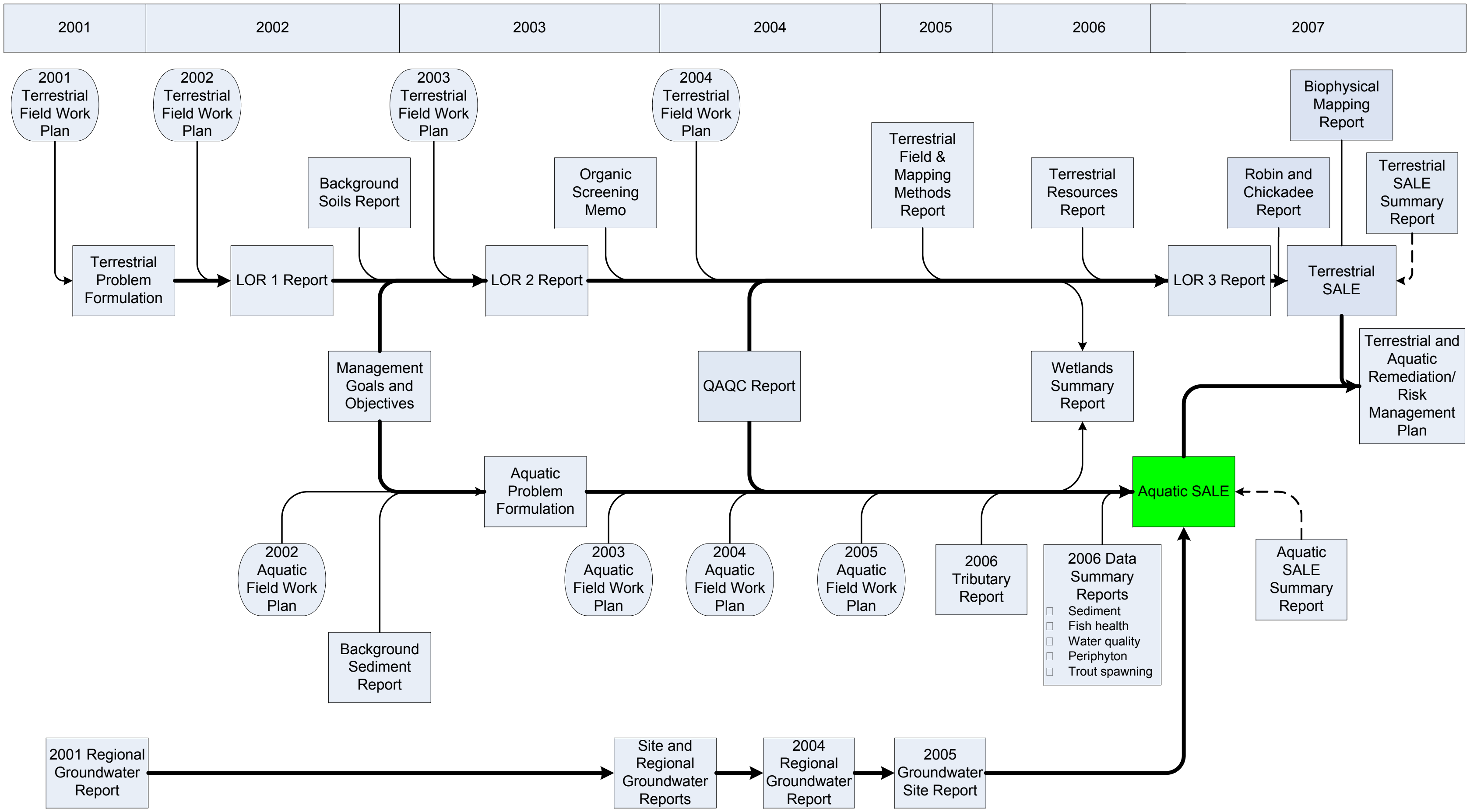
1.4 Organization of This Report

This report presents the ERA results for the mainstem Columbia River and its tributaries. The risk management goals, objectives, assessment endpoints and measures (lines of evidence) are presented in Chapter 2, which also includes a summary of the Problem Formulation (Golder 2003a). The risk assessment for tributaries to the Columbia River is presented in Chapter 3. The results of the SALE process for the mainstem Columbia River are presented in Chapter 4. The report ends with conclusions regarding the need for risk management in the tributaries and the mainstem Columbia River (Chapter 5).

The order of the chapters should not be interpreted to mean that the ERA proceeded in a linear fashion. As with all risk assessments, there were several iterations of goals, objectives and assessment endpoints as the study team developed a greater understanding of the possible connections between smelter-related emissions and responses in aquatic life. In addition, the selection of potential chemicals of concern (PCOC) and receptors (also called Valued Ecosystem Components) underwent change after consultation with the TAC and PAC. The conceptual model evolved from its original form in the Problem Formulation (Golder 2003a) to the one presented in this report in Chapter 2. The method for assembling and evaluating the lines of evidence into a weight-of-evidence evolved from published methods to the one developed and subsequently published by the study team (i.e., the SALE approach: Hull and Swanson 2006).

A large number of documents were produced as part of this risk assessment. To aid in understanding how this document “fits” with the other reports, a document map has been produced (Figure 1.3). The map highlights this document and where it contributes to the risk assessment process. The document map has been developed chronologically with two main, parallel pathways (terrestrial and aquatic) both converging with the development of a remediation plan. Several key documents link the two parallel processes and are shown between the terrestrial and aquatic pathways (i.e., the Management Goals and Objectives document, the QA/QC Report and the Wetlands Summary Report).

Figure 1.3 Ecological Risk Assessment Document Map



Notes: LOR = Level of Refinement; QAQC = Quality Assurance and Quality Control; SALE = Sequential Analysis of Lines of Evidence.

2.0 PROBLEM FORMULATION

2.1 Management Goal, Objectives, Assessment Endpoints and Measures

The approach used to develop management goals followed the guidance provided by the U.S. EPA (2001). The process led to the clear identification and articulation of management goals that can lead to decision-making; such clear identification is one of the most critical challenges for many ecological risk assessments (Landis and Weigers 1997; Obery and Landis 2002). The goals, objectives, assessment endpoints and measures were developed by the ERA team with input from the TAC and the PAC. They were reviewed and approved by the British Columbia Ministry of Environment (Harris pers. comm. 2006). A brief explanation of management goals, management objectives and assessment endpoints is presented below.

A management goal is a general statement about the trend toward or achievement of a desired future condition of ecological values of concern (U.S. EPA 1998). The U.S. EPA (1998) guidance indicates that management goals may result from regulations or laws, desired outcomes by the community and interests expressed by affected parties.

A management objective is a specific statement about the desired condition (or direction of preference) of ecological values of concern. The management objectives translate the more general management goal into more specific management objectives about what must occur in order for the goal to be achieved and to identify ecological values that can be measured or estimated in the ecosystem of concern (U.S. EPA 1998).

The development of management objectives can be very difficult because of the potential for a multitude of ecological values to emerge when the interests of stakeholders and the requirements of regulations are combined. These values often conflict. Therefore, the study team went to considerable effort to ensure that draft management objectives were reviewed and commented upon by the TAC and the external reviewer (Dr. Landis, WWU).

An assessment endpoint is an explicit expression of what is to be protected, defined by an ecological entity and its attributes. The “entity” can be a species (e.g., white sturgeon), a functional group (e.g., primary producers), a community (e.g., benthic invertebrates), an ecosystem (e.g., a river) or a valued habitat (e.g., sturgeon spawning areas). The attribute is the characteristic of the entity of concern that is important to protect and which is potentially at risk. Therefore, it is necessary to define what is important for the species (e.g., spawning or rearing habitat), the ecosystem (e.g., primary production) or valued habitat (e.g., flow velocity at the spawning ground).

The attributes of the assessment endpoint determine what is to be measured. For example, the spawning success of white sturgeon can be measured by the use of egg incubation trays placed at the spawning grounds. The primary production of attached algae can be measured either directly (e.g., through the use of carbon-14 uptake) or indirectly (e.g., through measurement of biomass). Although not always possible, it is best to select endpoints for which effects from both smelter and non-smelter related causes can be expressed in the same units (e.g., changes in the abundance of young fish from exposure to metals, fishing pressure and habitat loss) (U.S. EPA 1998).

Each line of evidence used in this ERA was evaluated in light of specific assessment endpoints. The measurement endpoints that were used are described later in this section and again as part of the two Conceptual Models for the ERA in Section 2.6.

2.1.1 Summary of the Decision Context

The risk management decision context is the Wide Area Remediation Plan under the B.C. Contaminated Sites Regulation. This ERA supplies input to that decision. The following provides a summary of the decision context:

- The decision to be made is the degree of remediation and other risk management required in the Columbia River and its tributaries between the Hugh Keenleyside Dam and the U.S. Border.
- The study area (called the Area of Interest [AOI]) is an area of the Columbia River and its tributaries from the Hugh Keenleyside Dam immediately upstream of Castlegar to the U.S. Border.
- The values held by the people affected by the decision are wide-ranging and varied; however, economic development, lifestyle, grass-roots participation and sustainability appear to have broad support.
- Relevant laws and regulations are the B.C. Contaminated Sites Regulation under the Environmental Management Act.
- Risk management options have not been finalized but will include remediation options. The options will be evaluated using a number of criteria including, but not limited to ecological risk.
- The temporal scope is the current condition and future risk resulting from 100+ years of operations at the Teck Cominco smelter at Trail. Although future use of the aquatic resources in the AOI is part of the risk management objective, the definition of “future” (i.e., the number of years into the future) and a description of planned or desired uses going into the future, have not been provided by regulatory agencies, local governments, or the public, except by implication via activities such as Water Use Planning and the Columbia River Integrated Environmental Monitoring Program (CRIEMP). Reports published by the Water Use Planning group and CRIEMP indicate an expectation that water and sediment quality should continue to improve, that fish habitat should be maintained or enhanced, and that current resource use would continue.
- Regulatory and public involvement is being achieved via the TAC, the PAC, general public meetings, regular newsletters, newspaper and electronic media articles, and the Teck Cominco web site.

This risk assessment was conducted to inform remediation planning. It did not assume that the most sensitive land use is the basis for planning across the whole AOI. Rather, it provided estimated risks for current uses of the water resources in the AOI. However, the assessment can also be used as a guide for assessment of future water resource uses. The risk assessment includes several assumptions regarding current water resource uses, as follows:

- Current water resource uses are recreational (e.g., fishing, boating), industrial (e.g., permitted discharges, hydropower production), agricultural (irrigation and livestock watering) and ecological (e.g., fish and wildlife habitat). Drinking water is another water use; however, this water use is relevant to human health risk assessment rather than ecological risk assessment.

- Current locations of water use are the basis for the assessment, and any current water use constraints related to Teck Cominco emissions in these locations will be addressed by the ultimate remedial plan.
- The current water resource uses reflect a consensus regarding ecological and socio-economic values in the AOI; future water resource uses will be the same as current uses (see above discussion of temporal scope).

2.1.2 Risk Management Goals, Objectives, Assessment Endpoints and Measures

The overall goal guiding the Teck Cominco Ecological Risk Assessment is:

> There will be no significant ecological impacts or constraints on desired land and water uses, in the AOI, related to past and present Teck Cominco smelter operations at Trail, B.C.

The risk management objectives for the aquatic ERA are as follows:

- Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on the diversity of aquatic plant and animal communities in the Columbia River and its tributaries.
- Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on fish populations in the Columbia River and its tributaries.
- Prevent, now and in the future, smelter operation-related direct and indirect effects on threatened and endangered aquatic species in the AOI.
- Definitions pertinent to the management objectives are provided below:
- *Minimize*: reduce ecological risks from smelter operations to levels that will protect aquatic populations and communities.
- *Prevent*: eliminate effects to individual aquatic organisms (as opposed to aquatic populations).
- *Smelter operation-related*: includes all air emissions and water effluent discharges from Teck Cominco Trail operations.
- *Future*: The timeframe over which the outputs from the smelter can reasonably be predicted; i.e., 10-20 years.

With regard to management objectives, “smelter operation-related direct and indirect effects within the AOI” refer to effects caused by stressors originating from the smelter that migrate outside of the Teck Cominco site. It was assumed that effects due to localized stressors (e.g., spills to ground on the site) would be confined to the site and mitigated, thereby preventing effects at a larger spatial scale. Nutrients from the former fertilizer operation were considered and discussed as part of the periphyton assessment but were not PCOC.

The definition of “minimize” begs an important question, “what level of risk will protect aquatic populations and communities?” The WOE approach is designed to answer this question by evaluating the magnitude of effects, the strength of the cause/effect link with smelter emissions, and uncertainty. Magnitude is judged by comparison with “critical effect sizes” established by Environment Canada’s guidance for interpreting monitoring measures in the national aquatic Environmental Effects Monitoring (EEM) Program (Environment Canada 2004). Causation is judged using causation criteria (Hull and Swanson 2006). Uncertainty is evaluated by examining the power of the study design to distinguish effects from natural variability, the adequacy of the information on confounding natural variables and other anthropogenic stressors, and a qualitative evaluation of our general level of ignorance about ecosystem structure and function. The combination of magnitude, causation and uncertainty will determine whether risks are minimal. For example:

- if magnitude of the response observed in the field or during toxicity tests does not exceed the critical effect size, and the strength of causation link with the smelter is weak and uncertainty is low, then risk is minimal;
- if the magnitude of the response exceeds the critical effect size but the causation link is weak and uncertainty is low then the risk is minimal; or
- if the magnitude of the response exceeds the critical effect size and the causation link is strong and the uncertainty is low-to-moderate, then some action may be required to minimize the risk.

The assessment endpoints and associated measures for each risk management objective are presented below.

Risk Management Objective #1: Minimize, now and in the future, smelter operation-related direct and indirect effects within the Area of Interest on the diversity of aquatic plant and animal communities in the Columbia River and its tributaries.

Assessment Endpoints

- periphyton (attached algae) community composition; and
- benthic invertebrate community composition.

Measures (Lines of Evidence)

The lines of evidence for the periphyton and benthic invertebrate communities are listed for the assessment of risks in the mainstem Columbia River as well as the tributaries (see parentheses after each line of evidence).

Periphyton Community

- metal concentrations in water compared to effects benchmarks derived from the literature (Columbia River and tributaries);
- periphyton community composition along a gradient from upstream to downstream (expressed as percent of total abundance for algal families) (Columbia River);
- total biomass (measured as chlorophyll *a* and ash-free dry weight [AFDW]) and total abundance along the upstream to downstream gradient (Columbia River and tributaries); and
- presence of metal-sensitive periphyton species (Columbia River).

Periphyton biomass (chlorophyll *a* and AFDW) supplements information on community composition by providing an indication of the amount of energy stored by periphyton that is available for consumption by higher trophic levels. It is important to measure effects on biomass because of the importance of periphyton as a food source. Reduced biomass of algae means less food for herbivorous invertebrates and fish. Effects on biomass can produce a “trophic cascade” of effects up the food chain. The concentration of PCOC may not have a direct effect upon higher trophic levels, but effects on periphyton biomass can produce indirect effects.

Benthic Invertebrate Community

- metal concentrations in water and sediment compared to effects benchmarks derived from the literature (Columbia River and tributaries);
- toxicity to *Chironomus tentans* (a midge species) in laboratory sediment toxicity tests (Columbia River);
- species richness, species evenness and species diversity along the upstream to downstream gradient (Columbia River and tributaries, though tributary data are qualitative because of the sampling method used);
- abundance along the upstream to downstream gradient (Columbia River and tributaries, though tributary data are qualitative because of the sampling method used); and
- presence of metal-sensitive benthic invertebrates (Columbia River).

Supporting information gathered concurrently with the above measures included: water temperature, dissolved oxygen, pH and hardness; light penetration; water velocity; water depth; substrate characteristics (such as % slag content); sediment particle size; and sediment organic carbon content.

Objective #2: Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on fish populations in the Columbia River and its tributaries.

Assessment Endpoints

- growth, condition and reproductive capability of the fish receptor species in the Columbia River;
- population characteristics of the fish receptor species in the Columbia River, including distribution within the AOI, relative abundance, and age or size distribution;
- fish habitat quality in the Columbia River; and
- fish habitat quality in the tributaries.

Measures (Lines of Evidence)

- metal concentrations in water and fish tissue compared to effects benchmarks derived from the literature (Columbia River);
- growth rates; condition factors; relative gonad size; relative liver size; fecundity; gross pathology and histopathology in mountain whitefish and prickly sculpin (Columbia River);
- laboratory fish toxicity test results (e.g., LC50s, EC50s) required under Teck Cominco's provincial licence to operate (Columbia River); and
- fish habitat quality for spawning, rearing, feeding, and over-wintering (Columbia River and tributaries).

Objective #3: Prevent, now and in the future, smelter operation-related direct and indirect effects on threatened and endangered wildlife and aquatic species in the AOI.

Assessment Endpoints

- presence, survival, and reproductive success of white sturgeon in the AOI; and

- habitat quality for white sturgeon in the AOI.

Measures (Lines of Evidence)

- white sturgeon presence and use of habitats in the AOI;
- mapped habitat suitability for white sturgeon;
- white Sturgeon Recovery Initiative information;
- metal concentrations in sturgeon tissue;
- incidence of deformities in the AOI;
- laboratory toxicity tests on juvenile white sturgeon; and
- genomics studies.

2.1.3 Supporting Information Relevant to the Risk Management Goals and Objectives

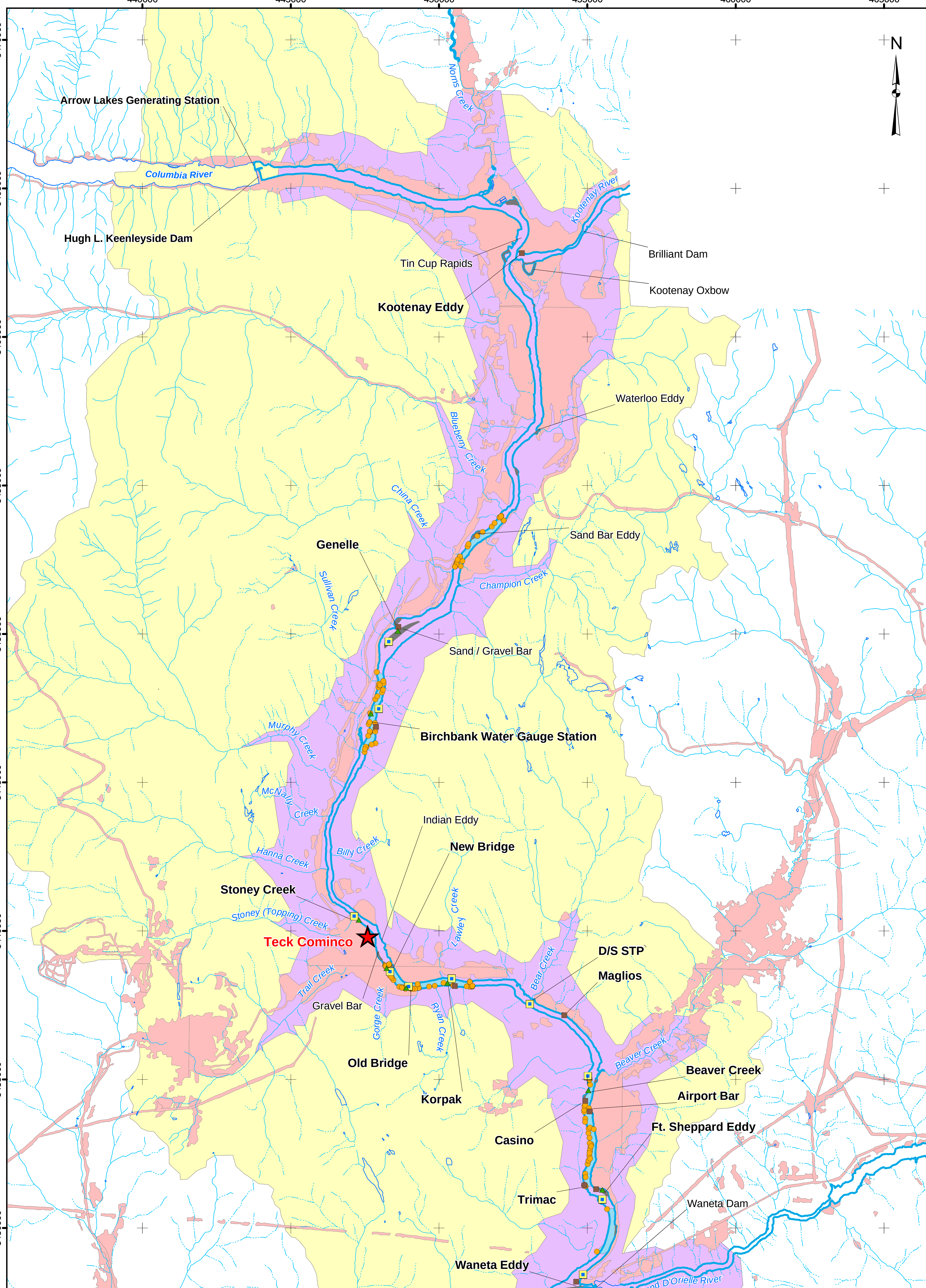
Several aquatic ecosystem initiatives already underway in the AOI provide supplementary information for this ERA. These initiatives include CRIEMP, the White Sturgeon Recovery Initiative, EEM requirements for the pulp and paper industry (required for the Zellstoff Celgar Ltd. pulp mill), monitoring under the Teck Cominco discharge permit, and the Water Use Planning process. Many, if not all, of the measures listed above have been measured under one or more of these initiatives. The ERA objectives, assessment endpoints and measures are amenable to being fully integrated into existing initiatives and the ERA results can be used to provide feedback to these initiatives.

2.2 Area of Interest

The aquatic AOI encompasses the Columbia River and its tributaries from downstream of the Hugh Keenleyside Dam, and Brilliant Dam on the Kootenay River, and Waneta Dam on the Pend d'Oreille River, to the International Boundary (Figure 2.1). This 56-km section of the Columbia River has also been used as the study area for several fisheries studies (Aquametrix 1994; Smith 1987; Norecol 1989; R.L. & L 1994, 1996, 1997a, b, 1998, 1999, 2000, 2001; Golder 2002a, b, 2003b, c, 2004a, b, 2005a, b). The Hugh Keenleyside, Brilliant and Waneta dams are physical barriers to fish migration, providing natural upstream endpoints for the study.

There are many tributaries to the Columbia River (Figure 2.2), ranging from small first order streams, often with intermittent flow (e.g., Billy 2 Creek) to third and fourth order streams containing important fish habitat (e.g., Blueberry Creek). All of these tributaries were included initially in the AOI; however, a short-list of tributaries was selected for risk assessment (see Chapter 4).

The initial dilution zone downstream of the smelter was considered to be part of the AOI, e.g., there was a periphyton sampling station within a few metres of the effluent diffuser. Therefore, risk assessment findings relative to the risk management goals include this zone. Sites located within the initial dilution zone during field studies encompassed the integration of responses to current as well as historic stressors (e.g., for sculpin).



LEGEND

- ELECTRO FISHING SITE
- PERIPHYTON SAMPLE
- SEDIMENT SAMPLE
- WATER SAMPLE
- LAKE OUTLINE
- RIVER
- STREAM (DEFINITE)
- STREAM (INTERMITTENT)
- DEVELOPED AREA
- 700 METRE ELEVATION AREA
- OCTOBER 2004 ELECTROFISHING STUDY AREA
- PROPOSED STUDY AREA
- SEDIMENT DEPOSITIONAL ZONE/ SAND AND SEDIMENT BAR

5 0 5

SCALE 1:125,000 KILOMETRES

REFERENCE

TRIM Data obtained from Teckcominco.
Datum: NAD 83 Projection: UTM Zone 11

PROJECT

teckcominco

TECKCOMINCO
AQUATIC ERA / TRAIL

TITLE

SAMPLING SITES ON THE COLUMBIA RIVER

Golder Associates
Calgary, Alberta

PROJECT No. 04-1335-025			SCALE AS SHOWN	REV. 1
DESIGN	MG	19 Oct. 2006	Figure 2.1	
GIS	VGV	30 Oct. 2006		
CHECK	MG	30 Oct 2006		
REVIEW				

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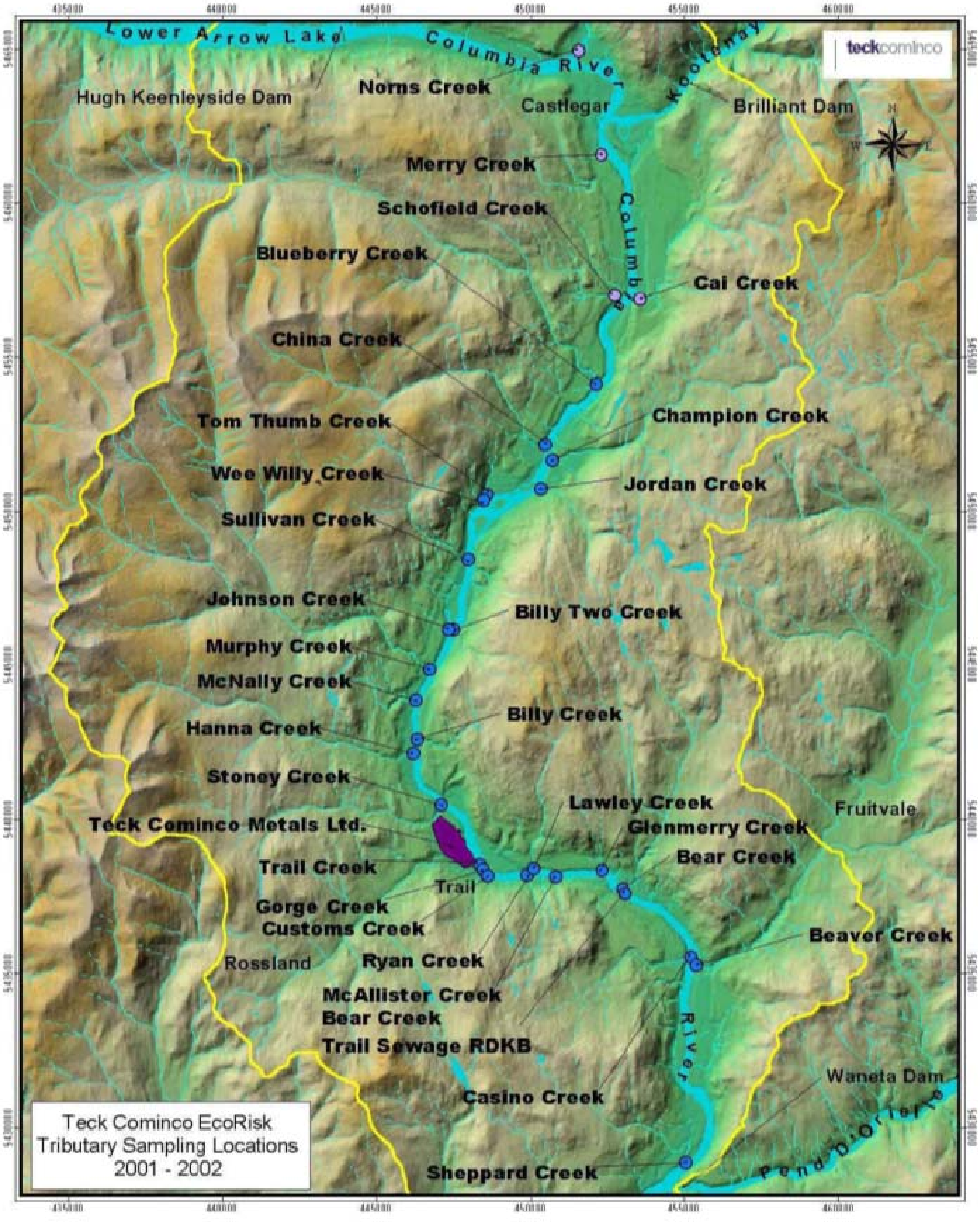
Figure 2.2 Tributaries to the Columbia River



The definition of an initial dilution zone varies within BC, ranging from 10-25% dilution over no more than 25-50% of river width (based on information available from MOE). Furthermore, the initial dilution zone cannot cause a blockage of river fish passage. The downstream distance of initial dilution zones vary from 100 m to more than 300 m. In the case of the Teck Cominco smelter, the initial dilution zone from "Combined II and III" outfalls can be assumed to extend to some point between the New Bridge and Old Bridge (depending upon flow) with attainment of water quality objectives at the Old Bridge. The lateral extent of the initial dilution zone can be assumed to be 25% of total river width (maximum), based on a dye study by Frew (1997). The water quality objectives attainment point for "Combined IV" outfall is in the nearshore zone of the Columbia River approximately 125 m downstream of the Stoney Creek mouth.

2.3 Potential Chemicals of Concern (PCOC)

The original Problem Formulation identified eight PCOC in water of the Columbia River, 12 in water of the tributaries and nine in sediment of the mainstem and tributaries, based upon screening against site-specific water quality objectives (B.C. MELP 2000) and the more conservative of the available sediment quality guidelines (CCME guidelines, the B.C. guidelines and proposed criteria, and the Lower Columbia River Objectives) (Tables 2.1 and 2.2). These PCOC were identified using data up to and including 2001.

Re-screening of more recent data (up to and including 2006) was conducted to examine whether the PCOC identified in the Problem Formulation continued to occur at concentrations that exceed water or sediment quality objectives. The results of this re-screening showed that cadmium, chromium, thallium and zinc concentrations continued to occasionally exceed water quality objectives. Details of the re-screening are presented in Chapter 4.

Table 2.1 PCOC in the Mainstem of Columbia River

Number	Water	Sediment
1	Arsenic	Arsenic
2	Cadmium*	Cadmium
3	Chromium	Chromium
4	Copper	Copper
5	Lead	Lead
6	Mercury	Nickel
7	Thallium	Thallium*
8	Zinc	Silver
9		Zinc

- Based upon higher concentrations at the downstream Waneta sampling station.

Table 2.2 PCOC in the Tributaries of the Columbia River

Number	Water	Sediment
1	Arsenic	Arsenic
2	Cadmium	Cadmium
3	Chromium	Chromium
4	Cobalt	Copper
5	Copper	Lead
6	Iron	Nickel
7	Lead	Thallium
8	Mercury	Silver
9	Selenium	Zinc
10	Silver	
11	Thallium	
12	Zinc	

2.4 Receptors of Concern

The original receptors of concern identified in the Problem Formulation report (Golder 2003a) were the periphyton community, benthic invertebrate community and fish. The fish receptors were:

- Sport fish
  - mountain whitefish;
  - rainbow trout;
  - walleye; and
  - white sturgeon.
- Forage fish guild
  - sucker group species;
  - sculpin group species (mottled sculpin, prickly sculpin, shorthead sculpin and torrent sculpin;
  - dace group species (longnose dace, Umatilla dace, speckled dace, leopard dace);
  - peamouth chub; and
  - redside shiner.

After further review and consultation, this list was reduced to mountain whitefish, white sturgeon and prickly sculpin. The number of fish receptor species was reduced for practical reasons, because the collection of detailed field data on fish health requires considerable time and effort. A more detailed explanation of the species selection process is provided below.

Mountain whitefish was chosen as the representative large-bodied fish species on the basis of the availability of historic and current data on fish health, the degree of exposure to metals of this predominately bottom-feeding species, its status as a member of the salmonid family (regarded as among the most sensitive fish species), its status as the most abundant sport fish in the AOI (and thus ease of capture along the gradient of exposure). Data on metal concentrations in mountain whitefish, walleye, rainbow trout and largescale sucker confirmed that mountain whitefish have higher concentrations than the other two sport fish species (rainbow trout and walleye) and similar concentrations to the bottom-feeding largescale sucker (Golder 2003a). The only exception to this is mercury, which is present in higher concentrations in walleye. This is to be expected because mercury can biomagnify up the food chain to humans, unlike any of the other PCOC. However, since mountain whitefish exposure to all other PCOC would be greater, mountain whitefish were determined to be the more appropriate receptor in terms of degree of exposure. Historical data on the health of mountain whitefish in the AOI confirmed its sensitivity to the range of stressors present in the Columbia River (Golder 2003a).

Prickly sculpin was chosen as the representative small-bodied fish species because of its small home range (thus making its exposure more site-specific), its bottom-feeding food habits and its known abundance in the study area (demonstrated by the Phase 1 field program in the spring of 2004), which allowed collection of the required sample size for statistical analysis.

White sturgeon was chosen because it is a red-listed species in British Columbia, it is listed under the Federal Species at Risk Act (SARA), and considerable public interest exists in the region for this species.

Amphibians were noted as a potential ecological receptor for the Columbia River; however, the relative sensitivity of the species present in the AOI was still under review at the time of publication of the aquatic Problem Formulation. Currently, a draft report on risks to aquatic and terrestrial biota using wetlands in the AOI has been prepared. Follow-up to this report will occur outside of the scope of the aquatic or terrestrial ERAs.

2.5 Pathways

The pathways of release of PCOC to the aquatic environment include the following:

- atmospheric deposition of PCOC produced in air emissions directly to the Columbia River;
- atmospheric deposition of PCOC to the watershed with subsequent surface water transport via tributaries;
- direct discharge of treated effluent; and
- groundwater transport.

Historic slag discharge was another pathway of release that ceased in 1995. The relative contribution of these pathways can be estimated by calculating loadings (Table 2.3).

Pathways of exposure of receptors to PCOC are direct exposure to water and sediments and water-based and sediment-based food chain transfer.

Table 2.3 Loadings Estimate from Pathways of Release of PCOC

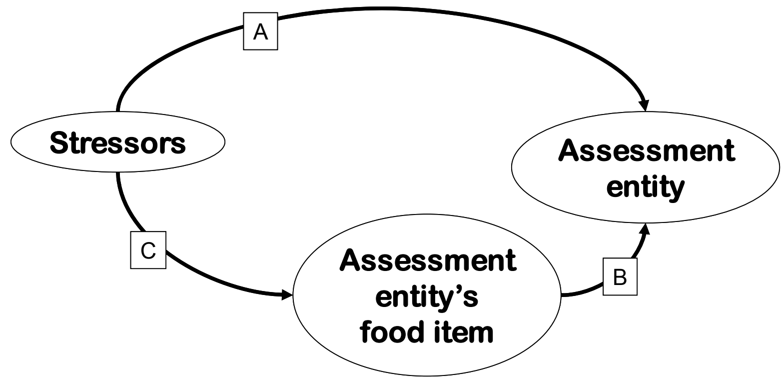
Location	Permit #	Discharge Description	Approximate Discharge (m^3/day)
Columbia R. Reach 1	PE 1272	Celgar Pulp Company – final industrial effluent	177,000
	PE 7622	Lion's Head Inn – secondary treated domestic effluent	20
	PE 80	City of Castlegar – treated effluent	2,728
	PE-5594	POPE & TALBOT LTD	>10
	PE 141	Selkirk College – secondary treated domestic effluent	536
Columbia R. Reach 2	PE 4008	City of Castlegar – secondary treated effluent	1600
Columbia R. Reach 3	PE 2753	Teck Cominco Effluents – industrial effluents	296,000 (74,000 effluent, 222,000 cooling water)
Columbia R. Reach 5	PE 274	Kootenay Regional District (Trail-Rossland) – secondary treated effluent	10,500
	PE 71	Village of Montrose – treated effluent	640
Beaver Creek	PE 133	Village of Fruitvale – treated effluent	910
	PE 2500	Village of Salmo – treated effluent	455
Kootenay River	PE-17354	Skanska-Chant Joint Venture (Brillant Dam)	14.5
Kootenay River	PE-11702	Kootenay Mobile Home Park	43.6

Source: BCMOE, Environment Protection, Nelson, B.C., November 2006.

2.6 Conceptual Models

Two conceptual models were developed for the current study because risks can result both from direct and indirect linkages between stressors and assessment entities (Figure 2.3). Assessment entities are the receptors (e.g., mountain whitefish) with their associated attributes (e.g., growth). The definition of assessment entity has been expanded in the current study to include habitat. For example, a stressor such as slag can act directly on habitat and then, in turn, on receptors. This is a departure from the standard practice of limiting assessment entities to receptor species. However, the inclusion of habitat as an entity allows the explicit assessment of the effects of both physical and chemical habitat alteration. Habitat alteration can have a much greater effect on receptors than direct chemical toxicity; however, standard risk assessment methods do not usually incorporate habitat-related effects (with the exception of including the role of habitat in determining exposure to chemicals).

Figure 2.3 Direct Versus Indirect Linkages Between Stressors and Assessment Endpoints

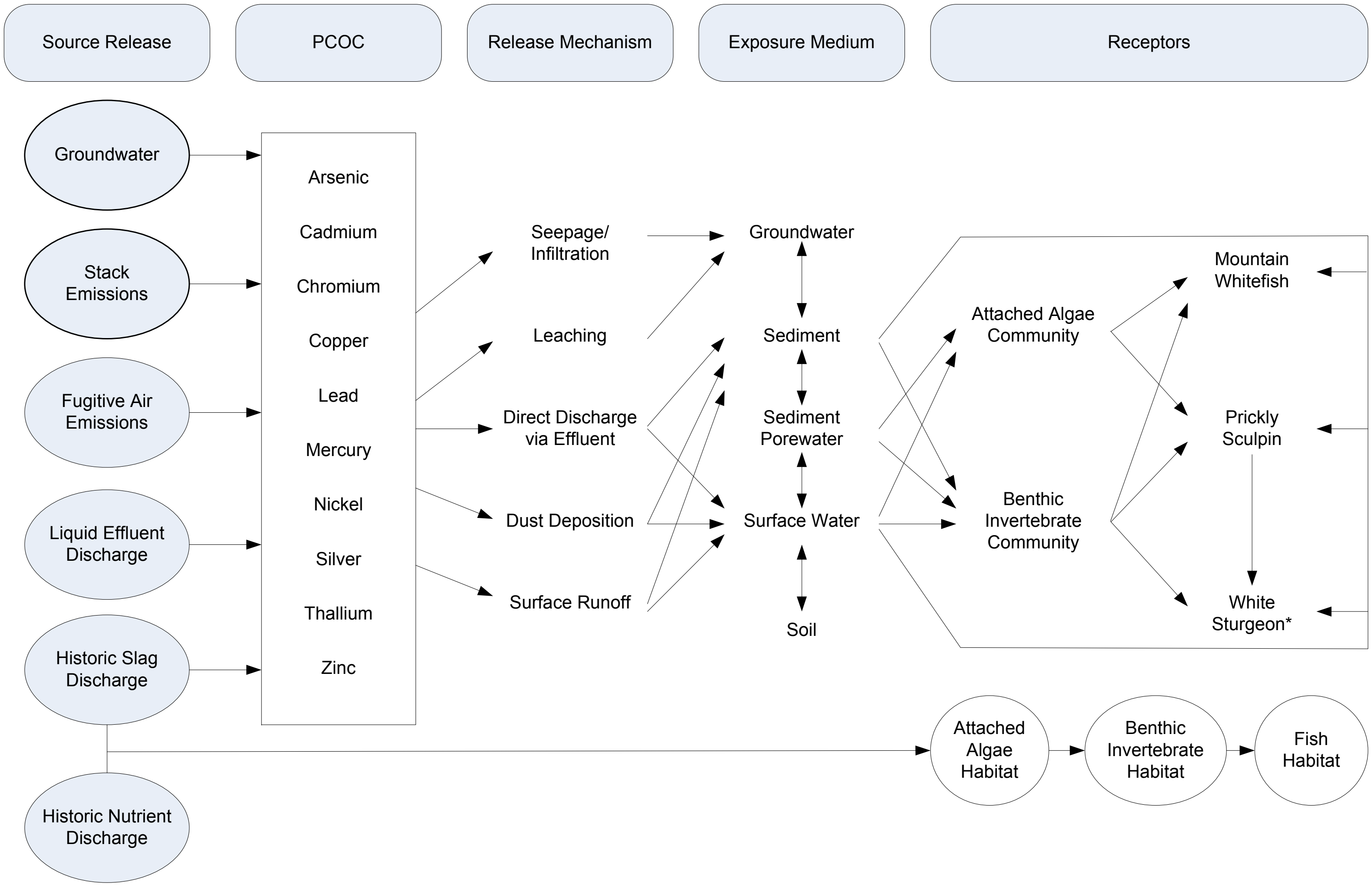


Note:
(A) Stressor goes directly to entity (e.g., direct contact).
(B) Chemical stressor reaches entity via food.
(C) Stressor impacts entity indirectly (e.g., loss of food causes starvation in entity; triggers disease).

Conceptual Model 1 (Figure 2.4) illustrates the direct linkages between stressors released by the Teck Cominco smelter and assessment entities. The model shows the sources of PCOC, plus the release of slag, which can be both a chemical and a physical stressor. Nutrients are included as an additional chemical stressor that historically was important regarding direct effects on periphyton and macrophytes and, in turn, on habitat for benthic invertebrates and fish.

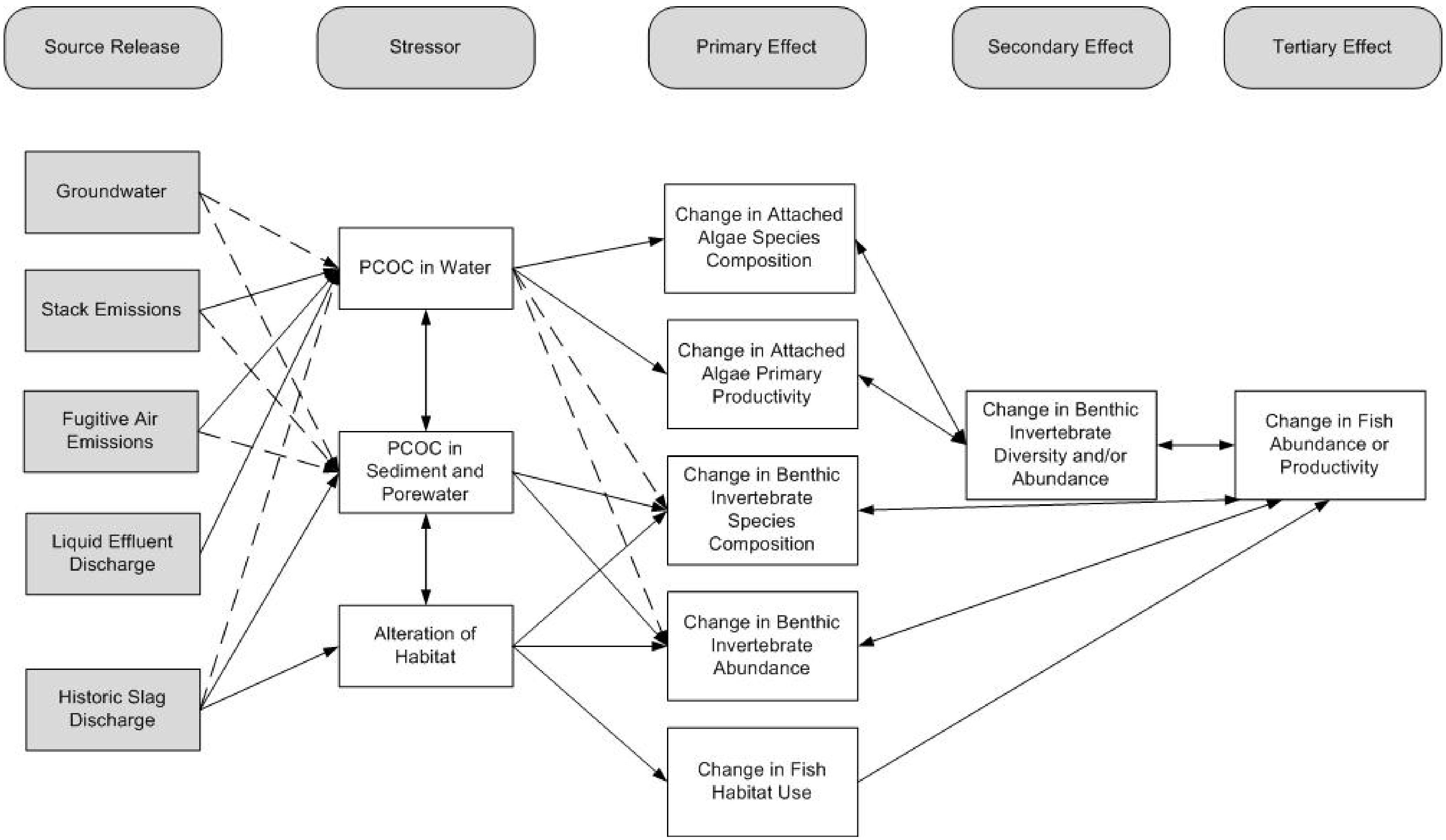
Conceptual Model 2 (Figure 2.5) illustrates the indirect linkages between stressors and assessment entities. Indirect effects can occur through so-called “trophic cascades”, which are effects mediated through interactions between consumer organisms and their food. These effects would include predator influences on lower trophic levels (top-down effects) and “bottom-up” effects through nutrient/food/prey influence on higher trophic levels (Fleeger et al. 2003). Strong top-down effects have been observed in studies of periphyton and benthic invertebrates when grazers were selectively affected by direct effects of metals (Jak et al*.* 1996). According to Fleeger et al*.* (2003), there is no evidence in the literature of bottom-up effects from metals; however, only seven of the studies reviewed by Fleeger et al. (2003) included metals as the stressor. Behavioural effects of contaminants can also produce indirect effects. For example, sediment-dwelling invertebrates may avoid burrowing in contaminated sediment, thus increasing their exposure to predation by a sediment-feeding fish (Hinkle-Conn et al*.* 1998). Metals may decrease decomposition or nutrient-release rates via direct effects on microbial populations; however, there are no studies that have tested this hypothesis (Fleeger et al. 2003).

Figure 2.4 Conceptual Model 1 of Direct Risks From Smelter-Related Releases of PCOC



Note: * Sturgeon are opportunistic feeders and eat live and dead fish, invertebrates and plants.

Figure 2.5 Conceptual Model 2 of Indirect Risks From Smelter-Related Emissions



Note Dotted lines - minor contributors to exposure or effects.

Conceptual Model 2 includes the effects of mixed stressors; i.e., all of the PCOC acting together, plus the potential combined effect of PCOC and habitat alteration. Unfortunately, very few studies have focused on the effects of mixed stressors on aquatic systems, and even fewer have considered the consequences relative to indirect effects (Fleeger et al*.* 2003). Therefore, multiple stressor impacts may be unpredictable at the community level.

2.6.1 Other Sources of Stress in the Area of Interest

The Teck Cominco smelter is not the only source of stress to the aquatic environment in the AOI. A variety of land uses in the AOI produce point and non-point sources of chemical stressors (surface and groundwater flow as well as atmospheric deposition) (Figure 2.6). In addition, physical stressors caused by habitat alteration or destruction occur as part of some land uses.

Other sources include the Zellstoff Celgar pulp mill, flow regulation by the Hugh Keenleyside, Brilliant and Waneta dams, recreational fishing, fish management programs, linear developments (transmission corridors, roads and railroads), urban development, and agricultural land use. These additional sources produce the following stressors:

- altered nutrient and dissolved gas concentrations;
- dioxin/furan and other chlorinated organic compound concentrations in water, sediments and fish tissue;
- altered flow regime (compared to natural flow regime prior to impoundments);
- altered water clarity due to upstream impoundments;
- physical fish habitat changes (e.g., bridge abutments, water intake structures, culverts, channel diversions or alterations, riparian habitat disturbances and sedimentation due to logging, agriculture or linear developments);
- altered mortality patterns caused by fishing pressure and by-catch; and
- introduced fish species (e.g., walleye).

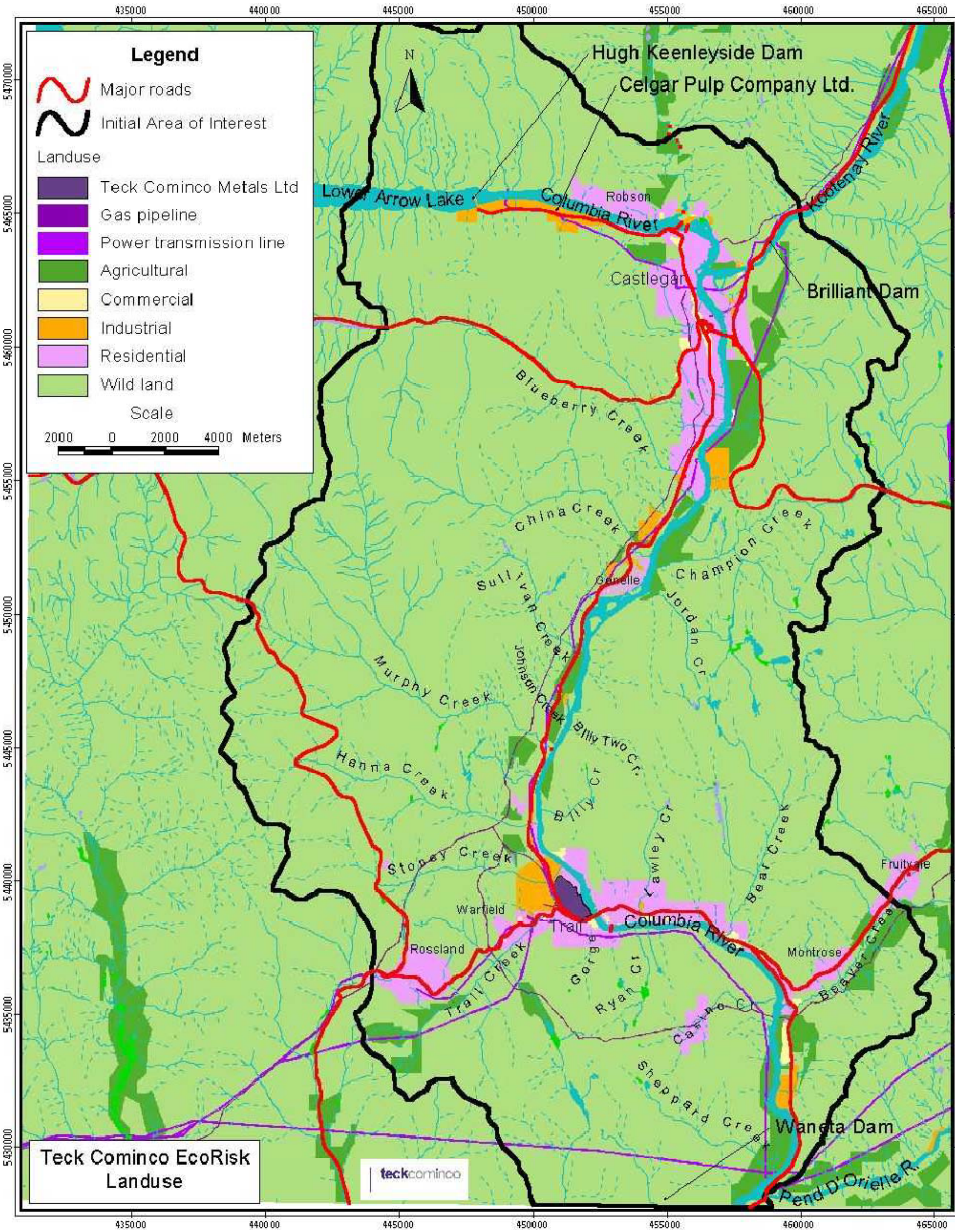
2.6.2 Uncertainty

There are four sources of uncertainty in this assessment:

- natural variability;
- model uncertainty;
- measurement error; and
- data errors.

Each of these potential sources of uncertainty was evaluated and rated for inclusion in the overall score for each line of evidence.

Figure 2.6 General Land Use



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Natural Variability

Natural variability exists in both the chemical concentrations measured within the AOI and in biological variability. Chemical concentrations vary spatially both vertically and horizontally, especially in sediments. The distribution and abundance of benthic invertebrates and fish vary seasonally and across locations, regardless of the presence of PCOC.

Variability in chemical concentrations was addressed in Step 1 of the SALE by using maximum observed concentrations in the entire water and sediment database. This level of conservatism was used because the purpose of Step 1 is to rule out risk from potential PCOC. The use of maximum concentrations provided confidence that potential PCOC that were screened out in Step 1 did not pose a risk to aquatic life.

Biological variability was addressed by using field study designs that complied with the requirements for statistical power established by Environment Canada in the national EEM Program. Statistical power is the ability to distinguish a particular level of effect from natural background variability (e.g., a 20% difference from upstream sites) (Golder 2007a, b, c). EEM guidance has been developed to ensure consistency across Canada for quantifying effects of pulp mills and metal mines on fish and invertebrates, and to achieve sound statistical design of field studies with an acceptable level of statistical power (Type I and II error rates of 0.1, with a corresponding level of power of 0.9). To achieve this, the EEM guidance document provides example study designs that incorporate the desired level of power, as well as power analysis methods for developing other study designs.

Biological variability was also addressed by using an upstream-to-downstream gradient design. Rivers have natural physical and chemical gradients upstream-to-downstream, producing natural variation in biota upstream versus downstream. The Teck Cominco smelter introduces an additional chemical gradient via its effluent discharge, and also via tributary and groundwater input (although this is very small relative to the effluent).

Seasonal variability in biological measurements was not addressed by the sampling program for this risk assessment. Instead, sampling was conducted at the same time of year (fall) as earlier studies. This helped make the evaluation of year-to-year trends less prone to be confounded by seasonal differences; however, it did not account for year-to-year variability in seasonal variables that affect biota (e.g., water temperature and flow).

The SALE process required a score for uncertainty for each line of evidence. The score for uncertainty related to natural variability was determined by rating the power of the statistical study design in the context of the actual variability encountered during the field studies. Laboratory data were rated according to the confidence limits of the test results and the validity of the tests based on performance of the negative and positive controls.

Model Uncertainty

Model uncertainty is a reflection of our ignorance about how stressors affect aquatic populations and communities. The two conceptual models developed for this assessment put forward the ideas that: (1) the PCOC emitted from the smelter directly affect aquatic life through exposure via water, sediments or in food items; and (2) smelter emissions indirectly affect aquatic life through physical changes in habitat quality or through changes in the abundance or distribution of prey and predators. One or both of these conceptual models could be in error.

Some of the main sources of uncertainty in Conceptual Model 1 were: the bioavailability of PCOC for uptake from water and sediment; the degree of food chain transfer; and the extent to which each pathway contributed to exposure. These uncertainties were addressed in several ways. Bioavailability was addressed indirectly by conducting sequential extraction analysis of sediments; this produced information on the form of PCOC in the sediments and thus provided an indication of the tendency for PCOC to be released from the sediment matrix. Bioavailability was also addressed by measuring PCOC concentrations in fish tissue; this allowed an evaluation of the bioaccumulation factors from water and sediment to fish, plus the degree of food chain transfer to fish from their food. The relative importance of the various pathways and release mechanisms was addressed, in part, by estimating total loading of PCOC from atmospheric deposition to the river, direct effluent discharge, groundwater releases and surface runoff via tributaries (Table 2.3).

Conceptual Model 1, when accompanied by the risk management objectives and assessment endpoints, assumes that exposure of aquatic receptors to PCOC can result in direct effects on receptor assessment endpoints (such as species diversity or fish health). The aim of the risk management goal and objectives is to minimize or prevent these direct effects. SALE addresses the uncertainty inherent in the assumption that exposure to PCOC above derived effects thresholds will result in effects by including assessment of other field and laboratory-based measurements. It also includes assessment of the potential for direct effects from physical habitat change.

Conceptual Model 2 illustrates modes of indirect effects from PCOC that alter the abundance or availability of quality food items for the assessment species (fish). It does not include the potential role of other stressors in the Columbia River such as flow regulation, nutrient inputs and introduced species. It does not include hypotheses about how multiple stressors (all PCOC acting together plus other stressors not related to the smelter) would produce effects in aquatic ecosystems.

Some of the uncertainty in Conceptual Model 2 was reduced by accounting for confounding natural and anthropogenic variables in statistical analyses and interpretation. For example, the role of natural habitat variables was included in the benthic invertebrate statistical analysis (Golder 2007a). Confounding anthropogenic stressors were included in the evaluation of results; however, direct measurement of these stressors was not always possible within the scope of this project (e.g., increased predation pressure from introduced walleye was not measured). The general theories of multiple stressor effects are inadequate, seldom going beyond simplified assumptions that these effects can be additive, synergistic or antagonistic depending upon the mode of action. The development of hypotheses for multiple stressor effects was outside of the scope of this assessment. However, the potential for such effects was included in the evaluation of the field-based lines of evidence by examining the data for responses that were unexpected in the context of measured PCOC concentrations.

The SALE process required a score for uncertainty related to model error. This was achieved by examining the extent to which confounding natural and anthropogenic variables were accounted for and whether the response was anomalous in the context of measured PCOC concentrations. The score was also based upon the current state of scientific knowledge regarding the mechanisms and processes that produce direct effects (Conceptual Model 1) or indirect effects (Conceptual Model 2). For example, there is uncertainty in the mechanisms of interaction of multiple stressors and their subsequent effects at the community level; therefore, the score for model error for Conceptual Model 2 included this large source of uncertainty (which applied to all assessment endpoints).

Measurement Error

Measurement error was minimized by adherence to Standard Operating Procedures (also called Technical Procedures) for all field sampling and laboratory analyses. Technical Procedures for the field program are described in the Quality Assurance Management Plan report (Golder 2006d). Quality Assurance/Quality Control (QA/QC) reports from the analytical laboratory were reviewed and trip and field blanks conducted during the sampling program indicated that sample contamination associated with sampling or handling procedures or laboratory accuracy did not occur.

Measurement error was not scored in the SALE process. Measurement error differs for each PCOC and for each biological measure; however, the degree of difference in error among the measures was not quantified in the current study. No one set of measures could be assumed to include more or less measurement error than any other; therefore, an arbitrary relative score could not be applied to chemical measurements versus periphyton measurements, etc. For example, in some cases, the measurement of gonad weights in fish may involve less error than the measurement of zinc in sediments, but in other cases the reverse may be true. All that could be assumed was that the measurement error in each of the sets of measurements was adequately controlled using standard procedures. Any attempt at scoring relative measurement error would have introduced new uncertainty into the overall analysis.

Data Errors

Standardized office protocols were adhered to as described in the Quality Assurance Management Plan (Golder 2006d). Quality control procedures included the following:

- examination of data provided to Golder Associates Ltd. (Golder) by sub-consultants and analytical laboratories for outliers, missing data, appropriate identification of data that did not meet QA requirements;
- transcription error checks (i.e., all data entries were reviewed);
- senior review of all documents; and
- document control procedures including chain-of-custody for all samples and a project filing system that ensured that all pertinent field and communication records were filed in the Project Master file.

Data error was not scored in the SALE process because it was assumed that the degree of data error was controlled in a similar manner across all lines of evidence.

3.0 ASSESSMENT OF RISKS TO TRIBUTARIES

3.1 Introduction

Risks to aquatic life in tributaries to the Columbia River in the AOI were evaluated in a screening-level assessment in 2005. If the screening-level assessment had shown that there were moderate or high risks in any of the tributaries, then a more detailed assessment would have been conducted. However, moderate or high risks were not identified. Therefore, the assessment of risks to tributaries was limited to the screening-level assessment published in Golder (2007d).

3.1.1 Background to the Tributary Study

Two key issues identified in the aquatic Problem Formulation were: (1) the potential role of groundwater as a pathway linking smelter emissions with surface water in tributaries; and (2) whether water and sediment quality in tributaries was sufficiently altered by smelter emissions to pose a risk to aquatic biota. Subsequently, a regional groundwater investigation was conducted by Klohn Crippen in 2004 and a tributary investigation was conducted by Golder in spring 2005 (Golder 2006a).

The regional groundwater investigation was reported by Klohn Crippen (2006). The study was conducted to gain an understanding of the interaction between groundwater and surface water within the study area. The study focused on understanding the water and sediment metal concentrations and their sources and transport pathways in selected tributaries, as well as developing an understanding of the hydrology of the study area (Klohn Crippen 2006). This assisted the assessment of risk to tributaries by providing a basis for assessing the potential aquatic ecosystem impacts within the study area, specifically the contribution of groundwater to tributary flow and the relative role of groundwater in linking smelter emissions with surface water.

The Klohn Crippen study showed that the majority of tributary catchment flows are sourced from areas above el. 800 m and these flows provide substantial dilution flow for areas below el. 800 m that would otherwise have higher PCOC concentrations. A regional hydrological model showed that on an average annual basis, the tributary catchments lose 48-66% of precipitation input to evapotranspiration and 1-8% to groundwater. The remaining 30-44% flows to surface water in the creeks. During low-flow periods, groundwater makes up much of tributary flow. Therefore, surface water quality during low-flow periods provides data regarding the quality of groundwater reporting to the tributaries.

Surface water quality data collected by Klohn Crippen were incorporated into the tributary risk assessment.

3.1.2 Tributaries Selected for Assessment of Risks from Smelter Emissions

The original Problem Formulation (Golder 2003a) produced a preliminary list of tributaries for assessment. This list was produced using the following criteria:

- exceedance of water/sediment criteria;
- presence of usable, accessible fish habitat; and
- exceedance of background metal concentrations.

Only a few tributaries could be eliminated from the AOI because of many gaps in the habitat data and because the background metals concentrations were not yet final at the time of the Problem Formulation.

Subsequent evaluation led to a final selection of tributaries to be included in the risk assessment. Three exposure creeks (Murphy, China and Bear creeks) and three reference creeks (Blueberry, Norns and Deer creeks) were chosen. These systems were selected based on their presence within the AOI, their similar size, the presence of elevated metals in past samples, and the use of the tributaries by both resident and migratory fish stocks (e.g., for spawning in their lower reaches by Columbia River-based fish species).

At the request of Teck Cominco, Ryan and Sullivan creeks were added to the list of exposure tributaries due to their capability to support fish (albeit at a lower productive level than the three primary exposure tributaries), as well as for the presence of elevated PCOC, and proximity to the smelter. Hanna Creek was selected instead of Sullivan Creek after determining that accessing all the reaches (high, middle, low) of Sullivan Creek was not possible due to steep grades at the bottom and heavy snow pack at the top. Hanna Creek has a similar capability of fish use, but a higher fish habitat quality than Sullivan Creek and also has the presence of elevated PCOC, and is in close proximity (approximately 4 km upstream) to the smelter.

Of the five exposure creeks, the relative ranking of water quality based on number of exceedances of criteria for PCOC (from most to fewest exceedances) from historic data is: Hanna Creek, Murphy Creek, Bear Creek, China Creek and Ryan Creek. The relative ranking of sediment quality based on number of exceedances of criteria for PCOC (from most to fewest exceedances) is: Ryan Creek, Bear Creek, China Creek, Murphy Creek and Hanna Creek. This result may be due to the presence of fine sediments in portions of Ryan Creek. Fine sediments would be expected to contain higher concentrations of PCOC than the coarser sediments found in the other tributaries.

These tributaries were selected for field evaluation of periphyton, benthic invertebrates and fish habitat, per the measures selected in support of the assessment endpoints (Section 2).

3.2 Screening Study Results

3.2.1 Water Quality

The evaluation of water quality from the 2005 sampling event showed a very weak indication of risk from smelter-related emissions (Golder 2006a). Only cadmium, silver and zinc concentrations exceeded the conservative screening criteria developed from the range of applicable water quality guidelines, and exceedances occurred in both reference and exposure creeks, indicating the presence of high natural background concentrations.

There was no consistent pattern in PCOC concentrations with upper, middle or lower tributary sites. This result indicates that sources of metals to the tributaries likely are distributed across the watersheds with no obvious point sources. This indication is supported by information on land use (Figure 2.5). All of the study creeks have at least two anthropogenic activities in their watersheds, including rights-of-way, logging and residential agricultural use. Thus, metals concentrations in the tributaries probably reflect a combination of natural geogenic sources, smelter emissions and other anthropogenic sources.

The frequency of metal concentrations exceeding screening criteria was less in 2005 than in past sampling events. In past sampling events, all PCOC have exceeded the screening criteria on at least one occasion. Bear Creek and Hanna Creek had the highest number of exceedances, although results were highly variable. The decline in frequency of exceedances in 2005 is consistent with the continuing decline in air emissions from the smelter (Table 3.1).

Table 3.1 Stack Emissions and Ambient Air Quality Improvements: Comparison Between 1995 and 2004

Substance	Stack Emissions	Ambient Air[(a)]
Lead	-98%	-75%
Arsenic	-98%	-87%
Cadmium	-99%	-70%
Zinc	-58%	-48%
Total Particulate	-94%	-42%
Sulphur Dioxide	-93%	-59%

(a) Measured at seven ambient air stations surrounding the smelter in the Columbia Valley.

Some of the elevated metal concentrations may be explained by anthropogenic activities other than smelting (see Figure 2.3). For example, Deer Creek has been logged in the past (Westcott et al. 1999). Blueberry Creek may be affected by highway runoff, erosion from power and gas transmission rights-of-way, and runoff from agricultural and residential areas. It also has mineral claims in its watershed. Norns Creek has agricultural activity and roads along the majority of its length and its water quality may also be affected by logging. There is a mineral claim in the Norns Creek Watershed. In 2001, blasting occurred near the mouth of Bear Creek, which may have caused high concentrations of iron and silver (Duncan 2005 pers. comm.). Erosion from roads, logged areas, and commercial and residential land development may also affect Bear Creek. Ryan Creek wetland is down-gradient of a historic trench mining operation (Duncan 2005 pers. comm.) and has mineral claims and logging in its watershed.

The screening-level assessment included comparison with an assessment conducted at the Teck Cominco Kimberley site (a closed mine site). Metal concentrations in the Kimberley exposure sites were much higher than in the Trail area exposure tributaries. The Trail area exposure tributaries had concentrations that were similar to Kimberley area reference sites, indicating that the Trail area exposure tributaries have metal concentrations that are within the range of background PCOC concentrations for mineralized areas in the region.

Toxicity data from the Kimberley study identified zinc as the greatest potential risk to aquatic life; however, the risks were ranked as "low." The Trail area zinc concentrations were an order of magnitude lower than at Kimberley. Therefore, it is unlikely that toxicity tests conducted on the Trail area tributaries would show effects and zinc toxicity was consequently screened out of further tributary studies.

On balance, the water quality line of evidence shows a low to negligible risk to aquatic life from the PCOC. This is based upon comparisons of water quality data with screening criteria and effects benchmarks, as well as comparisons with the findings of the Kimberley study.

3.2.2 Sediment Quality

Fine sediments were rare in both reference and exposure tributaries, reflecting the highly erosional nature of these streams. Only three sites with fine sediments (sand or finer) were located. These sites were in Deer

Creek, Blueberry Creek and Ryan Creek. The Blueberry Creek site was downstream of a wetlands complex and the Ryan Creek site was a wetlands area within the stream.

The reference sediments in Deer Creek and Blueberry Creek did not have metal concentrations that exceeded screening criteria, with the exception of nickel in Blueberry Creek. The Ryan Creek sediment site (which was a wetlands area) had several metals with concentrations that exceeded the screening criteria.

Concentrations of PCOC in 2005 were lower than concentrations observed in previous studies. This applies to both reference and exposure sites. The 2005 data are from fine sediments only (<50 µm), and previous data were from samples that ranged from fines to coarser material up to 4 mm in diameter. Because of these differences, and because of the relatively small number of sampling years, a true declining trend cannot be assumed. The primary finding is that fine sediments are rare in the tributaries.

Spatial trends in past tributary sediment metal concentrations include a slight increase in metal concentrations from upstream reference sites downstream to Murphy Creek, variable levels of metals between the smelter and Beaver Creek and then higher concentrations again at Sheppard Creek. The lack of any clear trend may indicate that the sediment chemistry in tributaries is more reflective of watershed geology than atmospheric emissions from the smelter. Furthermore, there are several additional anthropogenic sources of sediment load to the tributaries that could contribute to variable sediment metal concentrations over time.

Both reference and sediment exposure sites in the Kimberley risk assessment had several exceedances of metal criteria, unlike what was observed in the Trail area study. The similar pattern of exceedances in Mark Creek (Kimberley study) and Ryan Creek (this study) may reflect similar mining-related and background sources.

On balance, sediments in the study area tributaries are unlikely to pose significant risks to aquatic life in these systems. The exception may be the fine sediments present in wetlands areas such as the Ryan Creek wetland area. Therefore, follow-up on sediment-related risks is focussing on wetlands areas. This follow-up work is being conducted outside of the scope of this ERA.

3.2.3 Periphyton

Benthic algal biomass was low at both reference and exposure sites and was typical of oligotrophic mountain streams. Although biomass was lower in the exposure creeks, the degree of variability within reaches was high, and differences between reference and exposure area means were within one standard error of the mean as identified through statistical analysis.

There was no indication of risk to periphyton from exceedances of effects benchmarks by the metals of concern in 2005; however, previous data show some risk from cadmium and zinc in Bear Creek, McNally Creek, McAllister Creek and Glenmerry Creek. Cadmium and zinc concentrations in Bear Creek slightly exceeded the effects benchmark (1.6 µ/L) in 2001. Cadmium concentrations exceeded the effects benchmark in McNally Creek in 1995 and in McAllister Creek in 2002 and 2004. Zinc concentrations exceeded the effects benchmark in McNally Creek in 1995, 1999 and 2002, McAllister Creek in 1995, 2002 and 2004 and in Glenmerry Creek in 2002.

On balance, the 2005 data do not show strong evidence for risk to periphyton from metal concentrations. However, there may have been effects in the past in Bear, McNally, McAllister and Glenmerry Creeks. Zinc concentrations in Bear Creek have shown the largest exceedance of the effects benchmark; however, this occurred only in 2001.

3.2.4 Benthic Invertebrates

No dramatic or consistent differences were found in benthic community composition or diversity between reference and exposure sites in 2005. Total number of taxa at reference and exposure sites had overlapping ranges. The degree of dominance was relatively consistent at all but one of the eight sites. The exception was upper Bear Creek, where larval blackflies were exceptionally abundant, likely because of very good larval habitat at that location. Samples from reference and exposure streams had similar ranges of relative proportions of various taxa and B-IBI scores.

There were no consistent correlations between concentrations of metals, nutrients or other water quality variables and benthic invertebrate community variables. This suggests that water quality variables were not strong determinants of the benthic communities in the study streams; rather, communities largely reflected habitat variation.

Comparison of water quality data with effects benchmarks for benthic invertebrates showed no exceedances in 2005; therefore, effects on benthic invertebrates were not expected. However, concentrations of cadmium and zinc were above benchmarks during previous studies in several creeks, including Hanna, Ryan and Bear creeks. These exceedances indicate the potential for past effects on benthic invertebrates.

The sediment quality lines of evidence do not indicate significant PCOC-related responses in the benthic invertebrate communities of the study tributaries. Neither the field data nor comparisons with effects benchmarks showed a strong link with the PCOC.

3.2.5 Fish Habitat

Fish use of the tributary streams is limited in all study watersheds by natural or anthropogenic barriers to upstream movements. The high gradients and large bed material sizes limit spawning opportunities for redd building species of salmonids. The lower reaches of each study stream are used by fish species that reside in the mainstem Columbia River; these reaches provide important spawning and rearing habitat for mainstem populations of salmonids.

Six of the study streams are known to support resident fish populations (Deer Creek, Norns Creek, Blueberry Creek, China Creek, Hanna Creek and Murphy Creek). Species diversity is higher in the three reference streams (Deer, Norns and Blueberry Creeks). Rainbow trout are common to all watersheds that support resident fish populations.

The three reference watersheds are known to support seven to nine species, whereas the exposure streams are known to support one or two species. The difference is likely a result of habitat availability and quality in the reference streams versus that of the exposure streams rather than because of metal exposure. The three reference streams tend to be large (stream lengths of 17- 31 km and third-order watersheds) and have more complex stream networks (magnitude of 11-33), which is typical of larger streams with greater drainage areas. Therefore, more habitat of likely higher quality is available in the reference streams. The lower reaches of the three reference streams also have lower gradients, as evidenced by the greater availability of suitable gravel deposits for salmonid spawning (which provide important spawning habitat for Columbia River mainstem populations). In addition, the majority of the exposure streams had very short sections of channel that were accessible from the Columbia River (80-200 m), due to the presence of anthropogenic or natural barriers. This would also serve to limit the availability of habitat that could support use by Columbia River mainstem populations.

Given the difference in watershed characteristics between the reference and exposure streams and the limited fisheries information, it is not possible to determine if there have been direct or indirect effects on fish resulting from metal deposition in the watersheds. However, water quality data indicate that only silver and zinc concentrations exceed chronic effects benchmarks, and zinc concentrations in reference streams also exceed these benchmarks. Furthermore, the lack of evidence for metal-related responses in the periphyton or benthic invertebrate communities show that risks to fish via indirect effects on food supply would also be low. Therefore, there is little evidence to indicate that metal concentrations would be a driving factor in determining fish community composition or fish abundance in tributaries.

3.3 Uncertainty

There are several sources of uncertainty in the tributary assessment. These are:

- water and sediment quality data are “snapshots” and may not represent the true range of chemical concentrations in the tributaries;
- not all reaches could be sampled for water in 2005;
- the overall lack of fine sediments;
- the only data available for periphyton and benthic invertebrate communities in tributaries are those obtained in this study; therefore, no examination of year-to-year trends is possible, except for trends in the degree of exceedance of effects benchmarks;
- periphyton data from 2005 are limited by the lack of replication within sites;
- interpretation of periphyton biomass was limited by the fact that biomass typically reaches maximum in the fall when flows are relatively low; therefore, periphyton samples collected during the 2005 spring program may not be representative of overall biomass accrual;
- different flow regimes among the study creeks also complicated the interpretation of periphyton data;
- benthic invertebrate data interpretation is constrained by the fact that samples were collected on one occasion only and the primary sampling method used was qualitative; and
- data on resident fish populations are limited or lacking in some of the study streams.

The influence of the above sources of uncertainty that might underestimate risk was addressed by: (1) using conservative screening criteria and effects benchmarks when assessing the water and sediment quality data; (2) carefully examining all available water and sediment data for spatial and temporal trends; (3) comparing results from this study with a more detailed study conducted at a similar site at Kimberley; and (4) using a combination of chemical and biological evidence such that there was no reliance on any single source of information, with additional confidence being applied to the evidence when all the results pointed in the same direction.

3.4 Overall Assessment of Relative Risk to Tributary Systems

None of the study components summarized above provide strong evidence for metal-related risks to tributary systems. This consistency adds confidence in the overall assessment of low risk from smelter-related emissions to tributary systems. Available information indicates that natural habitat variables are likely to be the primary determinant of periphyton and benthic invertebrate communities. Natural habitat features and anthropogenic barriers to fish movement appear to be primary factors influencing fish abundance and presence in the tributaries.

The available information indicates that any follow-up investigations should focus on depositional wetland-type habitats within the tributary systems because these habitats are where water and sediment metal concentrations are usually the most elevated. The fish habitat quality of erosional areas throughout the remainder of the tributary systems does not demonstrate any pattern of metal-related effects.

4.0 MAINSTEM COLUMBIA ASSESSMENT OF RISKS USING SALE

4.1 Introduction

The assessment of risks to aquatic life in the mainstem Columbia River uses the full SALE process for a formal evaluation of magnitude of effect, strength of evidence for causation and rating of uncertainty.

The SALE process proceeds step-by-step through the lines of evidence, with opportunities at each step to rule out risk or to go directly to consideration of risk management options. The overview of the SALE process (Figure 1.2) was refined for Step 1 (Figure 4.1) to focus on comparisons to water quality and sediment quality objectives and protective benchmarks.

4.2 Step 1: SALE Screening

4.2.1 Water and Sediment Metal Concentrations Versus Guidelines

This component of Step 1 was completed in the aquatic Problem Formulation as part of the screening for PCOC (Golder 2003a). Risks were ruled out for all metals with maximum concentrations that did not exceed site-specific water quality objectives established by B.C. Ministry of Environment with exceedances noted for the PCOC in water in the Columbia River (Tables 4.1, 4.2 and 4.3). Cadmium had the greatest number of exceedances for the sampling periods examined. Sediment data collected in other programs showed exceedances for arsenic, cadmium, chromium, copper, lead, mercury, nickel, thallium and zinc (Golder 2003a, 2007b); however, these data were limited to samples taken from Birchbank (upstream of the smelter) and Waneta (downstream of the smelter). Sediment samples analyzed for this study showed that all of these PCOC exceeded sediment quality guidelines at least at one other downstream location (Tables 4.4 and 4.5).

Figure 4.1 Step 1 of the SALE Process

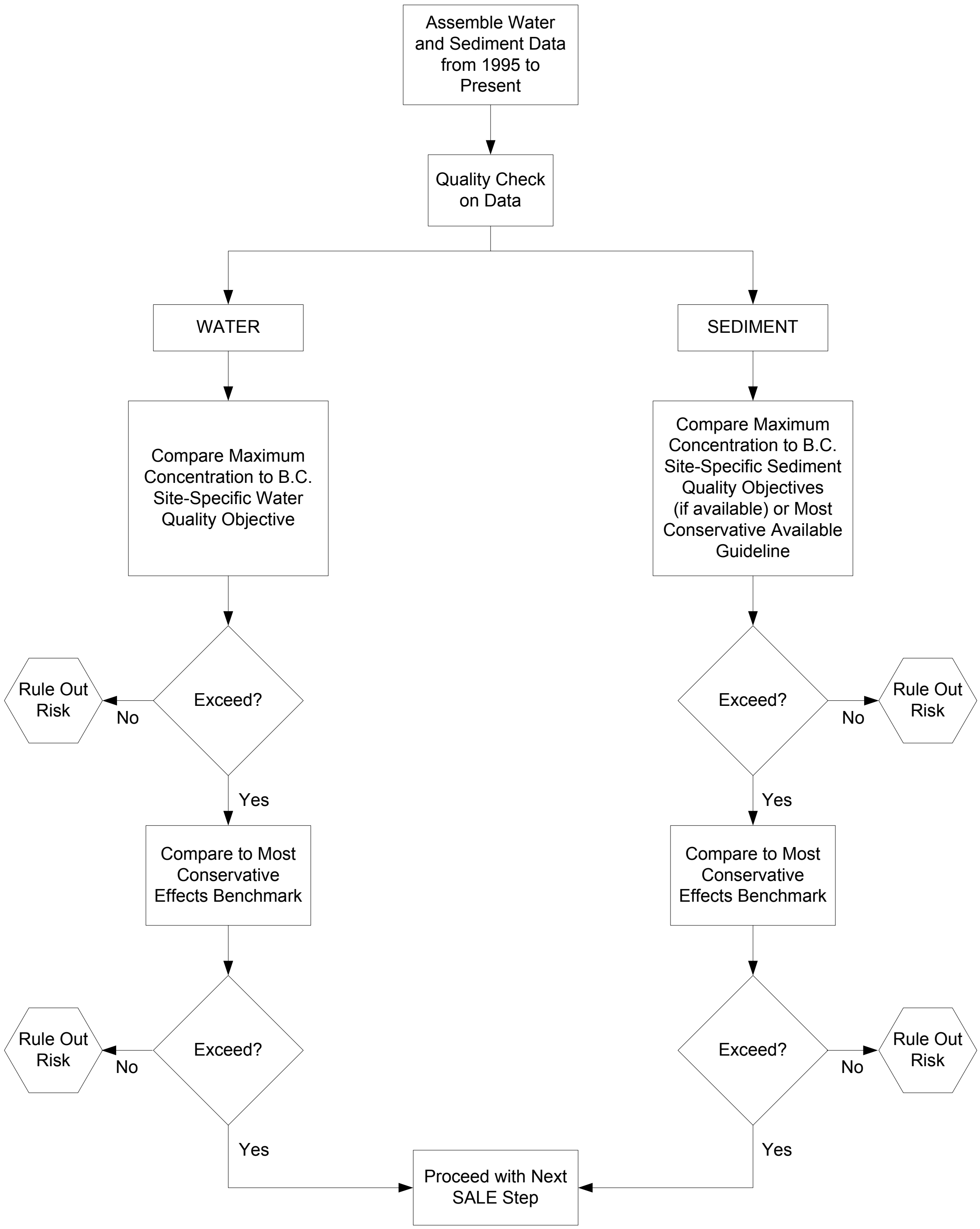


Table 4.1 Number of Samples with Concentrations of PCOC Exceeding Water Quality Objectives in the Columbia River (Golder 2003a)

PCOC	Number of Sample Sets Collected from All Locations in 1995, 1999 and 2000	Number of 30-Day Sets Exceeding Objectives[(a)]	Total Number of Samples	Number of Samples Exceeding Any Objective (Percentage of Total Samples)
Arsenic	42	2	214	3[(b)] (1.4)
Cadmium*	42	38	214	135[(b)] (63)
Chromium	31	11	159	16[(b)] (10)
Copper	42	4	214	7[(c)] (3.3)
Lead	42	5	214	2[(c)] (0.9)
Mercury	17	5	85	10[(c)] (11.8)
Thallium	42	12	214	26[(b)] (12)
Zinc	42	27	213	18[(c)] (8.5)

Notes:
PCOC = potential chemical of concern.
(a) 30-day sample set average greater than mean or 30-day average objective, any one sample greater than maximum objective.
(b) Greater than mean objective, no maximum objective provided.
(c) Greater than maximum objective.
* For many analyses the analytical detection limit for cadmium exceeded the screening objective.
Values in parentheses represent the number of samples exceeding any objective, expressed as a percentage of the total number of samples.

Table 4.2 Number of Samples with Concentrations of PCOC Exceeding Water Quality Objectives in the Columbia River (2003 to 2006)

PCOC	Number of Sample Sets Collected from All Locations 2003 to 2006	Number of 30-day Sets Exceeding Objectives	Total Number of Samples	Number of Samples Exceeding Any Objective[(a)] (Percentage of Total Samples)
Arsenic	36	0	180	0 (0)
Cadmium	36	24	180	100 (56)
Chromium	36	12	180	44 (24)
Copper	36	0	180	0 (0)
Lead	36	0	180	0 (0)
Thallium	36	0	180	1 (0.6)
Zinc	36	3	180	16 (9)

Notes:
PCOC = potential chemical of concern.
(a) greater than mean objectives.
Mercury concentration was available only for 1995 and 1999, and was therefore not included in this table.
There were no exceedances of maximum objectives (where provided).
Values in parentheses represent the number of samples exceeding any objectives, expressed as a percentage of the total number of samples.

Table 4.3 Summary of Exceedances of Water Quality Objectives in the Columbia River (1995 to 2006)

PCOC	Sampling Period	Maximum Concentrations of PCOC (µg/L)				
		Stations				
		Birchbank	D/S Stoney	New Bridge (within the allowed dilution zone)	Old Bridge (edge of allowed dilution zone)	Waneta
Arsenic	1	no	18.4(4.79)[a]	5.35(3.34)[a]	no	no
Cadmium	1	no	2.73(0.67)	4.07(2.53)	0.65(0.49)	0.68(0.25)
	2	no	0.49(0.26)	0.43(0.27)	0.05(0.04)	no
	3	0.09(0.03)[a]	0.12(0.08)	0.86(0.42)	0.68(0.22)	0.09(0.07)
	4	no	no	0.47(0.21)	0.12(0.06)	0.06(0.05)
	5	no	no	0.27(0.07)	no	no
	6	no	0.1(0.03)[a]	0.81(0.24)	0.08(0.06)	0.04(0.04)
	7	0.12(0.05)	0.23(0.08)	0.23(0.20)	0.1(0.05)	0.25(0.07)
	8	0.04(0.02)[a]	0.25(0.09)	0.24(0.12)	0.16(0.07)	0.19(0.07)
	9	no	0.04(0.03)[a]	0.13(0.06)	0.04(0.03)[a]	0.04(0.03)[a]
	10	no	0.63(0.23)	0.37(0.26)	0.16(0.08)	0.07(0.05)
	11	no	0.06(0.04)	0.09(0.04)	0.04(0.03)[a]	0.05(0.03)[a]
	12	no	0.05(0.04)	0.13(0.10)	0.06(0.05)	0.06(0.05)
Chromium	1	N/A	N/A	N/A	N/A	N/A
	3	1.4(1.02)	1.6(1.08)	1.6(1.04)	1.6(1.12)	no
	10	2.3(1.4)	2.2(1.64)	2.4(1.44)	2.4(1.68)	2.4(1.36)
Copper	1	no	no	73.5 (20)	4 (2.39)[b]	4.4 (3.05)[b]
Lead	1	no	no	161 (59)	23 (8.02)[b]	no
	2	no	no	8.98(4.93)[b]	no	no
	6	no	no	22 (5.06)[b]	no	no
Mercury	1	0.25(0.09)	0.2(0.08)	0.25(0.17)	no	no
	3	0.06(0.05)[b]	no	No	N/A	N/A
Thallium	1	no	no	14.5(8.22)	2.38(1.68)	no
	3	no	no	4.5(1.22)	39.1(7.9)	2.05(0.49)[a]
	4	no	no	39.1(8.14)	4.5(0.98)	2.1(0.5)[a]
	5	no	no	3.3(0.94)	no	2(0.5)[a]
	11	no	no	0.87(0.28)[a]	0.18(0.08)[a]	no
Zinc	1	no	189 (47)	339 (130)	31 (22)[b]	19 (9)[b]
	2	no	38 (22)	31 (17)[b]	no	no
	3	14 (9)[b]	20 (13)[b]	47 (27)	49 (19)	18 (14)[b]
	4	no	11 (8)[b]	29 (16)[b]	15 (8)[b]	17 (8)[b]
	7	no	no	17(10)[b]	no	no
	10	no	19.7(9.2)[b]	25.3(13.6)[b]	no	no

Notes:

Sampling periods:

Mar-Apr 1995=1, Jan 1999=2, Mar-Apr 1999=3, Oct-Nov 1999=4.

Jan-Feb 2000=5, Oct Nov 2000=6, Feb-Mar 2003=7, Apr-May 2003=8, Nov-Dec 2003=9, Feb 2004=10, Apr-May 2005=11, and April 2006=12.

Average values for sampling period appear in parentheses.

Shaded values indicate both maximum and average concentrations exceed screening objectives.

D/S = downstream; PCOC = potential chemical of concern; no = no exceedance.

(a) Only the maximum concentration exceeds the mean screening objectives.

(b) Only the average concentration exceeds the mean screening objectives.

Table 4.4 Exceedances of Sediment Quality Guidelines (Maximum Observed Concentrations, µg/g dry wt.) in the Columbia River, 1995 to 2004

PCOC (µg/g, dry wt.)	1995		1999		2000		2001		2003 (Spring)		2003 (Fall)		2004		Guideline	
	Birchbank	Waneta	Birchbank	Waneta	Birchbank	Waneta	Birchbank	Waneta	Birchbank	Waneta	Birchbank	Waneta	Birchbank	Waneta	CCME	BC
Arsenic	no	44.9	no	27.8	no	16	no	22.5	no	33.1	no	no	no	16.9	5.9	5.7
Cadmium	no	5.63	no	1.47	no	no	no	5.03	no	0.99	no	0.71	no	0.73	0.6	0.6
Chromium	no	321	no	62.7	no	no	no	39	no	146	no	79.8	no	79	37.3	36.4
Copper	no	4,270	no	1,190	no	279	no	272	no	3,428	no	1,685	no	1,620	35.7	35.1
Lead	no	341	no	260	no	154	no	275	no	455	no	128	no	281	35	33.4
Mercury	no	no	no	no	no	no	no	6.9	no	no	no	no	no	no	0.17	0.16
Nickel	no	28.1	no	no	20	28	no	16.9	no	17.7	no	no	no	no	no	16
Silver	0.14	14.5	0.09	7.46	1	8	0.07	3.0	0.01	6.8	0.01	1.24	0.09	3.55	no	0.5
Thallium	no	no	no	no	no	no	no	No	0.04	0.18	0.05	0.11	0.09	0.08	no	no
Zinc	no	25,300	no	5,920	no	900	no	1,038	no	23,141	no	17,925	no	14,400	123	120

Notes:

PCOC = potential chemical of concern; no = no exceedance.

The lower of the two available guidelines was used for comparison.

Table 4.5 Exceedances of Sediment Quality Guidelines (Maximum Observed Concentrations, µg/g dry wt.) in Sediment Samples Collected During the Benthic Invertebrate Sampling Program, Spring and Fall 2003

Variable (µg/g, dry wt. or as noted)	Reference Sites						Exposure Sites													CCME Guideline	BC Working Objective
	Kootenay Eddy		Genelle Eddy		Birchbank Eddy		Korpak		Beaver Creek Launch	Rainbow Trout Bar	Maglios	Casino		Airport Bar	Trimac	Fort Sheppard Eddy		Waneta Eddy			
	Spring 2003	Fall 2003	Spring 2003	Fall 2003	Spring 2003	Fall 2003	Spring 2003	Fall 2003	Spring 2003	Spring 2003	Fall 2003	Spring 2003	Fall 2003	Fall 2003	Fall 2003	Spring 2003	Fall 2003	Spring 2003	Fall 2003		
Arsenic	no	no	no	no	no	no	9.8	10	no	no	20	15	17	8.3	7.2	11	20	33	6	5.9	5.7
Cadmium	1.1	0.6	no	no	no	no	1.7	1.8	no	no	2.2	1.1	1.2	0.83	3.2	0.8	1.07	1	0.71	0.6	0.6
Chromium	no	no	no	no	no	no	no	no	no	no	56	no	no	no	no	49	no	146	80	37.3	36.4
Copper	no	no	no	no	no	no	300	415	37	no	1,156	707	466	338	174	842	506	3,428	1,685	35.7	35.1
Lead	no	no	no	no	no	no	171	173	no	no	335	204	142	122	150	181	193	455	128	35	33.4
Mercury	no	no	no	no	no	no	0.48	no	no	no	no	1.2	0.3	0.19	0.34	0.19	0.17	no	no	0.17	0.16
Nickel	no	no	no	no	no	no	no	no	no	no	no	no	no	no	18	no	no	18	no	no	16
Silver	no	no	no	no	no	no	3.2	1.8	no	no	5.2	5	10	1.8	1.5	2.3	3.4	6.8	1.2	no	0.5
Thallium	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Zinc	153	no	no	no	no	no	1,912	2,455	220	162	7,746	3,748	2,276	1,638	1,067	5,538	3,307	23,141	17,925	123	120
Slag[(a)] (%)	-	0	-	0	-	0	10 to 15	0	10 to 50	80	40	10	10	10	0	10	30	5 to 10[(b)]	90	-	-
Mean water depth (m)	-	4.8	-	2.5	-	2.2	1.5	2	5	11	2.8	2.8	2.5	1.6	1.9	3 to 5	3.6	1	15	-	-
Substrate Type (%)	sand	sand (85%)	sand	sand (87%)	sand (90%)	sand (77%)	sand (75%)	sand (75%)	sand (90%) incl. slag	slag (80%)	sand (96%)	sand (85%)	sand (90%)	sand (77%)	sand (67%)	sand (90%)	sand (94%)	fine grained sand	sand (81%)	-	-

Notes:

CCME Sediment quality guidelines are not available for nickel, silver and thallium.

B.C. nickel and silver guidelines - working guidelines for sediments (freshwater) (B.C. MELP 1998a, b). All other B.C. guidelines – Ambient Water Quality Assessment and Objectives for the Lower Columbia River Birchbank to the US Border (B.C. WLAP 2000). There is no B.C. guideline for thallium.

no no exceedance.

* Fort Sheppard and Waneta are adult and juvenile feeding and holding areas for white sturgeon and other fish species.

** Slag content at Waneta is highly variable and dependent upon depth. Deeper areas contain up to 90% slag.

\- no data/not applicable.

(a) Visual estimate subject to high uncertainty.

(b) Slag content at Waneta is highly variable depending on depth. Deeper areas contain up to 90% slag.

Screening of water quality data collected since the completion of the Problem Formulation showed that the number of exceedances has declined (Tables 4.2 and 4.3). Cadmium, chromium and zinc concentrations continued to exceed site-specific water quality objectives, particularly at the New Bridge site, which is within the initial dilution zone for the treated smelter effluent discharge. Concentrations at the other downstream sites were usually less than objectives, with the exception of cadmium. Concentrations of the other PCOC identified in the Problem Formulation did not exceed objectives during the period of 2003 to 2006, with the exception of thallium concentrations on one sampling date at the New Bridge site in 2005. In 2006, only cadmium concentrations exceeded objectives.

The total area of the Columbia River from the Hugh Keenleyside dam to the U.S. border is approximately 1,550 ha. Of this, the total depositional area (of which the above sites are a portion) is approximately 33 ha, or approximately 2% of the total area of the river. This reflects the erosional nature of the Columbia River in this region.

4.2.2 Comparison of Water, Sediment and Fish Tissue Metal Concentrations to Effects Benchmarks for Aquatic Biota

Water quality objectives are not effects benchmarks, and exceedance of water quality objectives does not mean that there will be effects on aquatic organisms. Therefore, as a secondary screening stage in Step 1, water and sediment concentrations were compared to effects benchmarks for each group of aquatic receptors (periphyton, benthic invertebrates and fish). These effects benchmarks were derived from the literature. The selected benchmarks were conservative to ensure that if they were not exceeded, unacceptable risks of adverse effects could be ruled out with confidence.

Details on the selection of effects benchmarks, the literature sources of the benchmarks and comparisons with data from the study area were presented in the aquatic Problem Formulation report (Golder 2003a).

Periphyton

Chronic effect values (CEVs) for periphyton for each PCOC were taken from Suter and Tsao (1996). Chronic effect values are the geometric mean of the lowest observable effect concentration (LOEC) and the no observable effect concentration (NOEC) (Suter and Tsao 1996).

Based on data presented in the Problem Formulation (Golder 2003a), risks to periphyton from concentrations of PCOC in water could be ruled out for arsenic, chromium, mercury and thallium because maximum concentrations did not exceed conservative effects benchmarks (Table 4.6). Risks to periphyton from concentrations of cadmium, copper, and zinc could not be ruled out.

Table 4.6 Maximum Water Concentrations (µg/L) from 1995 to 2001 that Exceed Chronic Effect Values for Periphyton

PCOC	CEV (µg/L)	D/S Stoney	New Bridge	Old Bridge	Waneta
Cadmium	2	2.7	4.1	no	no
Copper	1	no	1.1-74	4	1.3-5.5
Zinc	30	37.5-189*	31-339*	31-49	no

Notes: PCOC = potential chemical of concern; CEV = chronic effect value; D/S = downstream; no = no exceedance.
* Highest concentrations occurred in 1995.

Based on more recent water quality data (Table 4.7), only copper concentrations at Waneta exceeded CEVs and concentrations were lower than those recorded in 1995 to 2001.

Table 4.7 Maximum Water Concentrations (µg/L) from 2003 to 2006 that Exceed Chronic Effect Values for Periphyton

PCOC	CEV (µg/L)	D/S Stoney	New Bridge	Old Bridge	Waneta
Cadmium	2	no	no	no	no
Copper	1	no	no	no	1.12-1.13*
Zinc	30	no	no	no	no

Note: PCOC = potential chemical of concern; CEV = chronic effect value; D/S = downstream; no = no exceedance.
* Highest concentrations occurred in 2003.

The risk assessment proceeded with the field program in 2003 based upon the original Problem Formulation. Concentrations of PCOC decreased over the course of the risk assessment; therefore, responses observed in periphyton during the 2003 sampling program reflect different conditions than would have been predicted using the Problem Formulation.

Benthic Invertebrates

Chronic effect values for benthic invertebrates were taken from Suter and Tsao (1996). From the Problem Formulation, risks to benthic invertebrates from concentrations of PCOC in water were ruled out for chromium, mercury and thallium (Table 4.8). Risks from the remaining PCOC could not be ruled out.

Table 4.8 Water Concentrations (µg/L) from 1995 to 2001 that Exceed Chronic Effect Values for Benthic Invertebrates

PCOC	CEV (µg/L)	D/S Stoney	New Bridge	Old Bridge	Waneta
Cadmium	0.15	0.5-2.7	0.27-4.1*	0.65-0.68	0.68*
Copper	0.23	no	73.5*	4*	4.4*
Lead	12	no	22-161*	23*	no
Zinc	47	189*	339*	49	no

Note: PCOC = potential chemical of concern; CEV = chronic effect value; D/S = downstream; no = no exceedance.
* Highest concentrations occurred in 1995.

No exceedances for lead and zinc were noted when CEVs were compared to more recent water quality data (Table 4.9). The magnitude of the exceedances for cadmium and copper concentrations also declined.

Table 4.9 Water Concentrations (µg/L) from 2003 to 2006 that Exceed Chronic Effect Values for Benthic Invertebrates

PCOC	CEV (µg/L)	D/S Stoney	New Bridge	Old Bridge	Waneta
Cadmium	0.15	0.23-0.63*	0.23-0.37*	0.16*	0.19-0.25*
Copper	0.23	0.44-0.87	0.42-0.89	0.36-0.77*	0.57-1.13*
Lead	12	no	no	no	no
Zinc	47	no	no	no	no

Note: PCOC = potential chemical of concern; CEV = chronic effect value; D/S = downstream; no = no exceedance.
* Highest concentrations occurred in 2003 and 2004.

Concentrations of PCOC in sediments were compared to two benchmarks called the “effects range low” (ERL) and the “effects range median” (ERM). The ERL is the 10th percentile value below which adverse effects rarely occur and the ERM is the 50th percentile value representative of concentrations above which effects frequently occur (NOAA 1999, Suter 1999). The ERL and ERM values derived from the database assembled for sediment quality guidelines (Long et al. 1995) were expressed as the percentage incidence of biological effects in concentrations ranges defined by the two values (Table 4.10, adapted from NOAA 1999). Comparisons with both benchmarks are shown in order to illustrate the relative risk to benthic invertebrates, although any exceedance (even of the lower, more conservative ERL) was sufficient to carry forward the PCOC for further consideration.

Table 4.10 ERL and ERM Guideline Values (µg/g, dry wt.) for PCOC in Sediments Adapted from NOAA (1999)

PCOC	Guidelines		Percent Incidence of Effects		
	ERL	ERM	<ERL	ERL-ERM	>ERM
Arsenic	8.2	70	5.0	11.1	63.0
Cadmium	1.2	9.6	6.6	36.6	65.7
Chromium	81	370	2.9	21.1	95.0
Copper	34	270	9.4	29.1	83.7
Lead	46.7	218	8.0	35.8	90.2
Mercury	0.15	0.71	8.3	23.5	42.3
Nickel	20.9	51.6	1.9	16.7	16.9
Silver	1.0	3.7	2.6	32.3	92.8
Zinc	150	410	6.1	47.0	69.8

Note: PCOC = potential chemical of concern; ERL = effects range low; ERM = effects range median.

Concentrations of all PCOC in sediments exceeded effects ranges at least on one occasion at the Waneta sampling station (Table 4.11). Therefore, no risks could be ruled out.

Fish

Concentrations of PCOC in Water

A literature review and search of toxicological databases were conducted for the PCOC. The databases searched included the ECOTOXicology Database System (U.S. EPA 2002) and the Oak Ridge National Laboratory (ORNL) Toxicological Benchmarks (Suter and Tsao 1996). Chronic effect values were derived from the data obtained in these searches.

Table 4.11 Sediment Concentrations (µg/g, dry wt.) that Exceeded Effects Range Low (ERL) or Effects Range Median (ERM) for Benthic Invertebrates (Golder 2003a)

PCOC	Year of Sampling	Fort Sheppard/Waneta Reach*
Arsenic	1995/1999	44.9; 27.8
	2000	16
	2001	22.5
Cadmium	1995/1999	5.6-1.5
	2000	-
	2001	5.0
Chromium	1995/1999	321
	2000	-
	2001	-
Copper	1995/1999	1,190-4,270
	2000	279
	2001	272
Lead	1995/1999	260-341
	2000	154
	2001	275
Mercury	1995/1999	-
	2000	-
	2001	6.9
Nickel	1995/1999	28
	2000	28
	2001	-
Silver	1995/1999	7.5-14.5
	2000	8
	2001	3
Zinc	1995/1999	5,920-25,300
	2000	900
	2001	1,038

Notes: - = no data.

PCOC = potential chemical of concern; ERL = effects range low; ERM = effects range median.

* Fort Sheppard reach (1995 to 1999) and Waneta Eddy (2000 to 2001) were the same locations.

Cadmium, copper and zinc concentrations exceeded chronic effects benchmarks for fish at least once (Table 4.12) for sampling periods between 1995 and 1999. Comparison of PCOC concentrations in the period 2003 to 2006 showed that only zinc concentrations at New Bridge (within the initial dilution zone) exceeded chronic effects benchmarks (Table 4.13, Golder 2007b). Despite the reduction in recent concentrations, risk to fish health from cadmium, copper and zinc was not ruled out because longer-lived fish would have been exposed to higher concentrations. Risks to fish from concentrations of the other PCOC in water were ruled out.

Table 4.12 Maximum Water Concentrations (µg/L) from 1995 to 1999 that Exceed Chronic Effect Values for Fish

PCOC	CEV (µg/L)	Sampling Period	D/S Stoney	New Bridge	Old Bridge	Waneta
Cadmium	1.7	1995	2.7	4.1	na	na
Copper	3.8	1999	na	73.5	4	4.4
Zinc	36	1995	189	339	na	na
		1999	na	47	49	na

Note: PCOC = potential chemical of concern; CEV = chronic effect value; D/S = downstream; na = not available

Table 4.13 Maximum Water Concentrations (µg/L) From 2003 to 2006 Compared with Chronic Effect Values for Fish

PCOC	CEV (µg/L)	D/S Stoney	New Bridge	Old Bridge	Waneta
Cadmium	1.7	no	no	no	no
Copper	3.8	no	no	no	no
Zinc	36	no	67	no	no

Note: PCOC = potential chemical of concern; CEV = chronic effect value; D/S = downstream; no = no exceedance.

Concentrations of PCOC in Fish Tissue

In the Problem Formulation phase, data on concentrations of PCOC in fish tissue were examined relative to concentrations reported to have an effect on fish survival, growth or reproduction (Golder 2003a). Copper concentrations (wet weight) in all the fish species selected were above the concentration of 0.5 µg/g reported to have an effect on survival in fish muscle tissue (Jarvinen and Ankley 1999). In largescale sucker, the concentrations were as high as 4.5 µg/g (Golder 2003a).

Whole fish had a maximum zinc concentration of 84 µg/g in largescale sucker and 62 µg/g in mountain whitefish in 2001. The lowest observed effect concentration reported by Jarvinen and Ankley (1999) was 60 µg/g.

Risks to fish from tissue concentrations of arsenic, chromium, mercury, nickel, lead, selenium and thallium were ruled out (Golder 2003a).

Concentrations of PCOC in mountain whitefish and prickly sculpin collected in 2004 as part of the fish health study conducted for this risk assessment were compared with effects thresholds from Jarvinen and Ankely (1999) (Table 4.14, Golder 2007d). With the exception of zinc, concentrations of all metals listed in Table 4.14 in both mountain whitefish and prickly sculpin in 2004 were below the corresponding effects concentration.

Maximum selenium concentrations were compared to a separate set of draft criteria released by the U.S. EPA (2004). A review of available toxicological information completed by the U.S. EPA (2004) indicates that diet is the primary route of exposure that controls chronic toxicity of selenium to fish, which are considered to be the most sensitive aquatic organisms for this parameter (Coyle et al. 1993; Hamilton and Buhl 1990; Hermanutz et al. 1996). Based on these findings, the U.S. EPA has chosen to express their revised draft water quality criteria for selenium in terms of fish tissue concentrations, expressed in dry weight.

The lowest reported chronic genus mean value for selenium relevant to mountain whitefish in the Columbia River was for trout at a value of 10.66 µg/g dry weight. Using an assumed moisture content of 80 percent (U.S. EPA 1985), 10.66 µg/g dry weight translates into a wet weight concentration of 2.13 µg/g. This value was selected for use as the chronic effects benchmark for selenium in mountain whitefish. In 2004, the maximum concentration of selenium in mountain whitefish tissue was 0.46 µg/g wet weight.

The draft U.S. EPA criterion of 7.91 µg/g dry weight was used as the benchmark for slimy sculpin since there were no chronic genus mean values for species that are closely related to sculpin and because the U.S. EPA draft criterion represents a lower, more conservative benchmark. Using an assumed moisture content of 80 percent, the draft criterion becomes 1.58 µg/g wet weight. The maximum concentration found in prickly sculpin in 2004 was 0.57 µg/g wet weight. The maximum concentration was also below the concentration of 5.85 µg/g dry weight (1.17 µg/g wet weight) used to trigger further monitoring because of concerns that concentrations monitored during the summer would under-estimate risk to fish during the winter (U.S. EPA 2004).

The comparison of selenium tissue concentrations in mountain whitefish and slimy sculpin with tissue effects benchmarks indicated that risk from selenium exposure via food chain uptake was negligible. However, there is considerable controversy regarding the derivation and selection of tissue effects benchmarks (and thus regulatory tissue residue guidelines). McDonald and Chapman (2007) reviewed this controversy and suggested using a weight-of-evidence approach for selenium. This approach involves evaluation of adequacy of data, screening against available and appropriate effects benchmarks, comparison with reference concentrations and, if benchmarks and reference concentrations are exceeded, toxicity testing and field studies. The authors suggest that data should be collected from high-exposure sites with accompanying water and sediment data (which was done in this ERA). Comparison with reference concentrations was performed in this ERA. Furthermore, field studies on fish health were conducted. The field studies provided data that were relevant to the effects of the combined PCOC, notwithstanding that some PCOC concentrations did not exceed benchmarks.

While only a small number of mountain whitefish from all four study areas had concentrations of zinc above the lower effects concentration of 4.5 µg/g, most of the prickly sculpin examined had concentrations above this value (Golder 2007d). The highest concentrations were in sculpin from the exposure areas; however these values (maximum of 17.2 µg/g) were below the higher effects concentration of 60 µg/g (Table 4.14). In addition; the average zinc concentration in sculpin from all sites was higher than the 4.5 µg/g effects concentration.

Table 4.14 Fish Tissue Effects Thresholds (µg/g, wet wt.) and Maximum Concentrations (µg/g, wet wt.) Observed in Mountain Whitefish and Prickly Sculpin Collected in 2004

Chemical	Effects Concentration (µg/g, wet wt.)	Endpoint		Tissue	Fish Species	Size/Life Stage	Maximum Concentrations (µg/g, wet wt.) in Fish Tissue, Near-field and Far-field Areas, Fall 2004	
		No Effect	Reduction				Mountain Whitefish	Prickly Sculpin
Arsenic *Arsanilic acid*	6.1	survival/growth	-	carcass	rainbow trout	juvenile	0.51 female near-field	0.18 male near-field
Sodium arsenate	2.0	survival	-	whole body	rainbow trout	fingerlings		
Cadmium *Cadmium sulphate*	2.8	survival	-	muscle	rainbow trout	150 – 200 g	0.009 male far-field	0.029 male near-field
	0.6	-	reproduction	muscle	rainbow trout	adult		
	0.4	reproduction	-	muscle	rainbow trout	adult		
Cadmium	0.54	growth	-	whole body	rainbow trout	3.1 g		
Chromium *Potassium dichromate*	0.58	survival	-	muscle	rainbow trout	150 – 200 g	0.08 male near-field	0.11 male near-field
Copper *Copper sulphate*	0.5	survival	-	muscle	rainbow trout	138 g	0.28 female far-field	0.49 male near-field
	3.4	survival growth reproduction	-	muscle	brook trout	embryo juvenile adult		
Lead *Lead nitrate*	4.0	survival	-	carcass	rainbow trout	underyearlings (6.5 g)	0.15 male near-field	0.35 male near-field
	2.5-5.1	growth	-	whole body	brook trout	embryo juvenile		
Mercury *Mercuric chloride*	5.8	survival	growth	muscle	chum salmon	fry juvenile	0.22 female near-field	0.18 female near-field
	1.4	survival	-	edible flesh	rainbow trout	fingerling		
	7.6	survival	-	whole body	fathead minnow	larvae adult		
	0.8	growth	-	whole body	fathead minnow	larvae adult		

Table 4.14 Fish Tissue Effects Thresholds (wet weight) and Maximum Concentrations (wet weight) Observed in Mountain Whitefish and Prickly Sculpin Collected in 2004 (continued)

Chemical	Effects Concentration (µg/g)	Endpoint		Tissue	Fish Species	Size/Life Stage	Maximum Concentrations (µg/g) in Fish Tissue, Near-field and Far-field Areas, Fall 2004	
		No Effect	Reduction				Mountain Whitefish	Prickly Sculpin
Selenium	2.13 (for mountain whitefish) 1.58 (for slimy sculpin)	-	-	tissue	rainbow trout, Chinook salmon bluegill	various	0.46 male near-field	0.57 male near-field
Silver *Silver nitrate*	0.06	survival growth	-	whole body	bluegill	young-of-the-year	0.0005 female near-field	0.0002 male far-field
	0.003	survival growth	-	carcass	largemouth bass	young-of-the-year		
Zinc *Zinc sulphate*	4.5	survival growth	-	whole body	brook trout	embryo larvae	5.2 male near-field	17 male near-field
	60	survival growth	-	whole body	Atlantic salmon	juvenile		

Notes: Thresholds were obtained from Jarvinen and Ankley (1999) except selenium where thresholds are from US EPA (2004).
- = not applicable.

4.2.3 Summary of Results of Step 1

Risks to attached algae from concentrations of PCOC in water could be ruled out for arsenic, chromium, mercury and thallium because maximum concentrations observed from 1995 to 2001 did not exceed conservative effects benchmarks. Risks to attached algae from concentrations of cadmium, copper, lead and zinc could not be ruled out because maximum concentrations exceeded effects benchmarks on at least one occasion. However, many of the concentrations that exceeded the effects benchmarks occurred in earlier years of the period 1995 to 2001.

Risks to benthic invertebrates from concentrations of PCOC in water were ruled out for chromium, mercury and thallium. Risks from the remaining PCOC could not be ruled out.

Concentrations of all PCOC in sediments exceeded effects ranges on at least one occasion at the Waneta sampling station. Therefore, no risks could be ruled out.

Cadmium, copper and zinc concentrations in water exceeded chronic effects benchmarks for fish at least once; however, all of these exceedances occurred in earlier sampling periods (1995 or 1999). Only zinc remained above effects benchmarks when mountain whitefish and prickly sculpin specimens were analyzed in 2004. Risks to fish from concentrations of the other PCOC in fish tissue were ruled out.

In summary, the PCOC retained for further assessment are:

- Water - arsenic, cadmium, chromium, copper, lead, zinc;
- Sediment - arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc; and
- Fish tissue - zinc

The risk assessment should consider the potential for interactions between chemicals which may act via a similar mechanism on the same target organ. Zinc, copper and cadmium have been shown to produce synergistic effects in combination with other metals (Thompson et al. 1980, Forget et al. 1999, Ince et al. 1999, Morley et al. 2002). All three of these PCOC have been carried forward from Step 1.

The PCOC remaining after Step 1 are the result of the comparisons of maximum concentrations with conservative effects benchmarks. No allowance is made for important factors such as the frequency and extent of exceedance of benchmarks, the bioavailability of PCOC in sediments, or the validity of CEV as effects benchmarks (a question because CEVs incorporate the use of NOECs which have been criticized for many years because they are directly dependent upon the design of the original toxicity tests).

The results of Step 1 illustrate the need to proceed with further risk analysis because several PCOC may pose a risk singly or in combination to one or all of the three groups of aquatic receptors (periphyton, benthic invertebrates and fish).

4.3 Approach Used for the SALE Effects Assessment and Risk Characterization

4.3.1 Steps 2, 3 and 4: SALE Effects Assessment

The SALE Steps 2, 3 and 4 are combined to produce an effects assessment (Figures 4.2 to 4.4). Step 2 (Figure 4.2) is the assessment of indirect effects via changes in habitat. Step 3 (Figure 4.3) is the incorporation of laboratory and field studies into the assessment. Step 4 (Figure 4.4) is the evaluation of the magnitude of the direct and indirect effects measured in Steps 2 and 3. Uncertainty is analyzed for each line of evidence of direct and indirect effects.

Detailed results of the laboratory and field studies that provide the lines of evidence for Steps 3 and 4 are provided in supporting documents (Golder 2006a, 2007a, b, c). Studies described in these supporting documents used a control/impact design and compared upstream reference sites with sites downstream of the smelter. Although reference sites were located within the historical deposition zone of smelter aerial emissions, the primary source of smelter-related chemical concentrations in water and sediment of the Columbia River is the treated effluent discharge. Contributions from current aerial emissions deposited directly to the river or its tributaries are extremely small relative to effluent discharge. The effect of past aerial emissions would be part of the integrated effects of historic aquatic and aerial emissions as seen in sediments from depositional areas. Appropriateness of reference sites is confirmed by the observation that concentrations in upstream reference sediments were typical of regional background. The tributary water quality data also confirmed the small contribution via aerial deposition and also show reductions commensurate with reductions in smelter emissions.

The statistical difference noted in Figure 4.3 is for differences between upstream and downstream measures of periphyton community, benthic invertebrate community, or fish health characteristics. An assessment of uncertainty proceeds whether or not there are statistical differences because one of the sources of uncertainty is the power of the sampling design to distinguish between natural variability and a response to stressors. In other words, the lack of a statistical difference may be due to insufficient sampling rather than a true lack of response. All of the field and laboratory lines of evidence are carried forward to Step 4 of the SALE process (Figure 4.4), where the magnitude of the response is assessed.

The magnitude of effects must be greater than negligible for the SALE to proceed beyond Step 4 into an analysis of cause/effect. That is, there must be sufficient evidence that there is an effect and that the effect may be large enough to be of ecological significance. The exception to this rule is if there is high uncertainty attached to the magnitude rating.

Figure 4.2 Step 2 of the SALE Process

Assessment of Indirect Effects Due To Changes in Habitat Suitability

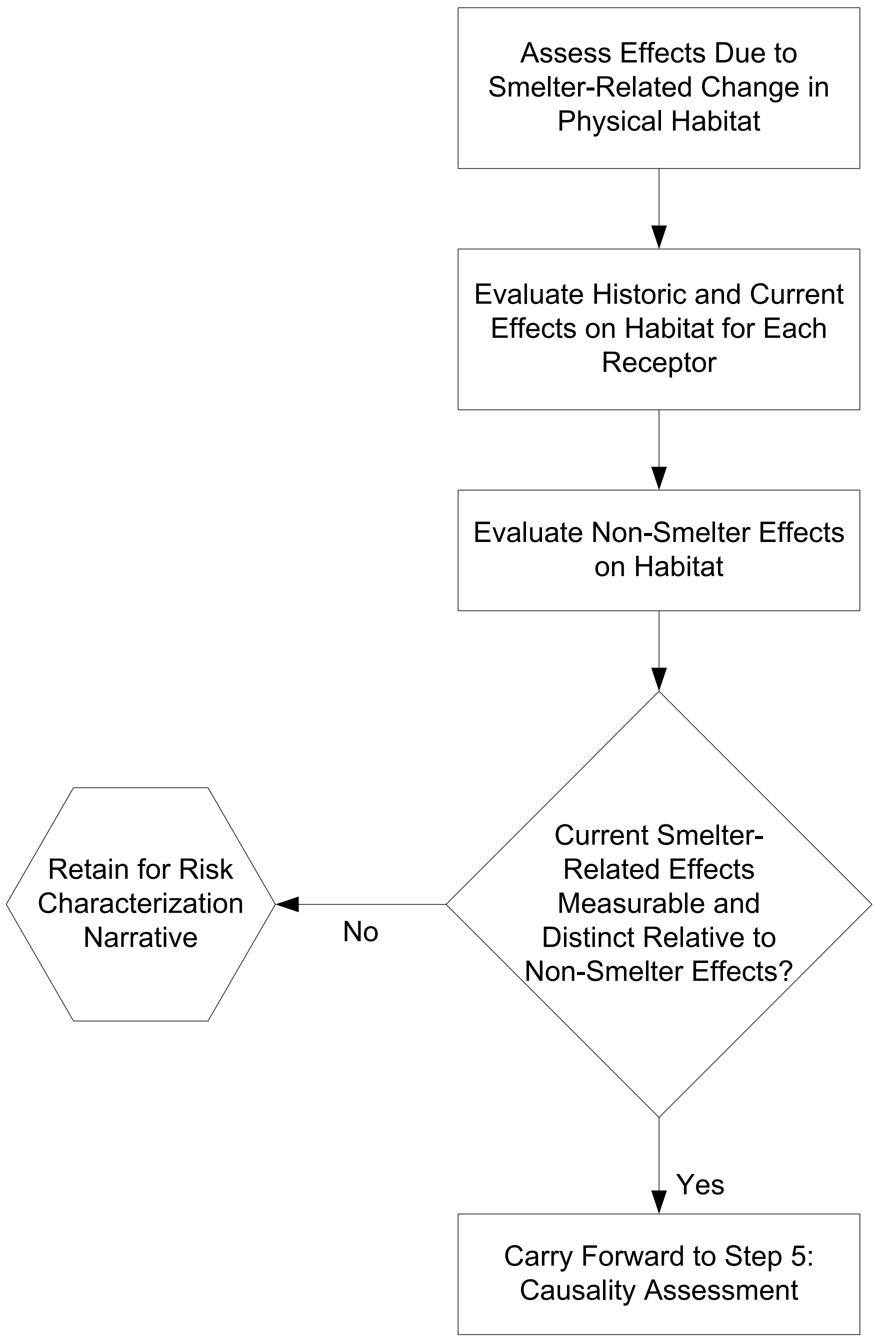


Figure 4.3 Step 3 of the SALE Process

Assessment of Lab and Field Data for Evidence of Statistically Significant Effects

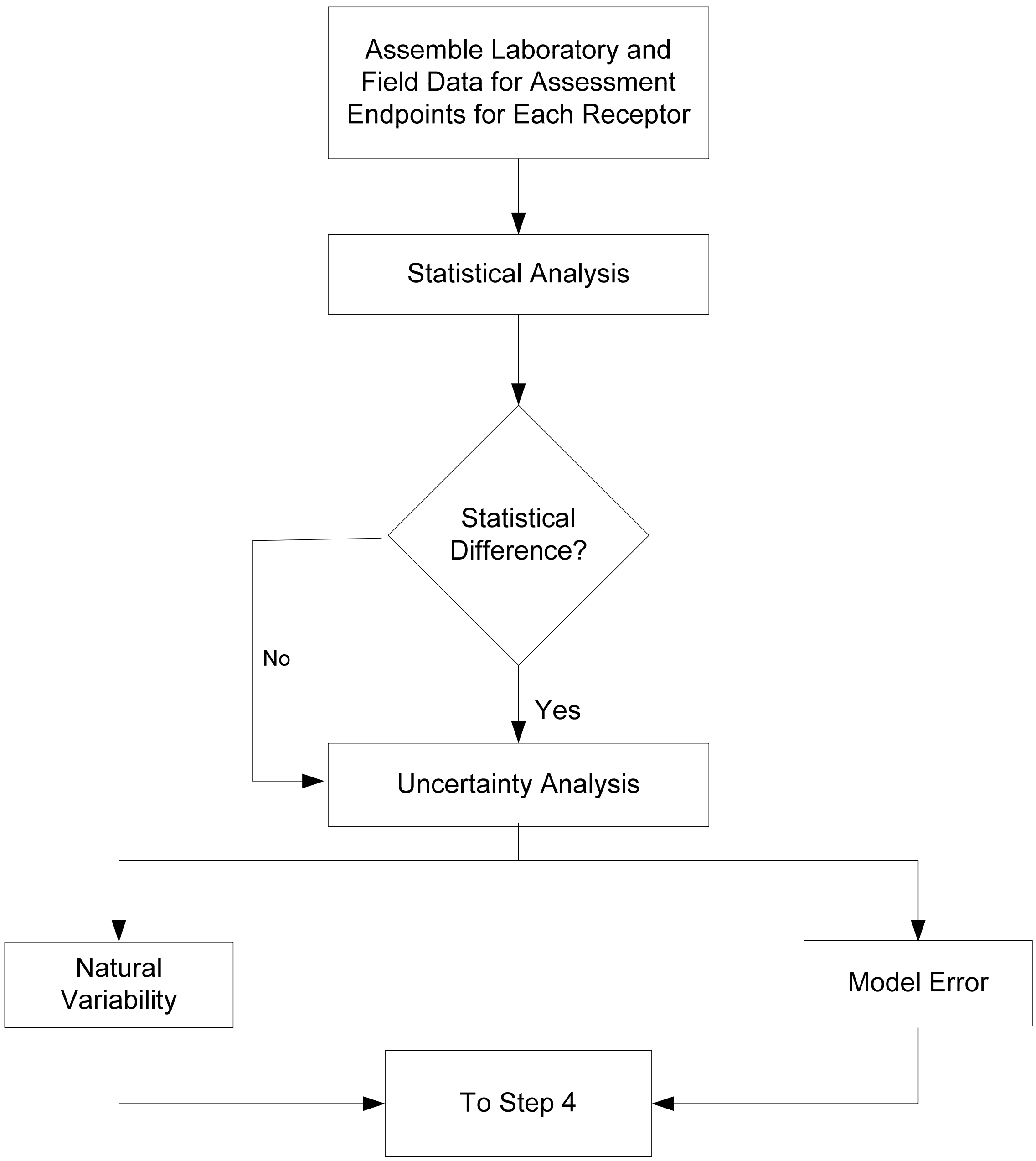
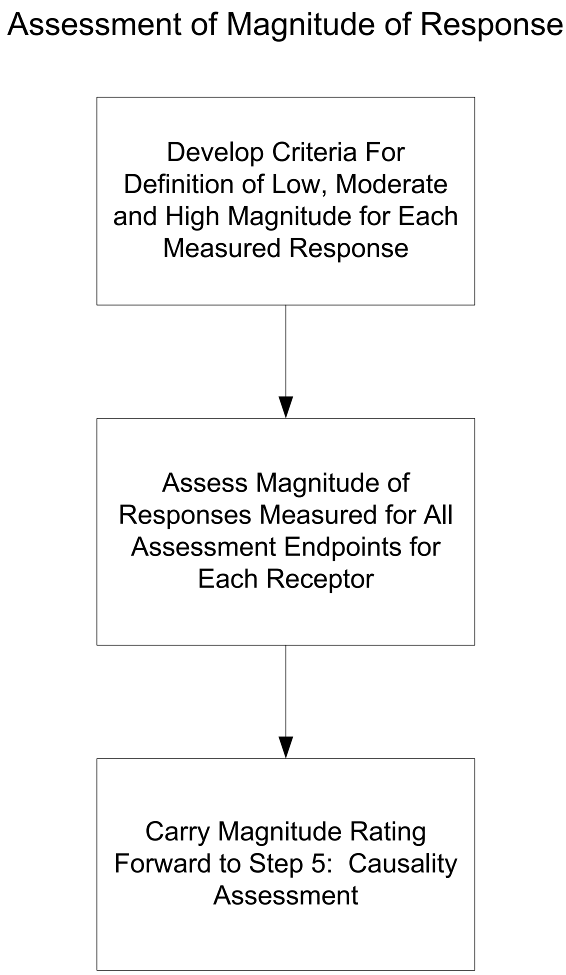


Figure 4.4 Step 4 of the SALE Process



4.3.2 Step 5: Assessment of Causality

Step 5 of the SALE process continues with an evaluation of causality for all lines of evidence (regardless of the magnitude of response, unless *all* responses are weak or inconclusive). Causality is evaluated using a formal set of criteria presented in Hull and Swanson (2006). These causal criteria assume that there will be a proportional response between exposure and effects. Landis (2002) cautions that we should not expect proportionality (i.e., clear and consistent dose-response relationships), because components of the ecosystem are linked, and may be affected by changes in other ecosystem components. However, many authors have succeeded in illustrating a relationship between population- or community-level responses and the exposure to stressors. The causal criteria used in the SALE process are as follows:

- **Spatial correlation:** Effects occur at the same place as exposure; effects do not occur where there is no exposure.
- **Temporal correlation:** Effects occur with or after exposure.
- **Biological gradient/strength:** Effects are greater where or when exposures are greater. Evidence for cause/effect is stronger if the exposure response is monotonic, which produces a relatively high magnitude response.
- **Plausibility (mechanism):** It must be known how the stressor causes an effect in the affected organisms. This will determine whether it is plausible that the observed effects are a result of the stressor. Consideration must be given to indirect mechanisms (e.g., increased nutrient levels in water cause algal blooms that decrease oxygen levels in water, which may decrease invertebrate density).
- **Plausibility (stressor-response):** The magnitude of effect is expected based on the level of the stressor.
- **Consistency of stressor/effect association:** Repeated observation of effect and stressor in different studies or different locations within the region being studied. In addition, there is existing knowledge from other regions where similar (analogous) stressors have caused similar effects.
- **Experimental verification:** Effects of the stressor are observed under controlled conditions and there is concordance of these experimental results with field data.
- **Specificity of Cause:** The tendency for effect to be associated with exposure to a particular stressor. Effects should be defined as specifically as possible to increase the specificity of the association between cause and effect. In the extreme case, causation is clear when a stressor results in only one effect, and that effect is only related to that one stressor. Of course, this is rare in environmental situations.

At least one of the first two causal criteria (spatial or temporal correlation) is considered necessary to make a case for causality. The temporal criterion is essential; however, the spatial criterion may not apply if metapopulation dynamics predominate or if up-gradient movement for reproductive purposes occurs. Both situations can and do result in significant responses being observable first in areas where the particular stressor is very low or non-existent. However, simply having correlation in space or time is insufficient to make a strong case for causality, especially for a large study area such as the AOI with historic contamination and multiple confounding variables (natural and anthropogenic).

A line of evidence was not considered inadequate if it was not supported by all causal criteria. In particular, the "specificity of cause" criterion is rarely met. This is because the measures used are often too general (e.g., abundance) to be linked to one specific stressor.

The results of the examination for causality among the laboratory, mesocosm and field lines of evidence were summarized by applying scores that reflected the performance of each line of evidence against the causal criteria (Table 4.15). The scoring varied with each criterion because each criterion has a different set of results that apply to causation and each criterion has a different level of relative importance to the overall score (Hull and Swanson 2006, U.S. EPA 2000).

Table 4.15 Causation Score Criteria

Criterion	Results	Score
Spatial Correlation	Strong evidence; Compatible; Uncertain; Incompatible	++; +; 0; ---
Temporal Correlation	Strong evidence; Compatible; Uncertain; Incompatible	++; +; 0; ---
Biological Gradient/Strength	Strong , monotonic and consistent among responses and (if applicable) sexes; Weak or other than monotonic or inconsistent among responses or sexes; None; Clear association, but the more the stressor, the lower the response	+++; +; -; ---
Plausible Mechanism	Actual evidence; Plausible; Not known; Implausible	++; +; 0; ---
Plausible Stressor-Response	Quantitatively consistent; Concordant; Ambiguous; Inconcordant	+++; +; 0; ---
Consistency of Association (across sites in the region)	Invariant; In many places and times; At background frequencies or many exceptions to the association	++; +; -
Experimental Verification	Experimental studies: Concordant; Ambiguous; Inconcordant	+++; 0; ---
Specificity of Cause	Only possible cause; One of a few; One of many	+++; ++; 0

4.3.3 Step 6: Risk Characterization

The final weighing of evidence involves summarizing magnitude, causation and uncertainty scores for each line of evidence for each receptor. Consistency of magnitude and causation scores across all lines of evidence provides a higher level of confidence in the recommendation to proceed or not to proceed to a risk management evaluation. High uncertainty scores for a site or area would indicate that a risk management decision may benefit from obtaining more information.

The SALE risk characterization for Conceptual Model 1 proceeded in the following manner:

1) Magnitude and causation scores and the narrative for uncertainty were examined for each line of evidence/site combination.

2) An overall score for uncertainty associated with variability for Conceptual Model 1 was assigned to each line of evidence/site combination.

3) If direct effects on physical habitat had magnitude scores above “low”, then effects on physical habitat were included in the overall risk characterization table.

4) The overall SALE table for each receptor was assembled.

The uncertainty score in the summary SALE tables is for uncertainty related to variability of measures and model error associated with Conceptual Model 1 (direct effects). It does not reflect uncertainty related to Conceptual Model 2 (indirect effects). Model error associated with Conceptual Model 2 was included in the narrative accompanying each SALE summary table.

The system for determining how the scores for magnitude, uncertainty and causation “added up” to a recommendation to proceed to risk management (or not) is presented in Table 4.16. The overall recommendation for each sampling station was based upon the predominant pattern. For example, if more than half of the scores for the lines of evidence indicated that risk management was required, then the overall recommendation was to proceed to risk management. However, if more than half of the scores indicated that risk management was not required, then the overall recommendation was not to proceed with risk management. If uncertainty scores were "high," the "Yes" or "No" answers to the "Proceed with Risk Management" question were accompanied with a recommendation to confirm with more data. If uncertainty scores were moderate, the "Yes" or "No" answers were accompanied with a suggestion that more data may be required to refine the scope and extent of risk management; however, this was only the case when there was a moderate or strong cause/effect link with the smelter.

Table 4.16 System for Summing the Magnitude, Causation and Uncertainty Scores

Magnitude	Causation	Uncertainty	Proceed to Risk Management?
●	●	?	Yes
●	●	??	Yes
●	●	???	Yes but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type I error or the Conceptual Model is incorrect
●	⊙	?	Yes
●	⊙	??	Yes but may want to confirm with more data and revisit the Conceptual Model because the moderate uncertainty may lead to Type I errors
●	⊙	???	Yes but confirm with more data and revisit the Conceptual model because the high uncertainty could mean that there is Type I error or the Conceptual Model is incorrect
●	○	?	No because no cause/effect link and low uncertainty
●	○	??	No because no cause/effect but may want to confirm with more data and revisit the Conceptual Model because the moderate uncertainty may lead to Type I or Type II errors
●	○	???	No but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type I or Type II error or the Conceptual Model is incorrect
⊙	●	?	Yes because of the moderate magnitude, strong cause/effect link and low uncertainty
⊙	●	??	Yes but may want to confirm with more data and revisit the Conceptual Model because the moderate uncertainty may lead to Type I or Type II errors
⊙	●	???	Yes but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type I or Type II error or the Conceptual Model is incorrect
⊙	⊙	?	Yes
⊙	⊙	??	Yes but may want to confirm with more data and revisit the Conceptual Model because the moderate uncertainty may lead to Type I or Type II errors.
⊙	⊙	???	Yes but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type I or Type II error or the Conceptual Model is incorrect
⊙	○	?	No because no cause/effect link

Table 4.16 System for Summing the Magnitude, Causation and Uncertainty Scores (continued)

Magnitude	Causation	Uncertainty	Proceed to Risk Management?
⊙	○	??	No because no cause/effect link but may want to confirm with more data and revisit the Conceptual Model because the moderate uncertainty may lead to Type I or Type II errors
⊙	○	???	No but confirm with more data and revisit the Conceptual Model since there is high uncertainty so the lack of a cause/effect link could be due to a Type II error or incorrect conceptual model
○	●	?	No because of the low magnitude
○	●	??	No because of the low magnitude but confirm with more data because the moderate uncertainty means that there may be Type I or Type II errors
○	●	???	No but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type I or Type II error or the Conceptual Model is incorrect
○	⊙	?	No
○	⊙	??	No
○	⊙	???	No but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type I or Type II error or the Conceptual Model is incorrect
○	○	?	No
○	○	??	No
○	○	???	No but confirm with more data and revisit the Conceptual Model because the high uncertainty could mean that there is Type II error or the Conceptual Model is incorrect

Notes:

Magnitude:

- ● strong response.
- ⊙ moderate response.
- ○ weak response.

Causation:

- ● strong overall strength of causal evidence.
- ⊙ moderate overall strength of causal evidence.
- ○ weak overall strength of causal evidence.

Uncertainty:

- ? low uncertainty (high statistical power, full gradient design, all important natural variables accounted for).
- ?? moderate uncertainty (moderate statistical power, control/impact rather than full gradient design; most natural variables accounted for).
- ??? high uncertainty (low statistical power, important natural variables not accounted for).

4.4 Periphyton

4.4.1 Step 2: Effects Due to Smelter-Related Change in Physical Habitat

There were historic effects on periphyton habitat because of the discharge of slag to the river by the smelter. The slag inundated the natural cobble, gravel or sand surfaces normally occupied by periphyton (Figure 4.5).

Figure 4.5 Historic Discharge of Slag to the Columbia River (Pre-1995 and Installation of Kivcet Smelter)

There is very little remaining impairment of habitat for attached algae caused by slag in the AOI, (Figure 4.6) with the possible exception of high flow years when remnant slag is remobilized and transported downstream. Since the cessation of slag discharge in 1995, most historic slag deposits in shallower water habitats where periphyton occur have been scoured and moved downstream. Remaining slag in shallow-water zones is limited to small amounts trapped in gaps between the cobble or interspersed with the gravel and sand.

Effects on periphyton habitat are caused primarily by flow variation related to the operation of upstream dams. Periphyton in shallower shoreline areas of the river are regularly exposed to desiccation during flow reductions related to river regulation for power production and flood control.

Nutrient conditions were historically higher downstream of Trail because of the discharge from the Teck Cominco fertilizer plant. These discharges resulted in a luxuriant growth of periphyton in some areas of the river (Figure 4.7).

Figure 4.6 Riverbank Conditions c. 2004

*Figure 4.7 Heavy Periphyton (*Fontinalis*) Growth on Cobble During the Period of Discharge from the Cominco Phosphate Fertilizer Plant (Pre-1994)*

Since the cessation of phosphate-rich discharges from the phosphate portion of the Teck Cominco fertilizer plant in 1994, the growth of periphyton and macrophytes in the Columbia River downstream of Trail has dramatically decreased (Figure 4.8). Fertilization of Arrow Lake above the Hugh Keenleyside Dam for fish production enhancement began in 1999 and fertilization of Kootenay Lake has also been occurring for over 10 years. These fertilization programs may be providing some additional nutrient loading to the AOI via the entrainment of zooplankton (especially mysids). However, overall nutrient concentrations in the river are low (G3 Consulting 2001).

Figure 4.8 Reduced Periphyton Growth in the Columbia River since 1994

Storm-water discharges from Trail occur within the initial dilution zone of the smelter. Stressors within storm-water discharge can include nutrients. Trail Creek is affected by urban runoff from Rossland and Warfield and by input from Haley Creek, which is influenced by drainage from legacy waste materials adjacent to the Teck Cominco Fertilizer Operations. In addition, during the timeframe of the periphyton studies, a small number of direct household sewer connections to Trail Creek were still in use (subsequently eliminated by the City of Trail).

A groundwater investigation conducted on the Teck Cominco smelter site revealed two areas of groundwater contamination, one on the northern boundary of the site in the vicinity of Stoney Creek and one on the southeastern margin of the site (Klohn Crippen 2004). The area near Stoney Creek is affected by seepage recharge from Stoney Creek and by the Regal Landfill. Groundwater quality was characterized by high TDS (up to 5,200 mg/L), acidic pH (as low as 5.6), hardness up to 1,610 mg/L, and elevated fluoride, ammonia, nitrite and nitrate concentrations relative to background groundwater concentrations. Aluminum, cadmium, cobalt, manganese, nickel and zinc concentrations also were elevated relative to background. It was estimated that the impacted area extended about 850 m up Stoney Creek, was an estimated 200-300 m wide at the Columbia River, and extended to at least 55 m below the water table.

The groundwater quality in the area near the southeastern margin of the smelter site was characterized by high TDS (up to 6,700 mg/L), neutral pH, high temperatures (up to 24^{o}C), high hardness (up to 2,190 mg/L), high sulphate (up to 4,860 mg/L), high fluoride (up to 6.7 mg/L), and very high ammonia (up to 1,120 mg/L as nitrogen). Concentrations of barium, cadmium, manganese, strontium and zinc were elevated relative to background concentrations. The area of contamination was estimated at 600 m along the Columbia River extending a minimum of 200 m inland and at least 80 m below the water table. Further investigations are underway to confirm the source or sources of contamination and to characterize this plume and its potential impact on the Columbia River.

The groundwater plume at the southeastern margin of the smelter site has the potential to affect the physical habitat of periphyton by creating localized impacts on water temperature. Furthermore, this plume may cause localized exceedances of water quality objectives in the immediate vicinity of discharge into the riverbed (Klohn Crippen 2004).

In summary, current effects of slag on the physical habitat for periphyton in the AOI are minimal. Nutrient concentrations in the river do not indicate that there are substantial effects of nutrient inputs from point and non-point sources in the AOI, with the possible exception of areas adjacent to storm-water discharges from the City of Trail, as well as inputs from Trail Creek and Ryan Creek. The most substantial confounding variable is flow regulation due to operation of dams in the AOI. There is a potential, but highly uncertain, source of effect on physical habitat from the contaminated groundwater plume originating at the smelter site.

4.4.2 Steps 3 and 4: Evaluation of Magnitude and Uncertainty in Periphyton Field and Laboratory Data

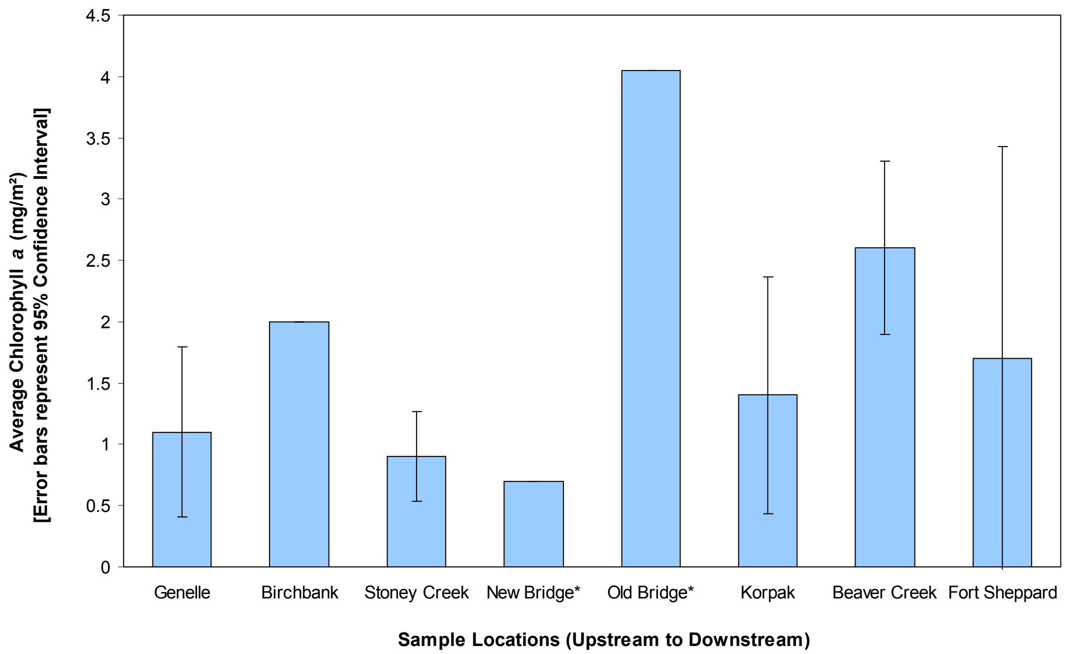
The periphyton community assessment endpoint was evaluated using field studies of periphyton colonization of artificial substrates placed in the Columbia River in a gradient from upstream to downstream (Figure 2.1) (Golder 2007c). In Step 3, the field evidence was examined for statistical differences between upstream and downstream measurements of periphyton community biomass and community structure (Figure 4.3). The uncertainty (both related to natural variability and to support for the two conceptual models) was then assessed. Uncertainty was assessed whether or not statistical differences were observed (Figure 4.3) because uncertainty can affect our ability to detect statistical differences. In Step 4, the magnitude of observed responses in the downstream periphyton community was assessed according to criteria developed to define low, moderate and high magnitude for each of the measured community characteristics (Figure 4.4).

Line of Evidence 1: Algal Biomass (Chlorophyll *a*, Ash Free Dry Weight and Cell Densities)

Unfortunately, statistical analysis of algal biomass data was not possible because of the loss of one of three replicates at the New Bridge and Old Bridge sampling sties. These replicates may have become dislodged by high flows during the one-month colonization period.

There was no strong spatial gradient in chlorophyll *a* concentrations upstream of the smelter-to-downstream in the fall of 2003 (Figure 4.9) (Golder 2007c). All chlorophyll *a* concentrations were in the oligotrophic range for benthic algae growing on natural substrate (Dodds et al. 1998). The only indications of a negative effect on biomass occurred at the New Bridge site immediately downstream of the smelter effluent discharge, and within the initial dilution zone, and at the Stoney Creek site where inflow from Stoney Creek, which is impacted by historic Teck Cominco landfills, enters the Columbia River (Figure 4.9). The landfills discharging to Stoney Creek have been remediated under a separate Teck Cominco risk management program, and consideration of further actions or monitoring that may be required is ongoing.

Figure 4.9 Chlorophyll a Concentrations at Periphyton Sampling Stations from Upstream to Downstream, Fall 2003



* One of the three replicate samplers was lost during the 1-month colonization period, possibly due to high river flows dislodging the sampler.

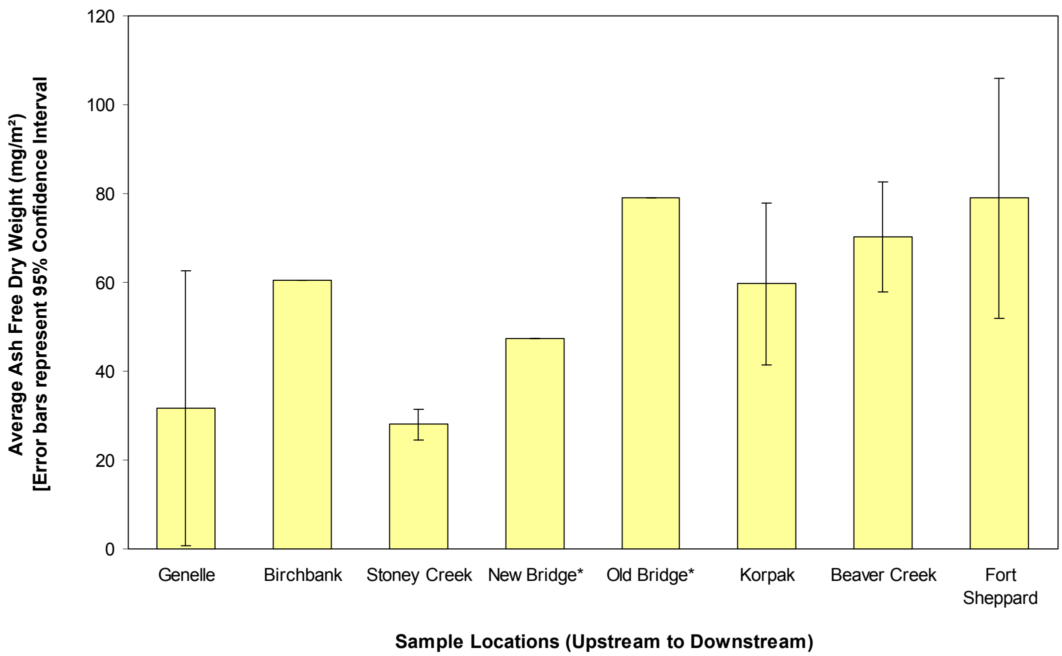
Chlorophyll *a* at the Old Bridge site appeared to rebound to levels that were substantially higher than upstream sites at Genelle and Birchbank. The Old Bridge site is within 500 m of the smelter effluent discharge and edge of the initial dilution zone. It may be affected by inflow from Trail Creek. Trail Creek is affected by legacy runoff from the Teck Cominco Fertilizer Operations, urban runoff and direct household sewer connections, with ammonia loads ranging from 14-156 kg/day. The far-field sites at Beaver Creek and Fort Sheppard had chlorophyll *a* concentrations that were within the same range as the upstream Birchbank site.

Chlorophyll *a* concentrations were higher in the fall of 2003 than in previous studies conducted in the fall of 1995 and 1999 at the upstream Birchbank site as well as the sites at New Bridge, Old Bridge, Korpak and Fort Sheppard. No direct comparisons between previous studies and the 2003 study could be made for the Beaver Creek site as it was not sampled in 1995 or 1999. Chlorophyll *a* concentrations in Stoney Creek and Fort

Sheppard during the spring of 1999 were within the range of mesotrophic conditions (20-70 mg/m^2), but fell back to the oligotrophic ranges in the fall of 1999.

Average ash free dry weight (AFDW) levels in 2003 generally corresponded well with chlorophyll *a* levels measured at the same locations with the exception of New Bridge (expected values would be less than Stoney Creek) and Fort Sheppard (expected values would be between Korpak and Beaver Creek) (Figure 4.10). Similar to chlorophyll *a*, potential negative effects on biomass occurred at the New Bridge and Stoney Creek sites. The apparent discrepancy between some of the AFDW and chlorophyll *a* concentrations is not unusual since AFDW does not distinguish algal material from other non-algal organic material (i.e., bacteria, fungi and detritus).

Figure 4.10 Ash Free Dry Weight at Periphyton Sampling Stations, Fall 2003



* One of the three replicate samplers was lost during the 1-month colonization period, possibly due to high river flows dislodging the sampler.

Current nutrient loading from the smelter is much lower than historic levels and too low to create any "nutrient enrichment". The current periphyton biomass is indicative of oligotrophic conditions, falling well within the range of 0-20 mg/m^2 associated with oligotrophic flowing waters. Nitrogen is still released from the smelter via air (115 tonnes per year in 2006) and water (70 tonnes per year in 2006). The releases to water are via the release of treated effluent as well as groundwater originating from the site. Although measurable, these releases are not sufficient to produce an increase in periphyton biomass to mesotrophic or eutrophic levels.

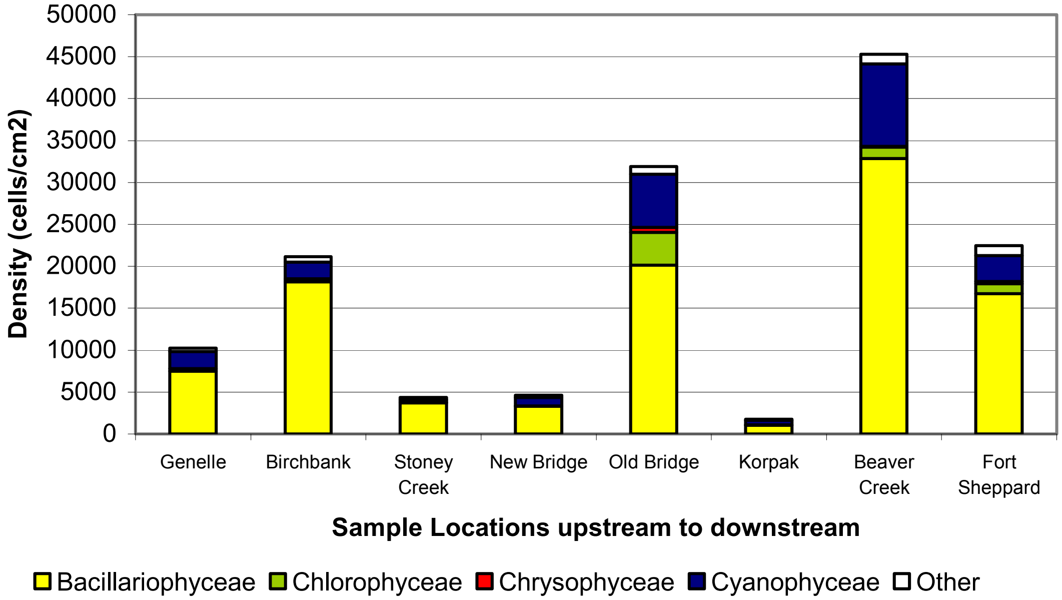
Since the periphyton biomass falls within the range of oligotrophic conditions, any "masking" of PCOC effects by the presence of an abundant supply of nutrients would not occur because nutrients are limiting in the study area. Furthermore, even if nutrients were more abundant, there is no literature that identifies a biological mechanism for "masking" of PCOC effects by nutrients. It is more likely that adequate nutrients provide an environment where periphyton are not stressed by nutrient limitation and so can divert energy into detoxification, sequestration, and/or elimination of excess metal ions.

Future reductions in nutrient loading to the Columbia River system because of reductions in erosion and run-off of nutrients from reclaimed lands or because of source control would simply keep the study area within the already-existing oligotrophic range. It is highly unlikely that any hitherto unobserved effects of PCOC on periphyton would emerge upon further nutrient reduction since these future nutrient reductions would not be sufficient to change the overall nutrient status of the system.

Comparison of periphyton biomass in the AOI with phytoplankton biomass in areas that are being fertilized to boost kokanee production provides further evidence that biomass is low in the AOI. For example, considerable effort has been expended to increase the production of kokanee in Arrow Lakes reservoir via the addition of 232-289 tonnes of nitrogen per year since 1999 and 39.5-52 tonnes of phosphorus per year since 1999 (Schindler et al. 2008). These nutrient additions have resulted in Arrow reservoir chlorophyll *a* concentrations peaking in mid-summer at levels above those observed in the AOI (i.e., 0.7-4 mg/m^2 in the AOI downstream of the smelter and 4-5.5 mg/m^2 in Upper Arrow Lake).

Abundance, as measured by cell density ($cells/cm^2$) showed no consistent pattern from upstream to downstream (Figure 4.11). The range varied greatly between sites, including within reference and within exposure sites. The total periphyton density at Beaver Creek was significantly higher than at Genelle, Korpak, New Bridge and Stoney Creek ($p < 0.05$, Tukey HSD test) (Golder 2007c). Maximum abundance was observed in Beaver Creek (46,441 $cells/cm^2$; standard deviation (SD) = 617,128), followed by Old Bridge (32,797 $cells/cm^2$; SD = 185,079) and Fort Sheppard (23,687 $cells/cm^2$; SD = 419,698). The lowest cell density was observed at Korpak (1,882 $cells/cm^2$; SD = 56,060). Among the three sites sampled upstream from the smelter, Stoney Creek (4,592 $cells/cm^2$; SD = 102,730) had the lowest cell density.

Figure 4.11 Periphyton Cell Densities with Taxonomic Class, Upstream-to-Downstream, Fall 2003



Cell densities measured in 2003 were comparatively lower than those measured at the same station in previous years (spring or fall) (Golder 2007c). The dominant class at all stations in 2003 was Bacillariophyceae (diatoms), followed by Cyanophyceae (blue-green algae). Green algae (Chorophyceae) were present in very low numbers upstream of the smelter; however, densities of green algae increased at the Old Bridge site and were also found in relatively higher numbers than upstream at the Beaver Creek and Fort Sheppard sites. The Old Bridge site was distinctive in the more even distribution among classes. Diatoms were also the dominant class in 1995 and 1999; however, there was lower abundance of cyanobacteria and a higher abundance of green algae (Golder 2007c). In addition, green algae occurred upstream of the smelter, unlike what was observed in 2003. The highest density was found at Fort Sheppard in the spring of 1999, followed by Stoney Creek in the spring of 1999. In both cases, the dominant group was Bacillariophyceae.

Line of Evidence 2: Algal Species Composition

The relative distribution of algal classes can be used as an indication of response to PCOC because some classes (e.g., Bacillariophyceae) contain more sensitive species than others. Therefore, if the proportion of particular algal classes changes, it may be because sensitive taxa are absent and more tolerant taxa predominate.

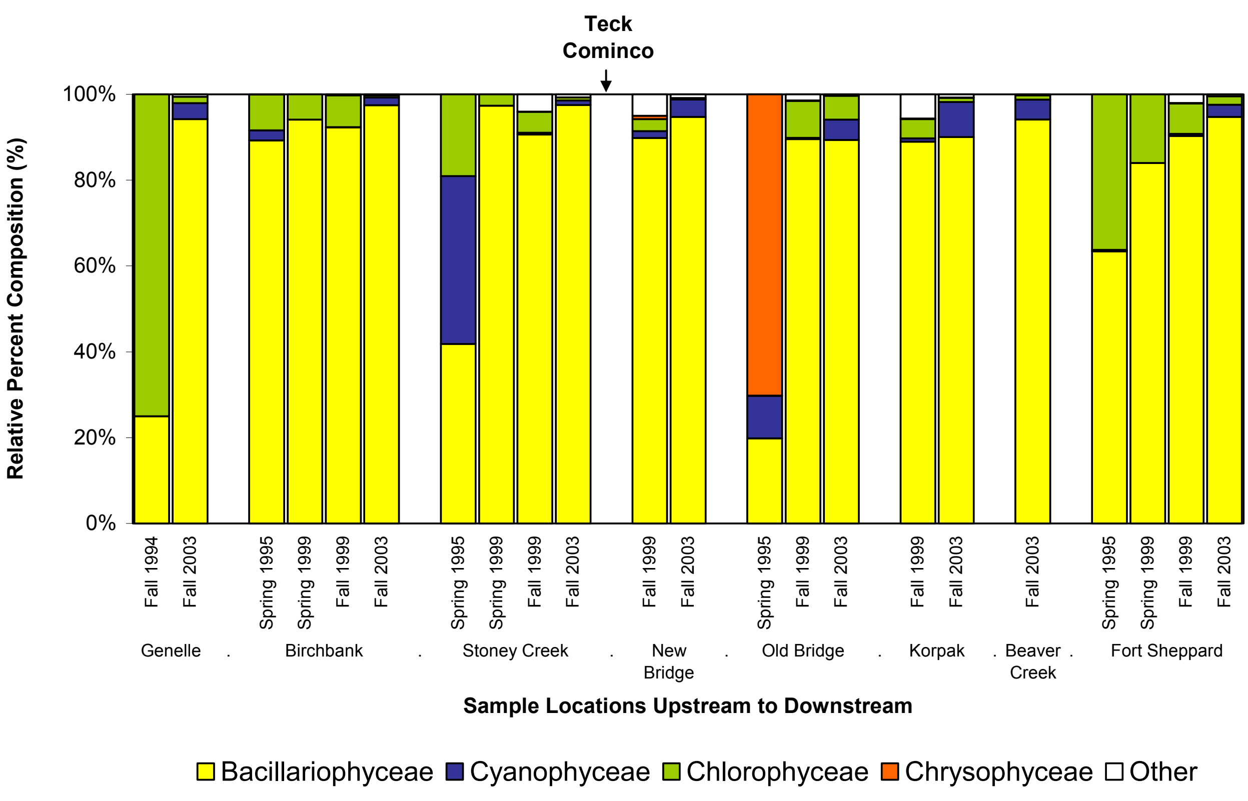
The total number of taxa in samples, Shannon-Weiner Diversity Index, Simpson's Diversity Index, and percent of a sample made up by the dominant taxon, did not differ significantly among the sampled sites (Golder 2007c).

There was no indication of a spatial trend in the presence of algal classes with distance downstream of the smelter in 2003 (Figure 4.12). As noted above, Bacillariophyceae was the most dominant class at all sites. Decreased predominance of diatoms and increased presence of green algae occurred at the Old Bridge site.

There was also no consistent spatial trend upstream-to-downstream in the period 1995 to 2003 (Golder 2007c). The Old Bridge site was the most distinctive site in all three sampling years (1995, 1999, 2003), showing a high proportion of golden yellow algae (Chrysophyceae) in 1995, then shifting to dominance by diatoms in 1999, and then showing a more diverse distribution in 2003, with diatoms, cyanobacteria, green algae, golden yellow algae and "other" classes all occurring.

Earlier studies had shown an increase in the overall abundance of diatoms (Families Centrales and Pennales) and a decrease in blue-green algae between 1995 (pre-Kivcet smelter) and 1999 (post-Kivcet smelter) (Duncan 1999; G3 Consulting 2001). Conversely, green (Chroococcales) and cyanobacteria (Oscilliatoriales) families were present at some sample sites in 1995, but were not observed at these same sites in 1999 (Duncan 1999; G3 Consulting 2001). This was interpreted as being consistent with observations that diatoms decrease in abundance while filamentous green algae or cyanobacteria increase in abundance in locations with elevated metals (Clements 1991). The recovery of diatoms and a decrease in blue-green algae in 1999 may reflect the decrease in metals since the Kivcet smelter was installed (G3 Consulting 2001); however, cyanobacteria increased in 2003 at most stations relative to 1999.

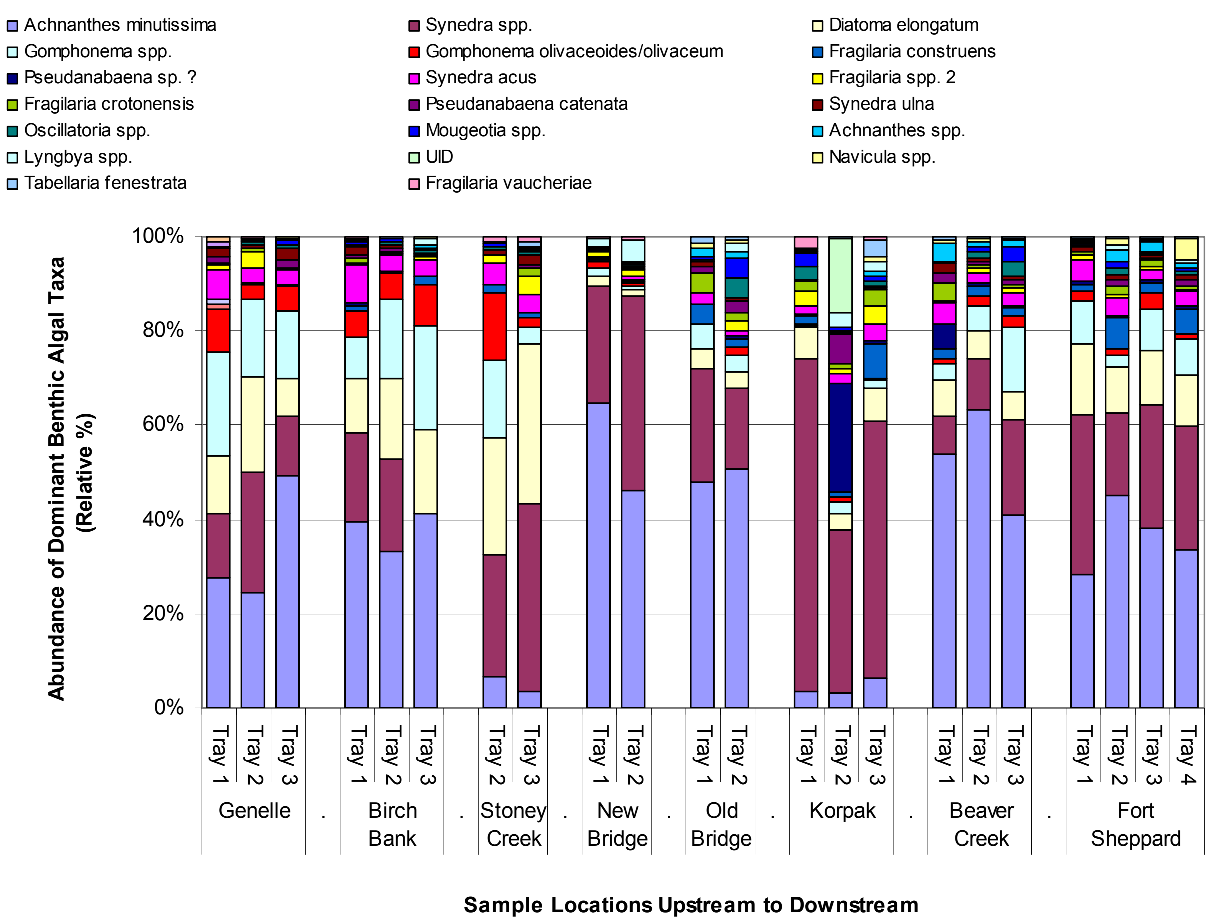
Figure 4.12 Columbia River Algae (Periphyton) on Artificial Substrates, Percent (%) Abundance by Class



A suggested list of periphyton indicator species for the Columbia River study area was developed by G3 Consulting (2001). The diatoms *Cymbella minuta, Diatoma elongatum, Fragilaria vaucheriae, Gomphonema* cf *olivaceum,* and *Tabellaria fenestrata*, are sensitive to some metals (particularly copper and zinc). The New Bridge location had much lower abundance of some of these sensitive species (Figure 4.13, Golder 2007c). The metal-tolerant diatoms *Synedra ulna* and *S. acus* were present in similar numbers upstream and downstream of the smelter, except at the New Bridge and Korpak, where they were much less abundant. This is the opposite pattern to what would have been expected, especially at the New Bridge site. The results at the New Bridge site may reflect the influence of high water velocity, where colonization of all species may have been limited due to constant scouring of the samplers.

Bray-Curtis similarity matrices showed that the species assemblages at upstream (Genelle and Birchbank) and far-field areas (Beaver Creek and Fort Sheppard) had a high level of similarity both within and between areas (Golder 2007c). The Korpak site was the most dissimilar to all other sites. The Korpak site was also dissimilar to other sites in the 1999 periphyton study, indicating the presence of local stressors, possibly related to local influences such as Trail Creek (which is affected by legacy runoff from the Teck Cominco Fertilizer Operations, urban runoff and direct household sewer connections and Ryan Creek (which contains elevated PCOC concentrations, including cadmium and zinc) (Golder 2007c).

Figure 4.13 Periphyton Community Composition, Fall 2003



The Shannon-Weiner Index was significantly negatively correlated with concentrations of lead and thallium ($p < 0.05$) (Golder 2007c). The Simpson's Index was significantly negatively correlated with concentrations of lead ($p < 0.01$) and thallium ($p < 0.05$), and the percentage of a sample made up of the dominant taxon was significantly positively correlated ($p < 0.05$) with the concentration of thallium (Golder 2007c). Concentrations of thallium and lead were significantly correlated with each other ($p < 0.05$).

The statistical correlations do not correspond with exceedances of water quality objectives. Teck Cominco and B.C. MOE monitoring data show that thallium concentrations did not exceed water quality objectives at either the New Bridge or Old Bridge in 2003 (Golder 2007b). The only PCOC that exceeded objectives in 2003 were cadmium and zinc (Golder 2007b).

The proportion of a given phytoplankton taxon in samples was generally not significantly correlated with the metal concentration at the sampling location (Golder 2007c). Of 124 separate phytoplankton taxa, metal concentrations were significantly correlated ($p < 0.05$) with 21 of the taxa.

Thallium was significantly negatively correlated with the largest number of taxa (12) and also was not significantly positively correlated with any taxa (Golder 2007c). The negative correlations were with 10 diatom species, 1 green alga and 1 golden yellow alga. Zinc had significant negative correlations with 5 taxa (3 diatoms, 1 green alga and 1 cyanobacterium) and significant positive correlations with 2 taxa (the diatoms *Rhizosolenia* sp. and *Fragilaria vaucheriae*). Lead also had significant negative correlations with 5 taxa (3 diatoms, 1 green alga and 1 golden yellow alga). There was one significant positive correlation between lead and the diatom *Achnanthes minutissima*. Cadmium had significant negative correlations with 4 taxa (2 diatoms, 1 green alga and 1 cyanobacteria), and 2 positive correlations with the diatoms *Rhizosolenia* sp. and *Fragilaria vaucheriae*. Arsenic concentrations were significantly negatively correlated with the diatoms *Cymbella ventricosa,* and *C. cistula*. There were 4 significant positive correlations between arsenic and algal taxa (the diatoms *Diatoma elongatum* and *Fragilaria vaucheriae*, and unidentified diatom and the green alga *Schroederia* spp.).

The significant correlations do not always corroborate earlier suggestions made by G3 Consulting (2001) regarding the taxa that are sensitive to metals in the study area. The G3 Consulting report suggested that the diatoms *Cymbella minuta, Diatoma elongatum, Fragilaria vaucheriae, Gomphonema* cf *olivaceum,* and *Tabellaria fenestrata*, are sensitive to some metals (particularly copper and zinc). However, in 2003, *Diatoma elongatum* was positively correlated with arsenic and *Fragilaria vaucheriae* was positively correlated with arsenic, cadmium and zinc.

Bray-Curtis similarity matrices showed that the species assemblages at upstream (Genelle and Birchbank) and far-field areas (Beaver Creek and Fort Sheppard) had a high level of similarity both within and between areas (Golder 2007c). The Korpak site was the most dissimilar to all other sites. The Korpak site was also dissimilar to other sites in the 1999 periphyton study, indicating the presence of local stressors, possibly related to local influences such as Trail Creek (which is affected by legacy runoff from the Teck Cominco Fertilizer Operations, urban runoff and direct household sewer connections and Ryan Creek, which contains elevated PCOC concentrations, including cadmium and zinc).

Summary of the Periphyton Lines of Evidence

Average chlorophyll *a* levels in 2003 were within the expected range of 0-20 mg/m² for oligotrophic (nutrient poor) mountain streams. There was no strong spatial gradient in chlorophyll *a* upstream-to-downstream. The only indications of a negative effect occurred at the New Bridge site within the initial dilution zone and at the Stoney Creek site where inflow from Stoney Creek, which is impacted by historic Teck Cominco landfills (now remediated), enters the Columbia River.

Average AFDW levels in 2003 generally corresponded well with chlorophyll *a* levels measured at the same locations. Similar to chlorophyll *a*, potential negative effects on biomass occurred at the New Bridge and Stoney Creek sites.

Among the sites sampled during Fall 2003, maximum abundance was observed at downstream sites (Beaver Creek, followed by Old Bridge and Fort Sheppard). The lowest cell density was observed at Korpak. Among the three sites sampled upstream from the smelter, Stoney Creek had the lowest cell density.

There was no indication of a spatial trend in the presence of algal classes with distance downstream of the smelter in 2003. Bacillariophyceae (diatoms) was the most dominant class at all sites. Decreased predominance of diatoms and increased presence of green algae occurred at the Old Bridge site.

The dominant order in all cases was Pennales (within the Bacillariophyceae), which is typical of attached algal communities. The dominant species was *Achnanthes minutissima* at all sites except Korpak and one of the three replicates at Stoney Creek. In general, the downstream sites had less similarity among them than was observed among upstream sites. The Fort Sheppard site had greater similarity to upstream sites than to the other downstream sites.

The 2003 species composition was not consistent with what would be expected when compared with a suggested list of periphyton indicator species for the Columbia River study area prepared by G3 Consulting (2001). For example, while the New Bridge location had much lower abundance of some sensitive species, the metal-tolerant diatoms were also much less abundant. This result may be related to the high-velocity conditions at the New Bridge site; these conditions may have caused a general limitation of colonization of the samplers placed at this location. However, it may simply reflect year to year variability in the periphyton community in response to differences in river flow, weather, etc.

Although there were correlations between lead and thallium concentrations and the presence of specific taxa, these correlations did not correspond with exceedances of water quality objectives. This lack of correspondence indicates that the statistical correlations are not a strong or reliable indicator of a cause/effect link between the PCOC and species composition (see the analysis of causation below).

Bray-Curtis similarity matrices showed that the species assemblages at upstream (Genelle and Birchbank) and far-field areas (Beaver Creek and Fort Sheppard) had a high level of similarity both within and between areas (Golder 2007c). The Korpak site was the most dissimilar to all other sites.

Magnitude of Response in the Periphyton Lines of Evidence

The criteria for judging the magnitude of response in the periphyton lines of evidence (Table 4.17) are defined in terms of periphyton community biomass and community composition. The magnitude of response in the three measures of biomass (chlorophyll *a*, ash free dry weight and cell density) was evaluated using three criteria: (1) whether there was any change downstream versus upstream of the smelter in 2003; (2) whether there was an indication of a gradient in the response, i.e., changes in biomass decreased with increasing distance from the smelter in 2003; and, (3) the degree of consistency in responses downstream of the smelter observed in the 1999 post-Kivcet study and the 2003 study. As explained above, statistical criteria could not be used for evaluating magnitude because of the loss of replicates at the New Bridge and Old Bridge sites. Therefore, “change” was evaluated qualitatively by visually comparing biomass downstream of the smelter with the two upstream sites at Genelle and Birchbank.

The magnitude of response in measures of community composition was evaluated by examining: (1) statistically significant differences in community metrics upstream versus downstream of the smelter; (2) statistically significant correlations between community metrics and concentrations of PCOC; and (3) the degree of similarity among sites as determined by the Bray-Curtis analysis. The magnitude criterion for the qualitative measure of “presence of sensitive or tolerant species” is a narrative based upon a conservative interpretation of the relative occurrence of sensitive or tolerant species, i.e., all it takes is a difference in one species to push the magnitude from low to moderate.

Table 4.17 Magnitude Criteria for Periphyton Lines of Evidence

Line of Evidence	Method of Assessment of the Line of Evidence	Evidence of Negligible to Low Magnitude ○	Evidence of Moderate Magnitude ⦿	Evidence of High Magnitude ●
Periphyton Community Biomass	Qualitative analysis of trends in chlorophyll *a*, ash free dry weight and cell density upstream-to-downstream of the smelter. Statistical analysis was not conducted because of the loss of 1 of 3 replicates at the New Bridge and Old Bridge sites.	No decline in chlorophyll *a*, ash free dry weight or cell density downstream of the smelter.	Some decline in chlorophyll *a*, ash free dry weight and/or cell density downstream of the smelter relative to upstream, but no evidence of a gradient in the response, i.e., decreasing response with increasing distance downstream.	Definite decline in chlorophyll *a*, ash free dry weight and cell density downstream of the smelter relative to upstream and evidence of a gradient in the response, i.e., responses decrease with increasing distance downstream.
Periphyton Community Composition	Statistical analysis community metrics versus PCOC concentrations of upstream-to-downstream sites; narrative description of presence of metal-sensitive taxa and metal-tolerant taxa.	No significant difference ($p < 0.05$) in community composition metrics at the site vs. other sites; no significant correlation between community metrics and PCOC concentration; Bray-Curtis analysis shows site is similar with all others; no difference in presence of metal-sensitive or metal-tolerant species.	A significant difference ($p < 0.05$) in community metrics at the site vs. other sites; at least one statistically significant ($p < 0.05$) correlation between community composition metrics and PCOC concentration; Bray-Curtis shows site is dissimilar with at least one other site; a difference in presence of at least one metal-sensitive or metal-tolerant species.	A significant difference ($p < 0.05$) in community metrics at the site vs. most or all other sites; most or all community metrics have a significant correlation with PCOC concentration; Bray-Curtis shows site is dissimilar to most or all other sites, especially sites with lower PCOC concentrations; difference in presence of several metal-sensitive or metal-tolerant species.

The New Bridge site had one high-magnitude response, based upon several significant correlations between lead and thallium concentrations and specific taxa (Golder 2007c). This site had two moderate-magnitude responses, one for density and another for presence of sensitive or tolerant taxa. The moderate magnitude ranking for density was based upon the decline in chlorophyll *a* and cell density at the New Bridge site relative to upstream sites at Genelle and Birchbank. The moderate magnitude ranking for the presence of sensitive or tolerant taxa was based upon the decreased presence of some sensitive taxa, paradoxically combined with a decreased presence of tolerant taxa. The lack of consistency led to a moderate rather than a high ranking (Table 4.18).

The Korpak site had one moderate and one high magnitude response (Table 4.18). There were significant negative correlations between the proportion of specific taxa and cadmium and zinc concentrations at this site. The Korpak site was also dissimilar to other sites when examined using the Bray-Curtis similarity index.

All other sites except the Genelle site had at least one significant negative correlation between the proportion of specific taxa and the concentration of arsenic, cadmium, lead, thallium and zinc. These findings were given a moderate magnitude ranking.

Uncertainty in Periphyton Lines of Evidence

There are two major sources of uncertainty: natural variability and our understanding of how the smelter may cause effects, either directly, or indirectly (which is portrayed in the two conceptual models). Uncertainty in the assessment of the magnitude of response was evaluated according to how well natural variability was addressed and how well the data supported the conceptual models of smelter-related effects (Table 4.19).

The criteria for judging the amount of uncertainty presented in Table 4.19 were used for all of the lines of evidence (for attached algae, benthic invertebrates and fish). The following discussion presents the reasoning behind the criteria. This reasoning was applied to all lines of evidence.

Table 4.18 Magnitude Ratings for Periphyton Lines of Evidence

Sites	Biomass: Total Cell Density	Biomass: Chlorophyll *a*	Biomass, Ash Free Dry Weight	Statistical Difference in Community Metrics Between the Site and Other Sites	Significant Correlation Between Community Metrics and PCOC Concentrations	Similarity as Measured by Bray-Curtis Analysis	Presence of Indicator Sensitive or Tolerant Taxa
Reference Sites							
Genelle	○	○	○	○	○	○	○
Birchbank	○	○	○	○	◉	○	○
Exposure Sites							
Stoney Creek	◉	◉	○	○	◉	○	○
New Bridge	◉	◉	○	○	●	○	◉
Old Bridge	○	○	○	○	◉	○	○
Korpak	●	○	○	○	◉	◉	○
Beaver Creek	○	○	○	○	◉	○	○
Fort Sheppard	○	○	○	○	◉	○	○

Note:
● = high magnitude.
◉ = moderate magnitude.
○ = low magnitude.

Table 4.19 Criteria for Uncertainty Scores

Source of Uncertainty	Uncertainty Score		
	Low **?**	**Moderate** **??**	**High** **???**
Natural Variability	acceptable statistical power in the sampling design (minimum is $\beta \leq 0.1$ and $\alpha \leq 0.1$ as per EEM requirements); all important natural variables that affect the periphyton response are quantified; and all measurements of the response (e.g., cell density and chlorophyll *a* for biomass; species richness, species evenness) show consistent direction, magnitude of response.	statistical power in the sampling design is less than EEM requirements; most important natural variables that affect the periphyton response are quantified and others that are not quantified are described with a narrative; and most measurements of the response show consistent direction, magnitude of response.	statistical power in the sampling design is much less than EEM requirements; most important natural variables that affect the response are not quantified, and narrative descriptions are not always available for those that are not quantified; and measurements of the response do not show consistent direction, magnitude of response.
Conceptual Model 1 (Direct Effects) Model Error	Several Lines of Evidence Available *and* They Indicate Direct Effects several lines of evidence from the laboratory and the field indicate the presence of direct effects. All Important Confounding Variables Quantified *and* They Do Not Account for All of the Observed Responses all important confounding anthropogenic variables that affect the periphyton response are quantified *and* their contribution to the observed biological response is well-understood *and* the responses to the other stressors do not account for all observed responses; therefore, the conceptual model can still be valid.	At Least Two Lines of Evidence *and* They Indicate Direct Effects at least two lines of evidence indicate the presence of direct effects. Most Confounding Variables Quantified *and* They Do Not Account for All of the Observed Responses most of the important confounding anthropogenic variables that affect the biological response are quantified and others that are not quantified are described with a narrative *and* the contribution to the observed biological response is understood for at least some of the stressors *and* the responses to the other stressors may account for most of the observed responses; therefore, the validity of the conceptual model is in question.	Only One Line of Evidence *or* Most or All Lines of Evidence Do Not Indicate Direct Effects only one line of evidence or no lines of evidence indicate direct effects. Confounding Variables Not Quantified *or* They Do Account for Most or All of the Observed Responses most of the important confounding anthropogenic variables that affect the response are not quantified, *or* narrative descriptions are not always available for those that are not quantified, *or* the confounding variables are quantified and the responses to the other stressors accounts for all of the observed responses; therefore, the conceptual model does not apply.

Table 4.19 Criteria for Uncertainty Scores (continued)

Source of Uncertainty	Uncertainty Score		
	Low ?	**Moderate** ??	**High** ???
Conceptual Model 2 (Indirect Effects) Model Error	Data Available *and* They Strongly Support Hypotheses of Indirect Effects relevant experimental and field data are available that test the hypothesis of indirect effects *and* indirect effects are the most plausible explanation for responses observed in experimental data obtained using environmentally realistic concentrations of PCOC; and indirect effects strongly indicated by quantitative field data because response is greater than expected at the observed PCOC concentrations, *and* the pattern of response cannot be explained on the basis of direct effects of PCOC concentrations alone, *and* concurrent data for all major trophic levels indicate the strong possibility of trophic cascade effects. Sufficient Knowledge to Develop Hypotheses of Multiple Stressor Effects *and* Data Support these Hypotheses multiple stressor effects in the receiving environment are well-understood because of relevant experimental data for that environment and/or comprehensive field data that show responses that are explained best by indirect mechanisms *and* the observed responses are in accordance with the understanding of multiple stressor effects in the study area.	Limited Data Available *and* Some Data Support Hypotheses of Indirect Effects limited experimental or field data are available that test the hypothesis of indirect effects *and* indirect effects are one of the plausible explanations for experimental data obtained using environmentally realistic concentrations of PCOC; and indirect effects are indicated by quantitative field data because response is greater than expected at the observed PCOC concentrations, *or* the pattern of response cannot be explained on the basis of direct effects of PCOC concentrations alone, *or* concurrent data for all major trophic levels indicate the possibility of trophic cascade effects. Limited Knowledge with Tentative Hypotheses of Multiple Stressor Effects *and* Data are in Partial Accordance with These Hypotheses multiple stressor effects in the receiving environment are somewhat understood because of some relevant experimental data for that environment and/or limited field data that show responses that are explained best by indirect mechanisms *and* the observed responses are at least partly in accordance with the understanding of multiple stressor effects in the study area.	No Data Available *or* the Data Do Not Support Hypotheses of Indirect Effects experimental or field data that test the hypothesis of indirect effects are not available *or* indirect effects are not a plausible explanation for experimental data obtained using environmentally realistic concentrations of PCOC; and indirect effects are not indicated by quantitative field data because response is what is expected at the observed PCOC concentrations, *or* the pattern of response can be explained on the basis of direct effects of PCOC concentrations alone, *or* concurrent data for all major trophic levels indicate no trophic cascade effects. Insufficient Knowledge to Develop Hypotheses of Multiple Stressor Effects *or* Data are not in Accordance with Multiple Stressor Hypotheses multiple stressor effects in the receiving environment are not understood because of the lack of any relevant experimental data for that environment and/or the lack of any field data that show responses that are explained best by indirect mechanisms *or* multiple stressor effects are well understood or somewhat understood and the observed responses are not in accordance with this understanding.

Note:

? low uncertainty (high statistical power, full gradient design, all important natural variables accounted for).

?? moderate uncertainty (moderate statistical power, control/impact rather than full gradient design; most natural variables accounted for).

??? high uncertainty (low statistical power, important natural variables not accounted for).

Uncertainty was judged by the ability of the sampling design to distinguish a response from natural variability. Natural variability is the result of the response of aquatic biota to factors such as water depth, flow, substrate characteristics, temperature and light penetration. Natural variability can be very large, which creates challenges in distinguishing a response to PCOC from a response to natural variables. For example, the difference in attached algae abundance between a site upstream of the smelter and another site downstream of the smelter may be due to differences in water velocity at the two sites and not PCOC discharged by the smelter. The statistical power in the sampling design was the primary criterion for judging the uncertainty related to natural variability. Statistical power was evaluated based upon requirements of the Environment Canada EEM program.

Uncertainty was also judged by how well the relative role of natural variables in determining the characteristics of aquatic populations and communities was understood (the second row of bullets under “natural variability” in Table 4.19). Observational field studies (such as those conducted for this assessment) should include measurement of all important natural variables that could contribute to the measured response in aquatic life. If measurement is not practical, then a narrative description of the variables should be produced (e.g., a description of the relative amount of growth of rooted aquatic plants).

There was more confidence that natural variability was accounted for in the study design if all measurements of the response to the smelter showed a consistent direction (i.e., increase or decrease) as well as a consistent magnitude. Responses within sites closer to the smelter (where PCOC concentrations can be higher) should be similar, and responses should decrease with decreasing PCOC concentration. Therefore, another criterion used to judge uncertainty is consistency in the measured response (the third row of bullets under “natural variability” in Table 4.19).

There was more confidence that the two conceptual models were not in error if the data supported the models (Table 4.19). Model error is a reflection of our ignorance about how stressors affect aquatic populations and communities. The two conceptual models developed for this assessment put forward the ideas that: (1) the PCOC emitted from the smelter directly affect aquatic life through exposure via water, sediments or in food items; and (2) smelter emissions indirectly affect aquatic life through physical changes in habitat quality or through changes in the abundance or distribution of prey and predators. One or both of these conceptual models could be in error.

The uncertainty due to natural variability was judged to be moderate because: the study design did not have a high level of statistical power; several variables known to affect periphyton communities were not accounted for in the sampling design; confounding anthropogenic stressors were present near at least one of the downstream sampling sites; there was a lack of correspondence between statistical correlations with PCOC and exceedances of water quality objectives; and there was a disparity between cell density and algal biomass in 2003.

Insufficient data were available before the implementation of the periphyton study to calculate the required number of replicates per site to achieve the desired statistical power of $\beta = 0.1$ with α of 0.1 (as per Environment Canada EEM requirements). In retrospect, there should have been 6 or 7 replicates per site instead of 3. Notwithstanding the lower-than-ideal statistical power, responses that were distinguishable from natural variability were detected in response to the gradient in PCOC concentrations. However, the magnitude of the response may be underestimated because of the low statistical power.

The development of periphyton communities is determined by the combination of physical habitat characteristics, the relative competitive advantage of various algal taxa under the current habitat conditions, and the changes created by the periphyton on habitat conditions (which can give a competitive advantage to new species). The sampling design did not account for all of these variables. Algae that grow quickly and adhere closely to the substrate such as diatoms are usually first to colonize followed by algae that are better competitors and that adhere more loosely to the substrate such as filamentous cyanobacteria and green algae (Cattaneo 1983; Peterson and Grimm 1992). Species richness is often greater in early colonization when compared with later colonization (Peterson and Grimm 1992). During high flow events, resident periphyton communities may be scoured away from substrate surfaces, causing the periphyton assemblage to be "reset" to early colonizers. Hydrological regime and frequency of high flow events are important factors that determine periphyton community structure. Therefore, it is difficult to compare periphyton community assemblages between years in a waterbody that has a variable hydrological regime even if samples were collected on the very same day. Water velocity is another important natural variable. Water velocity varied among the sampling sites, with highest velocities at the Korpak and New Bridge sites (1.3 and 1.0 m/s, respectively).

Potentially confounding anthropogenic stressor sources along the gradient of smelter-related PCOC include storm-water discharges from the city of Trail, Trail Creek and Ryan Creek. Storm-water discharges from Trail occur within the initial dilution zone of the smelter directly confounding the interpretation of data from the New Bridge and Old Bridge sites in particular. Stressors within storm-water discharge can include nutrients, metals, and organic compounds. Trail Creek is affected by urban runoff from Rossland and Warfield and by input from Haley Creek, which is influenced by drainage from legacy waste materials adjacent to the Teck Cominco Fertilizer Operations. In addition, during the timeframe of the periphyton studies, a small number of direct household sewer connections to Trail Creek were still in use (subsequently eliminated by the City of Trail). Trail Creek input is most likely to confound the interpretation of data from the Old Bridge and Korpak sites. Ryan Creek contains elevated PCOC concentrations, including cadmium and zinc, possibly related to a combination of natural mineralization in the watershed, and historic mining activity in the upper portion of the watershed. Ryan Creek input is most likely to confound the interpretation of data from the Korpak site.

The lack of correspondence between statistical correlations of PCOC with specific taxa and exceedances of water quality objectives indicates that other factors may be influencing the presence of specific taxa, as discussed above. Water quality objectives are conservative, i.e., they are designed to be protective of all taxa, including the most sensitive taxa. Therefore, if PCOC concentrations are below objectives, there is high uncertainty with respect to any relationship between these concentrations and the presence of specific periphyton taxa.

Periphytic algal cell densities corresponded well with algal biomass (chlorophyll *a*) for all years and stations except 2003. Although cell densities were lower in the fall of 2003 compared with the same stations sampled in the fall of 1999, biomass was higher. An examination of the relationship between cell density and biomass may not be practical, however, because biomass during these times was very low and ranged from 0.005 μg/cm² at New Bridge in 1999 to 0.45 μg/cm² at Old Bridge in 2003. The inconsistency also cannot be explained by differences in biovolumes since dominant taxa were generally of similar size or smaller in 2003 compared with 1999.

There is a low-to-moderate level of confidence in Conceptual Model 1 because, although there were moderate-magnitude responses in abundance at the New Bridge and Korpak sites, statistical correlations between PCOC and specific periphyton taxa at all sites, and an overall statistical distinction between the Korpak site and all other sites, confounding natural and anthropogenic stressors are present at all of these sites. In particular, the high-velocity conditions at the New Bridge site may have limited colonization on the samplers while confounding stressors originating from storm-water discharges, and input from Trail and Ryan Creeks may have influenced the results at the Old Bridge and Korpak sites. Therefore, there is uncertainty regarding the relative role of exposure to PCOC via the linkages in Conceptual Model 1 versus the effect of linkages to other stressors.

There is a lower level of confidence (and thus a moderate-to-high level of uncertainty) in Conceptual Model 2 because of a combination of a lack of experimental and field data collected to test hypotheses of indirect effects, and a fundamental lack of understanding of how, why and when indirect effects might occur in the study area. There are no experimental data regarding indirect effects using environmentally realistic concentrations of PCOC for the study area. The pattern of response in the field is not strongly indicative of indirect effects because the observed responses in the periphyton community can be explained by a combination of natural variability, near-field effects of PCOC and confounding anthropogenic stressors. Multiple stressor effects in the study area are not understood because of the lack of any relevant experimental data and the lack of any field data that show responses that are explained best by multiple stressor effects.

The level of confidence in the ability to assess future risks is limited by the extent to which the operation of the smelter can be predicted. This assessment assumes that the smelter outputs can reasonably be predicted for 10-20 years. During this period, climate change will not affect the main stem Columbia River as much as in other areas because of the storage capacity in the Columbia River system due to impoundments. Furthermore, the terms of the Columbia River Treaty govern how river flow is managed. This assessment assumes no change in the terms of the Treaty. Therefore, a change in river flows and volumes sufficient to affect PCOC concentrations is not anticipated for the 10-20 year time period identified for this assessment.

Summary of Evidence for Direct and Indirect Effects on Periphyton

No direct effects on periphyton from physical changes in habitat are expected from current smelter operations because slag discharge ceased in 1995 and existing slag deposits have been scoured and removed or greatly reduced in water depths that would support periphyton growth. The exception may be direct effects from a high-temperature groundwater plume originating from the smelter site. This groundwater plume is still under investigation; however, effects of this plume would be expected to occur in the near-field (i.e., New Bridge, Old Bridge or Korpak). In addition, there may be some highly-localized nutrient inputs via storm-water discharges from the City of Trail as well as Trail Creek (due to legacy waste materials adjacent to the Teck Cominco Fertilizer Operations).

There is some evidence for direct effects from PCOC on the periphyton community (Conceptual Model 1). The abundance assessment endpoint was affected at the Stoney Creek, New Bridge, and Korpak sites. There was no indication of a spatial trend in the presence of algal classes with distance downstream of the smelter in 2003. The dominant order in all cases was Pennales (within the Bacillariophyceae), which is typical of attached algal communities. The 2003 species composition was not consistent with what would be expected when compared with a suggested list of periphyton indicator species for the Columbia River study area prepared by G3 Consulting (2001). For example, while the New Bridge location had much lower abundance of some sensitive species, the metal-tolerant diatoms were also much less abundant. Although there was at least one negative correlation between community metrics and PCOC concentrations at all sites except Genelle, these statistical correlations did not correspond with PCOC concentrations that exceeded water quality objectives.

There is no evidence for indirect effects of PCOC on periphyton biomass (Conceptual Model 2). Initially, the Old Bridge site data appeared to indicate that there could be effects via a reduction in sensitive benthic invertebrate grazer species (thus causing a rebound in abundance of periphyton at this site). However, there are confounding variables at this site, such as storm-water input, that could create the observed response in periphyton density. Furthermore, concurrent data for benthic invertebrates plus periphyton for the two sites closest to the smelter (New Bridge and Old Bridge) could not be obtained because of logistical constraints (very high velocity flows and deep water). Therefore, examination of data for the presence of important benthic invertebrate grazer species and possible correlation with periphyton biomass or community composition was not possible.

4.4.3 Step 5: Assessment of Causation for Periphyton Lines of Evidence

The lines of evidence for evaluation of Conceptual Model 1 (direct effects of PCOC on periphyton; physical effects on periphyton habitat) are scored for causation in Table 4.20.

On balance, the overall evidence for a cause/effect link between the periphyton measures and the smelter is weak. This conclusion is based upon the following reasoning:

- *Spatial Correlation*: There was inconsistent evidence for smelter-related effects on biomass, with lower cell density and chlorophyll *a* at the New Bridge site (within the initial dilution zone) and at Stoney Creek (reflecting impacts of historic Teck Cominco landfills (now remediated), as well as lower cell density at the Korpak site. No effects on any of the measures of biomass were noted at the Old Bridge site (which is closer to the smelter than the Korpak site). There was lower abundance of both sensitive and tolerant taxa at the New Bridge site, whereas if PCOC were the dominant influence, only sensitive taxa should have had lower abundance. Furthermore, if PCOC were a dominant influence, the Old Bridge site (which is within the initial dilution zone) should have shown some response consistent with an expected decrease in abundance or lower proportion of sensitive taxa whereas the opposite was observed. Bray-Curtis similarity matrices showed that the species assemblages at upstream (Genelle and Birchbank) and far-field areas (Beaver Creek and Fort Sheppard) had a high level of similarity both within and between areas. The Korpak site was the most dissimilar to all other sites in contrast to the two sites closer to the smelter (New Bridge and Old Bridge). The spatial correlation criterion was given a score of "0" for "uncertain" for some measures and "+" corresponding with "compatible" for others (Table 4.20), depending upon whether there was any indication of a response at least at the two sites with highest PCOC concentrations (Stoney Creek and New Bridge).

Table 4.20 Causation Scores for Periphyton Lines of Evidence for Direct Effects of PCOC

Causal Criterion	Line of Evidence						
	Chlorophyll *a*	Total Cell Density	Ash Free Dry Weight	Statistical Difference in Community Metrics Among Sites	Correlation Between Community Metrics and PCOC Concentrations	Bray-Curtis Similarity	Presence of Sensitive or Tolerant Taxa
Spatial Correlation	+	+	+	0	+	0	+
Temporal Correlation	+	0	0	0	+	0	0
Biological Gradient/Strength	+	+	+	+	+	+	+
Plausibility: Mechanism	+	+	+	+	+	+	+
Plausibility: Stressor-Response	0	0	0	0	0	0	0
Consistency of Association	-	-	-	-	-	-	-
Experimental Verification	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Specificity of Cause	0	0	0	0	0	0	0
OVERALL STRENGTH OF EVIDENCE	⊙	**o**	**o**	**o**	⊙	**o**	**o**

Notes: See Table 4.15 for key to individual causation scores.

● strong overall strength of causal evidence.

⊙ moderate overall strength of causal evidence.

o weak overall strength of causal evidence.

n/a = not available.

- *Temporal Correlation*: There were no consistent temporal trends in the measures of biomass or taxonomic composition. Chlorophyll *a* concentrations were higher in 2003 than in previous studies conducted in 1995 and 1999 but cell densities were lower and ash free dry weight, while tracking with chlorophyll *a*, did not correspond with chlorophyll *a* at every site. The only temporal similarity in cell density between the 1999 and 2003 data was between the 1999 "downstream Island" (between the smelter and New Bridge) and the 2003 New Bridge and Korpak sites. There was also no consistent trend in community composition from upstream-to-downstream in the period 1995 to 2003. The Old Bridge site was the most distinctive site in all three sampling years, with major shifts in the proportion of algal classes over time (Golder 2007c). Because of the inconsistency of the evidence, the temporal correlation criterion was given a score of "0" for "uncertain" for all measures except for chlorophyll *a*.

- *Biological Gradient/Strength:* There was no consistent gradient of response with increasing distance downstream of the smelter among measures of biomass or taxonomic composition and any responses noted were not monotonic. Differences that occurred at the New Bridge did not occur slightly farther downstream at the Old Bridge, yet differences appeared again at Korpak, which was farther downstream. Several natural and anthropogenic variables along the PCOC concentration gradient are likely contributors to the lack of a gradient in response. The score assigned for the biological gradient/strength criterion was "+" for all measures, which corresponds with "weak or other than monotonic or inconsistent among responses."

- *Plausibility: Mechanism:* There are plausible mechanisms for the effect of PCOC on periphyton communities, usually via effects on photosynthesis (Overnell 1975; Clijsters and van Assche 1985; Singh and Singh 1987; Takamura et al. 1989; Guanzon et al. 1994). The score assigned for this criterion was "+" for all measures, which corresponds with "plausible."

- *Plausibility: Stressor/Response:* Although there were several statistical correlations between concentrations of PCOC and periphyton measures, these correlations were both positive and negative (except for thallium where all of the correlations were negative). The statistical correlations did not correspond with exceedances of water quality objectives, including thallium. Significant correlations did not always corroborate earlier suggestions made by G3 Consulting (2001) regarding the taxa that are sensitive to metals in the study area. Therefore, the score assigned for this criterion was 0 for "ambiguous" for the statistical correlation measure. Other measures showed a response at the New Bridge and Stoney Creek sites with the highest PCOC concentrations but did not demonstrate a consistent response at other sites. Therefore, the scores for these measures was also 0 for "ambiguous."

- *Consistency of Association*: There was very little consistency in the evidence within sites or among sites along the upstream-to-downstream gradient. The score assigned for this criterion was "-" because of the observed exceptions to association with PCOC.

- *Experimental Verification*: There was no experimental verification of the field-based lines of evidence in the present study. No laboratory toxicity tests were performed using water from the sampling sites. No score was assigned for this criterion because there were no experimental data.

- *Specificity*: None of the responses could be considered to be specific to the effects of PCOC. There were several important confounding natural or anthropogenic variables such as high water velocity at the New

Bridge site and storm-water and tributary inputs at the Old Bridge and Korpak sites. A score of “0” was assigned for this criterion for all measures, corresponding with “one of many” potential causes (Table 4.20).

In summary, the responses observed in the AOI during the present study did not present strong, consistent evidence of a link to smelter-related emissions as per Conceptual Model 1. In no case did all lines of evidence at a site indicate strong or moderate causative links. The probable confounding influence of non-smelter related stressors was illustrated by the low magnitude of response, the lack of a monotonic gradient upstream-to-downstream, and the lack of consistency in response.

The potential for indirect effects as per Conceptual Model 2 via changes in grazing pressure or alterations in competitive interactions appears to be low; however, the uncertainty associated with Conceptual Model 2 is high, partly because of the lack of experimental data that test hypotheses related to indirect effects. The pattern of response along the upstream-to-downstream gradient may not be consistent with the hypothesis of indirect effects.

4.4.4 Step 6: Periphyton Risk Characterization

The risk management objective for periphyton is:

> “Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on the diversity of aquatic plant and animal communities in the Columbia River and its tributaries.”

The assessment endpoint is periphyton community composition.

The frameworks for this objective and assessment endpoint are Conceptual Model 1 (direct effects) and Conceptual Model 2 (indirect effects). SALE Steps 1-5 produced an evaluation of the magnitude of response of measures of periphyton community composition, the uncertainty associated with these measures, and the strength of the evidence for a cause/effect link with smelter-related emissions for both conceptual models. However, as explained above, the SALE summary tables apply only to Conceptual Model 1. A narrative risk characterization was produced for Conceptual Model 2.

Conceptual Model 1

The combination of magnitude, causation, and uncertainty scores was used to produce a recommendation regarding the need for consideration of risk management options (Table 4.21). Physical effects on periphyton habitat are not included in this table because there were no physical effects with a magnitude greater than “low”. The overall causation scores for each measure presented in Table 4.20 were examined for applicability to each sampling site in Table 4.21. Causation scores for chlorophyll *a* were lower than the overall score of “moderate” at the Old Bridge, Korpak, Beaver Creek and Fort Sheppard sites because these sites no longer showed any sign of gradients in response or consistency of response. The causation score for presence of sensitive taxa was higher than the overall score of “low” at the New Bridge site because this was the only site where there was a clear decline in taxa identified in previous studies as “sensitive.”

Table 4.21 SALE Summary Table for Periphyton

Site	Periphyton																		Presence of Sensitive Taxa			Proceed to Consideration of Risk Management Options?
	Total Cell Density			Chlorophyll *a*			Ash Free Dry Weight			Statistical Difference in Community Metrics Among Sites			Correlation Between Community Metrics and PCOC Concentrations			Bray-Curtis Similarity						
	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	
Stoney Creek	⊙	○	??	⊙	⊙	??	○	○	??	○	○	??	⊙	⊙	??	○	○	??	○	○	??	Dealt with in separate risk management program
New Bridge	⊙	○	??	⊙	⊙	??	○	○	??	○	○	??	●	◉	??	○	○	??	⊙	◉	??	Addressed through permitting process
Old Bridge	○	○	??	○	○	??	○	○	??	○	○	??	◉	◉	??	○	○	??	○	○	??	No
Korpak	●	○	??	○	○	??	○	○	??	○	○	??	◉	⊙	??	◉	○	??	○	○	??	Yes
Beaver Creek	○	○	??	○	○	??	○	○	??	○	○	??	⊙	⊙	??	○	○	??	○	○	??	No
Fort Sheppard	○	○	??	○	○	??	○	○	??	○	○	??	◉	⊙	??	○	○	??	○	○	??	No

Notes:

Magnitude:
- ● strong response.
- ⊙ moderate response.
- ○ weak response.

Causation:
- ● strong overall strength of causal evidence.
- ⊙ moderate overall strength of causal evidence.
- ○ weak overall strength of causal evidence.

Uncertainty:
- ? low uncertainty (high statistical power, full gradient design, all important natural variables accounted for).
- ?? moderate uncertainty (moderate statistical power, control/impact rather than full gradient design; most natural variables accounted for).
- ??? high uncertainty (low statistical power, important natural variables not accounted for).

The results of the SALE process indicate that the risk management objective is being met at all sites for the periphyton assessment endpoint except Stoney Creek, New Bridge and Korpak. The Stoney Creek site is being dealt with under a separate risk management program. The New Bridge site lies within the initial dilution zone authorized by the current MOE permit. Nevertheless, risk management options at the New Bridge site would be considered within the context of the risk management goals for the wider ecological risk assessment but addressed through permitting.

There is moderate confidence in the risk characterization because:

- several lines of evidence examined not only for magnitude, but also for causation and uncertainty, indicate that the risk management objective is currently being met at all sites except Stoney Creek, New Bridge and Korpak; the uncertainty associated with the individual lines of evidence contributing to the risk characterization is moderate;
- sampling was conducted along a gradient of exposure, including areas of maximum exposure to PCOC from the smelter in the near-field;
- the periphyton community is well-known for its responses to metals, thus absence of the expected response is important and convincing information;
- natural variability in periphyton was addressed satisfactorily via the sampling design; and
- no future increases in smelter-related stressors are expected.

Conceptual Model 2

The pattern of response of the periphyton community along the upstream-to-downstream gradient is not consistent with the hypothesis of indirect effects. The exception may be at the Old Bridge site, where biomass rebounded compared to the New Bridge site immediately upstream. This response may be caused by reductions in metal-sensitive grazer populations at PCOC concentrations that are no longer directly toxic to periphyton. The reduced grazing pressure would result in increased algal biomass. However, it is equally plausible that the biomass at the Old Bridge/Trail Creek sites reflects nutrient inputs from urban runoff and sewage effluent.

The evidence for indirect effects is not strong enough to lead to a recommendation for risk management; however, the uncertainty in the assessment of indirect risks is high. If the evidence for direct effects on other trophic levels had been stronger, there would have been a need to reduce the uncertainty regarding indirect effects on periphyton.

4.5 Benthic Invertebrates

The assessment endpoint for the benthic invertebrate community is “benthic invertebrate community composition”. This endpoint includes the measurement of both abundance and diversity. Lines of evidence were examined for direct effects of smelter-related emissions (as per Conceptual Model 1) and indirect effects (as per Conceptual Model 2).

4.5.1 Step 2: Effects Due to Smelter-Related Change in Physical Habitat

There were historic effects on benthic habitat because of the discharge of slag to the river by the smelter. Since the cessation of slag discharge in 1995, historic slag deposits have, for the most part, been re-distributed and transported downstream. There are few depositional habitats in the Columbia River within the AOI; therefore, there are few areas with significant slag deposits remaining in the AOI. The Fort Sheppard and Waneta eddies are the two areas with the highest amount of slag present in sediments, ranging from less than 10% to over 90% slag (based on visual observation) depending on the location within the eddy.

Slag occurs as glassy, black, sand-sized or smaller particles with a dull-etched appearance when weathered. Slag particles have a combination of rounded and angular features (Figures 4.14, 4.15 and 4.16). Weathering produces "rinds" of metal oxides that coat the particles (Figure 4.14); however, these "rinds" may be eroded during bedload transport producing small flakes and fresh surfaces on the slag particle (Cox et al. 2005). The glassy matrix is calcium-iron-silicate with varying amounts of aluminum. Various mineral phases occur internal to the glassy matrix. Some slag particles can have many voids; these particles can sometimes float. However, most slag particles are dense, with density usually greater than 2.9 g/cm^3 (Cox et al. 2005).

Because of their physical characteristics, slag particles may create a lower-quality habitat than natural substrates, including sand substrates.

Figure 4.14 Electron Microscope Image of Slag Particle with Rind

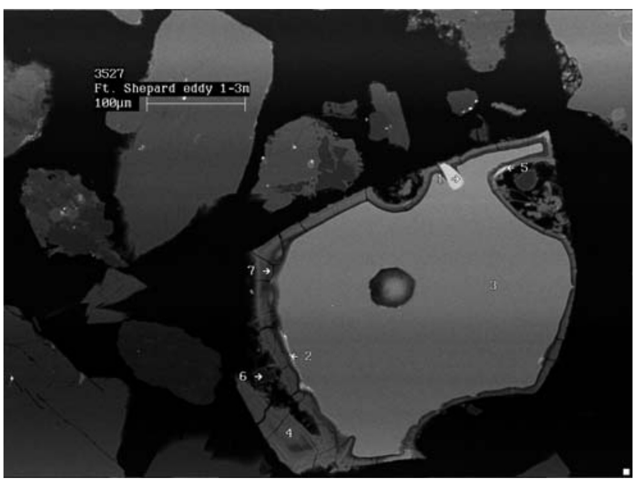


Figure 4.15 Fresh Slag Particles

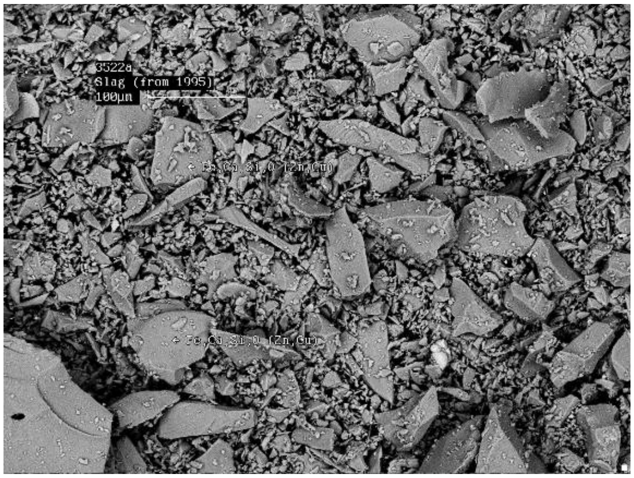
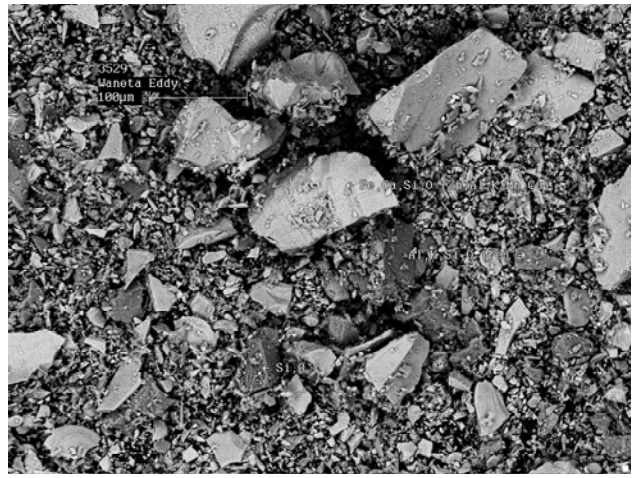


Figure 4.16 Slag from River



Given the highly erosional nature of the Columbia River downstream of the smelter, the distance from the Teck Cominco smelter was not a good indicator of slag content in bottom sediments (Golder 2007a). Korpak and Trimac (mid-way downstream between the smelter and the U.S. border) were the only downstream depositional sites without any visible slag in the sediments (Table 4.22). At the remaining exposure sites, the amount of slag increased in the order Casino = Airport Bar < Fort Sheppard Eddy < Maglios (closest to the smelter) < Waneta Eddy (farthest from the smelter) (Table 4.22). The highest proportion of slag and volume of slag was observed at the farthest downstream site (Waneta), indicating downstream transport.

Based upon the observed slag content, effects on benthic invertebrates from physical alteration of the habitat due to slag deposition would be expected to be greatest at the Maglios and Waneta sites.

The area of depositional habitat in the AOI is estimated at 0.1% of the total sediment habitat. Therefore, the spatial extent of physical effects on habitat is small relative to the context of the entire AOI.

Other natural habitat characteristics are also summarized in Table 4.22. These characteristics were found to be important variables influencing the benthic invertebrate community (Golder 2007a).

Table 4.22 Habitat Characteristics of the Sampling Sites in the Columbia River, September 2003

Variable	Units	Reference Sites			Exposure Sites						
		Kootenay Eddy	Genelle Eddy	Birchbank Eddy	Korpak	Maglios	Casino	Airport Bar	Trimac	Fort Sheppard Eddy	Waneta Eddy
Site Location (UTM; NAD 83) and Sampling Date											
Easting	-	452793	448710	447868	450530	454219	454930	455083	454898	455517	454621
Northing	-	5462824	5450161	5446883	5438153	5437169	5434287	5433929	5431440	5431245	5428196
Date	-	24-Sep	24-Sep	22-Sep	18-Sep	22-Sep	19-Sep	22-Sep	17-Sep	19-Sep	19-Sep
Field Measured Water Quality Variables											
Dissolved oxygen	mg/L	8.9	8.4	8.2	8.1	8.1	7.8	7.9	8.9	8.0	7.8
Conductance	µS/cm	180	140	150	150	150	150	150	160	130	160
pH	-	8.6	8.6	8.6	8.7	8.5	8.4	8.6	8.7	8.4	8.4
Water temperature	^{o}C	16.4	15.3	15.6	15.5	15.4	14.9	15.3	15.7	14.9	16.0
Habitat Characteristics											
Mean water depth	m	4.8	2.5	2.2	2.0	2.8	2.5	1.6	1.9	3.6	14.6
River wetted width[(a)]	m	215	225	165	125	95	120	150	150	150	200
Mean current velocity	m/s	n/m	0.28	0.29	0.02	0.20	0.34	0.07	n/m	0.06	0.18
Macrophyte cover	%	60	10	0	10	0	20	10	75	75	0
Particle Size and Carbon Content											
Larger than 2 mm	%	2.1	12.0	17.9	17.9	0	0.2	17.9	0.3	0	16.1
Sand	%	84.9	86.5	76.9	74.9	95.7	90.4	76.9	66.8	94.0	80.9
Clay	%	11.0	1.5	3.5	5.6	3.5	7.5	3.5	29.2	4.0	3.0
Silt	%	2.0	0	1.7	1.6	0.9	1.9	1.7	3.6	2.0	0
Slag[(a)]	%	0	0	0	0	40	10	10	0	30	90
Total carbon	%	0.75	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.38	<0.5	<0.5
Organic carbon	%	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	1.36	<0.8	<0.8

Notes: (a) Visual estimate subject to high uncertainty.
- = not applicable.
n/m = Non-measurable current velocity.

4.5.2 Steps 3 and 4: Evaluation of Magnitude and Uncertainty in Benthic Invertebrate Field and Laboratory Data

In Step 3, the laboratory toxicity test results and field data were examined for statistical differences between upstream and downstream sediment toxicity and measurements of benthic invertebrate abundance and community structure (Figure 4.3). The uncertainty (both related to natural variability and to support for the two conceptual models) was then assessed. Uncertainty was assessed whether or not statistical differences were observed (Figure 4.3) because uncertainty can affect our ability to detect statistical differences. In Step 4, the magnitude of observed responses in the downstream benthic invertebrate community was assessed according to criteria developed to define low, moderate and high magnitude for each of the measured community characteristics (Figure 4.4).

The evidence assembled for Step 3 came from sediment chemistry, toxicity and the benthic invertebrate community data collected from ten depositional sites in the Columbia River (Figure 2.1). These sites included three upstream reference sites and seven sites downstream of the Teck Cominco smelter (i.e., exposure sites), which were intended to represent a gradient in the concentration of metals in bottom sediments. The ten sites also represented gradients in habitat features (e.g., water depth, sediment particle size distribution) that may influence the benthic community.

Sediment chemistry and toxicity were measured in composite samples collected at each site. Following the approach suggested for gradient designs by the metal mining EEM guidance document (Environment Canada 2002), replication at individual sites was not considered necessary for benthic invertebrates. The aim of a gradient-type analysis is to detect relationships between environmental variables and biological variables, rather than compare individual sites. Statistical tests appropriate for detecting relationships (e.g., correlation, regression) do not require replication, which allows the efficient use of the analytical budget to maximize the number of sites by compositing samples for taxonomic analysis.

Although the original intent was to analyze all benthic samples as composites, five of the ten sites were selected for analysis of individual benthic samples, for use as replicates in statistical tests comparing reference sites and exposure sites. The five sites included two reference sites (Kootenay Eddy and Birchbank Eddy), and three exposure sites (Airport Bar, Fort Sheppard Eddy, Waneta Eddy) corresponding to a range of metal concentrations in bottom sediments. The inclusion of the analysis of some replicates allowed additional statistical analysis and more detailed interpretation.

The sediment chemistry information was used to assist in the interpretation of the effects measures (toxicity tests and benthic invertebrate community characteristics). The concentrations of PCOC at the sampling stations used in the 2003 program are presented in Table 4.23.

Table 4.23 Sediment Chemistry at Sites in the Columbia River, September 2003

PCOC	Units (dry wt)	Sediment Quality Guidelines/Criteria				Reference Sites			Exposure Sites						
		SedQC$_{scs}$	SedQC$_{tcs}$	ISQG	PEL	Kootenay Eddy	Genelle Eddy	Birchbank Eddy	Korpak	Maglios	Casino	Airport Bar	Trimac	Fort Sheppard Eddy	Waneta Eddy
Arsenic	µg/g	11.0	20.0	5.9	17.0	1.44	0.56	0.90	**10.28**[c]	**19.61**[a,c,d]	**16.60**[a,c]	**8.32**[c]	**7.16**[c]	**19.51**[a,c,d]	5.90
Cadmium	µg/g	2.2	4.2	0.6	3.5	0.60	0.19	0.23	**1.82**[c]	**2.18**[c]	**1.21**[c]	**0.83**[c]	**3.16**[a,c]	**1.07**[c]	**0.71**[c]
Chromium	µg/g	56.0	110.0	37.3	90.0	14.2	3.5	7.5	30.0	**56.0**[c]	25.7	24.2	27.3	32.4	**79.8**[a,c]
Copper	µg/g	120.0	240.0	35.7	197.0	7.0	4.4	4.1	**414.9**[a,b,c,d]	**1,155.8**[a,b,c,d]	**466.2**[a,b,c,d]	**337.7**[a,b,c,d]	**173.6**[a,c]	**506.0**[a,b,c,d]	**1,685.0**[a,b,c,d]
Lead	µg/g	57.0	110.0	35.0	91.3	11.1	6.2	7.9	**172.8**[a,b,c,d]	**335.1**[a,b,c,d]	**141.5**[a,b,c,d]	**122.0**[a,b,c,d]	**150.2**[a,b,c,d]	**192.8**[a,b,c,d]	**127.7**[a,b,c,d]
Mercury	µg/g	0.300	0.580	0.170	0.486	0.007	0.001	0.003	0.106	0.057	**0.296**[c]	**0.187**[c]	**0.340**[a,c]	0.166	0.062
Nickel	µg/g	-[e]	-[e]	-[e]	-[e]	11.15	5.11	7.12	10.44	10.52	11.92	12.13	17.61	12.20	7.79
Silver	µg/g	-[e]	-[e]	-[e]	-[e]	0.06	0.04	<0.01	1.82	5.23	10.04	1.78	1.53	3.36	1.24
Thallium	µg/g	-[e]	-[e]	-[e]	-[e]	0.12	0.03	0.05	0.29	0.27	0.24	0.17	0.57	0.27	0.11
Zinc	µg/g	200	380	123	315	109	39	50	**2,455**[a,b,c,d]	**7,746**[a,b,c,d]	**2,276**[a,b,c,d]	**1,638**[a,b,c,d]	**1,067**[a,b,c,d]	**3,307**[a,b,c,d]	**17,925**[a,b,c,d]

Notes:

- = not applicable; concentrations are reported on a dry weight basis; concentrations above guidelines are bolded.

SedQC$_{scs}$ = Sediment quality criterion for sensitive contaminated sites; SedQC$_{tcs}$ = Sediment quality criterion for typical contaminated sites; ISQG = Interim Sediment Quality Guideline; PEL = Probable Effect Level.

(a) Concentration greater than SedQC$_{scs}$ (BCWLAP 2003).

(b) Concentration greater than SedQC$_{tcs}$ (BCWLAP 2003).

(c) Concentration greater than ISQG (CCME 1999 with 2001 and 2002 updates).

(d) Concentration greater than PEL (CCME 1999 with 2001 and 2002 updates).

(e) Sediment quality guidelines are not available for nickel, silver and thallium.

Line of Evidence 1: Toxicity Tests

Sediment toxicity was assessed by calculating the percent effect on survival and growth of *Chironomus tentans*, over a 10- and 20-day period, relative to reference site sediments (Golder 2007a). The chironomids were fed throughout the test with flaked fish food. Percent-effect was calculated relative to the mean results for the three reference sites. The percentage difference between each reference site and the mean of the three reference sites was also calculated to estimate variability among reference sites.

Clean silica sand was used as the laboratory control for particle size effects, given that most river sediments are coarser than true depositional environments. Lower survival and growth was noted in these controls, demonstrating that particle size alone can affect *Chironomus* survival and growth.

The criterion of 20% reduction in an endpoint relative to the reference mean was used to identify the potential for an adverse effect. This degree of change may not indicate an environmentally relevant difference between sediments; however, without more detailed work in this field, a lesser effect could not be detected (Chapman and Anderson 2005). Sites with a percentage effect greater than 20%, but less than 50% were considered to have the potential for an adverse effect. Adverse effects were considered likely at sites with a percentage effect greater than 50% relative to the reference mean.

During the 10-day test, test organisms in Maglios and Fort Sheppard Eddy sediments experienced a greater than 20%, but less than 50% negative effect on survival (Table 4.24). The observed reductions were statistically significant compared to reference sediments. Re-running the statistical test for Fort Sheppard Eddy after removing an outlier identified by diagnostic tests resulted in a non-significant result (Golder 2007a).

Significant negative effects on growth during the 10-day test occurred in sediments from Maglios and Waneta and at the Genelle reference site (Table 4.24). The effects on growth at these sites were all greater than 50%. The decreased growth at Genelle may reflect the relatively coarse sediment particle size at this site.

During the 20-day test, survival and growth in Genelle Eddy sediments were significantly reduced compared to the other two reference sites, with a magnitude greater than 20% but less than 50% (Table 4.25). No organisms survived in the Maglios sediment sample; consequently, no value was reported for growth. Sediments from Fort Sheppard Eddy had a greater than 20% but less than 50% negative effect on *Chironomus* survival, but the difference from reference sediments was not significant. Sediments from Waneta Eddy had a statistically significant, greater than 50% negative effect on survival compared to the reference sites. However, survival in sediments from Waneta Eddy was greater than the laboratory control using silica sand and growth rate was similar to the laboratory control. This indicates the possibility of physical effects of substrate.

Chironomus biomass in Genelle Eddy sediments was 26% lower than the reference mean in the 20-day test (Table 4.25), (Golder 2007a). This difference was statistically significant only after removing an outlier. Sediments from Trimac and Waneta Eddy had greater than 20% and 50% negative effects on *Chironomus* growth, respectively. Both of these effects were statistically significant.

In summary, during the 10-day test there were effects on survival and growth in Maglios sediments, survival in Fort Sheppard Eddy sediments, and growth in Waneta Eddy sediments. Similarly, based on the 20-day test, there were effects on survival (and likely growth) in Maglios sediments, growth in Trimac sediments, and on both endpoints in Waneta Eddy sediments. Both survival and growth were lower in sediments from Genelle (a reference site) compared to the other two reference sites.

Table 4.24 10-Day Sediment Toxicity Test Results for Survival and Growth of *Chironomus tentans*

Sample Type	Site (% sand)	Survival (%)		Percent-Effect on Survival[(b)]	Growth (mg dry wt./organism)		Percent Effect on Growth[(b)]
		Mean	SD		Mean	SD	
Laboratory Control	-	70	20	-	0.29	0.07	-
Laboratory Control	-	60	27	-	0.34	0.10	-
Laboratory Control[(a)]	-	82	15	-	0.28	0.07	-
Reference[(a)]	Kootenay Eddy (84.9)	94	5	5	0.63	0.10	-10
Reference[(a)]	Genelle Eddy (86.5)	80	16	-11	0.27	0.03	-61[#]
Reference	Birchbank Eddy (76.9)	94	6	6	1.20	0.18	71
Mean of Reference Sites		90	-	-	0.70	-	-
Exposure	Korpak (74.9)	88	16	-2	0.90	0.10	29
Exposure	Maglios (95.7)	50	19	-44*	0.16	0.04	-77*
Exposure	Casino (90.4)	84	11	-6	0.77	0.17	11
Exposure	Airport Bar (76.9)	92	11	3	1.64	0.23	134
Exposure	Trimac (66.8)	92	4	3	0.98	0.19	41
Exposure	Fort Sheppard Eddy (94.0)	64	33	-29[*/ns]	1.62	0.17	132
Exposure	Waneta Eddy (80.9)	86	5	-4	0.26	0.05	-62*

Notes:

Statistically significant differences between an exposure site and the reference sites are identified by *.

Statistically significant differences between a reference site and the other two reference sites are identified by #.

- = not applicable.

SD = standard deviation.

*/ns indicates that removal of an outlier identified by diagnostic tests resulted in no significant difference.

(a) These samples were run in a separate batch from the rest of the samples.

(b) Percent-effect was calculated relative to the mean of the three reference sites.

Table 4.25 Twenty-Day Sediment Toxicity Test Results for Survival and Growth of *Chironomus tentans*

Sample Type	Site	Survival (%)		Percent-Effect on Survival[(a)]	Growth (mg dry wt./organism)		Percent Effect on Growth[(a)]
		Mean	SD		Mean	SD	
Laboratory Control	-	58	8	-	1.03	0.25	-
Laboratory Control	-	58	15	-	1.08	0.17	-
Reference	Kootenay Eddy	82	13	12	1.94	0.57	22
Reference	Genelle Eddy	52	31	-29[#]	1.17	0.24	-26[ns/#]
Reference	Birchbank Eddy	86	11	17	1.66	0.39	4
Mean of Reference Sites		73	-	-	1.59	-	-
Exposure	Korpak	74	13	-1	1.63	0.88	3
Exposure	Maglios	0	0	-100*	-	-	-
Exposure	Casino	86	15	17	1.75	0.25	10
Exposure	Airport Bar	86	11	17	2.34	0.41	47
Exposure	Trimac	76	11	4	0.85	0.24	-46*
Exposure	Fort Sheppard Eddy	52	41	-29	2.16	0.45	36
Exposure	Waneta Eddy	24	18	-67*	0.31	0.18	-81*

Notes:

Statistically significant differences between an exposure site and the reference sites are identified by *.

Statistically significant differences between a reference site and the other two reference sites are identified by #.

SD = standard deviation.

- = not applicable.

ns/# indicates that removal of an outlier identified by diagnostic tests resulted in a significant difference when there was no significant difference before.

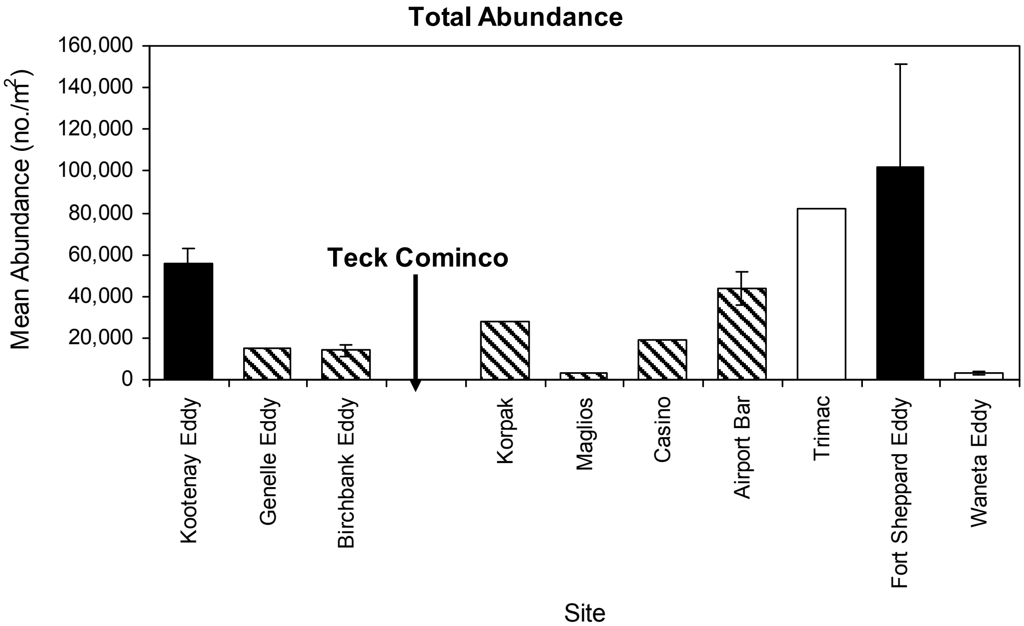
(a) Percent-effect was calculated relative to the mean of the three reference sites.

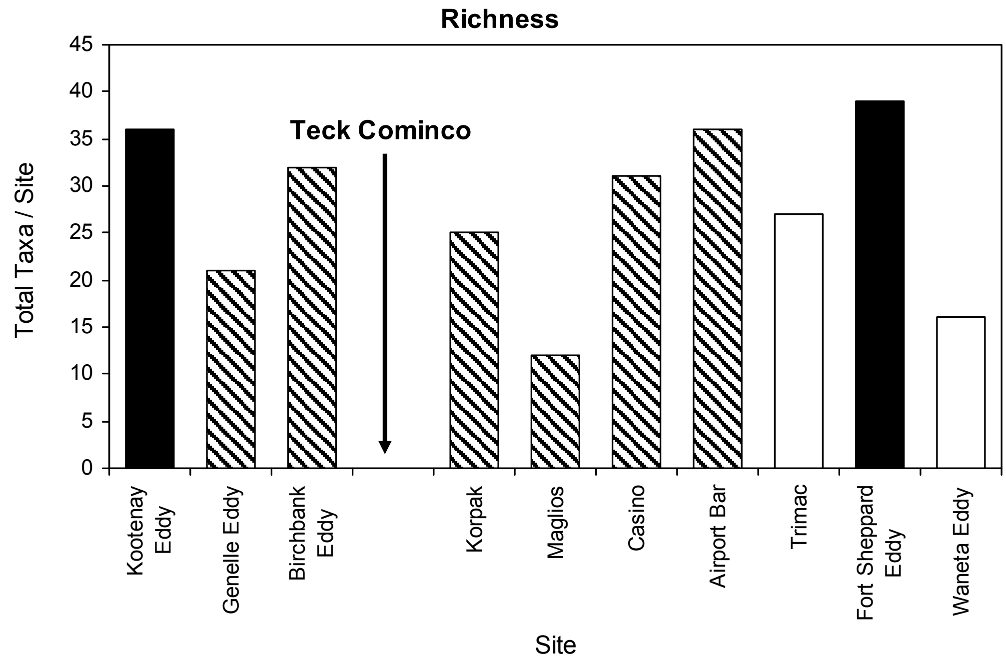
Line of Evidence 2: Comparison of Benthic Invertebrate Community Characteristics Among Sites

Mean total abundance of benthic invertebrates was variable among sites (Figure 4.17), (Golder 2007a). Values ranged between 14,000 and 55,000 organisms/m^2 at reference sites upstream of the Teck Cominco plant. Downstream of the plant, mean total abundance ranged between 2,900 and 150,000 organisms/m^2. The two sites with the lowest abundances were Maglios and Waneta Eddy. The highest abundance was observed at Fort Sheppard Eddy.

Total richness at reference sites ranged between 21 and 36 taxa (Figure 4.17)(Golder 2007a). Exposure sites had generally similar richness values. The two exceptions were Maglios and Waneta Eddy with 12 and 16 taxa, respectively.

Figure 4.17 Total Abundance and Richness at Depositional Sites Sampled in the Columbia River, September 2003





Notes:

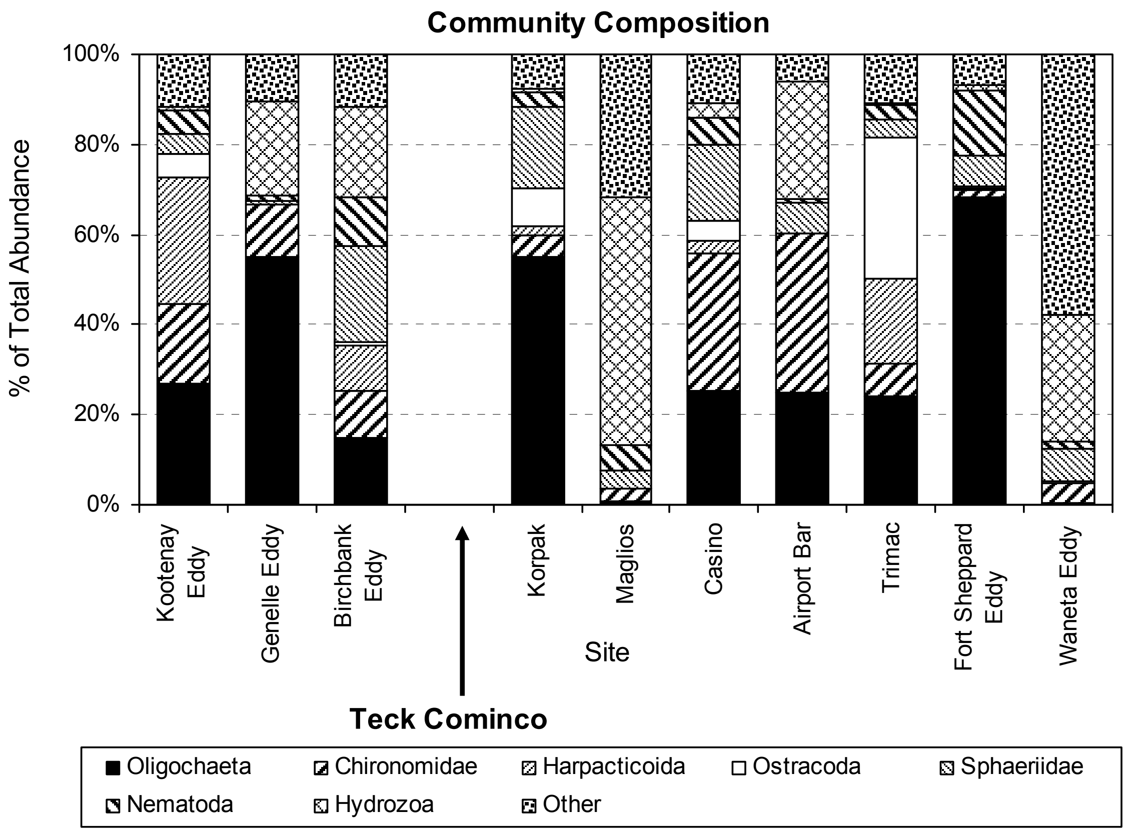
Abundance bars (top graph) without standard error bars represent composite samples.

Sites are arranged from upstream to downstream.

Patterns represent the two groups of sites based on habitat characteristics. Trimac and Waneta Eddy (unshaded bars) had habitat characteristics that did not match the two site groups.

Community composition was variable at the reference sites (Figure 4.18)(Golder 2007a). Aquatic worms (Oligochaeta) were the dominant group at Genelle Eddy with Tubificidae, Lumbriculidae and Naididae accounting for over 50% of the community. No single group displayed this level of dominance at either Kootenay Eddy or Birchbank Eddy. Copepods (Harpacticoida), tubificid worms and midges (Chironomidae) were the three largest groups at Kootenay Eddy. The three largest groups at Birchbank Eddy were fingernail clams (*Sphaerium*), *Hydra* (Hydrozoa) and aquatic worms. Other common invertebrates observed at reference sites included *Asellus* (Isopoda), seed shrimp (Ostracoda), *Hyalella* (Amphipoda), *Bezzia* (Diptera) and *Gyraulus* (Gastropoda).

Figure 4.18 Composition of the Benthic Invertebrate Community at Sites Sampled in the Columbia River, September 2003



Community composition was highly variable at exposure sites (Figure 4.18), (Golder 2007a). Four of the seven sites (Korpak, Maglios, Fort Sheppard Eddy and Waneta Eddy) were dominated by one group that constituted greater than 45% of the community. Korpak was dominated by tubificid worms, fingernail clams and seed shrimp, while Maglios was dominated by Hydra, *Gyraulus* and *Bezzia*. Fort Sheppard Eddy was dominated by tubificid worms, roundworms (Nematoda) and fingernail clams, while Waneta Eddy was dominated by *Bezzia* ("Other" category in Figure 4.18), *Hydra* and fingernail clams. Diversity was moderate at the other three exposure sites. Common groups observed at Airport Bar included *Hydra*, Naididae and three midge groups (Chironomini, Orthocladiinae and Tanytarsini). At Casino, tubificid worms, fingernail clams, two groups of midges (Chironomini and Tanytarsini), and nematodes were the most dominant. At Trimac, seed shrimp, tubificid worms and copepods were the dominant groups. Other common groups observed at exposure sites included Lumbriculidae, *Asellus*, *Fossaria* (Gastropoda), *Valvata* (Gastropoda), *Dugesia* (Turbellaria), *Ephemerella* (Ephemeroptera) and *Nectopsyche* (Trichoptera).

The presence of PCOC in the sediments of sites such as Maglios and Waneta is not the only potential cause of the taxonomic composition found at these sites. The lack of oligochaetes and the relatively low proportion of chironomids at the Maglios and Waneta sites may, in part, be due to the coarser particle size at these two sites. The dominance of the predatory *Hydra* and *Bezzia* at the Maglios and Waneta sites may indicate that there was a lack of organic content for food in the sediments. This may have led to the dominance of predatory taxa such as *Hydra*, which likely feed on zooplankton (possibly entrained mysids originating from upstream reservoirs). Some species of fingernail clams (*Sphaerium*) (another of the more common taxa at Waneta) prefer sandy substrates, and the snail *Gyraulus* (dominant at the Maglios site) is a scraper/grazer that feeds on attached algae.

Statistical tests detected significant differences in all benthic community variables compared among Birchbank Eddy, Airport Bar and Waneta Eddy (Golder 2007a). Pair-wise comparisons of Airport Bar with reference site data from Birchbank Eddy detected significant differences for half of the variables tested and nearly significant differences for two additional variables; in all cases abundances were significantly higher at Airport Bar (i.e., no indication of an adverse effect due to sediment toxicity). Comparisons of Waneta Eddy with the reference site detected significant differences for all variables, and all differences from the reference site were in the negative direction (i.e., suggesting the potential for an adverse effect).

Statistical tests comparing Kootenay Eddy (reference site) and Fort Sheppard Eddy (exposure site) detected significant differences in Chironomini and Tanytarsini abundances, whereas the difference in Orthocladiinae abundance was nearly significant. As in the case of Waneta Eddy, all significant differences from the reference site were in the negative direction.

The benthic invertebrate communities at Waneta Eddy had large differences from the reference community at Birchbank Eddy (Table 4.26)(Golder 2007a). Water depth at Waneta Eddy site was considerably deeper than at Birchbank Eddy (which contained some silt), which must be considered when interpreting differences in the benthic invertebrate communities of these two sites. The significantly lower values of all variables at Waneta Eddy would be expected due to the greater depth at Waneta Eddy. Also, Waneta Eddy experiences high and variable water velocities and directions of flow which change hourly with varying flows from the Pend d'Oreille river, which explains the gravel at the site and increased zooplankton entrainment. However, sediment toxicity may be a contributing factor, given the observed PCOC concentrations at this site.

The direction of the differences between Birchbank Eddy and Airport Bar suggests no adverse effects on the benthic community at Airport Bar (Table 4.26). There were very few habitat differences between Birchbank Eddy and Airport Bar that might explain differences in the benthic communities. Current velocity was lower at Airport Bar; however, the difference was not large enough to cause a substantial effect on the benthic community.

Table 4.26 Effect Sizes for Benthic Community Variables (Comparison to Most Relevant Reference Site).

Variable	Birchbank Eddy vs. Airport Bar and Waneta Eddy		Kootenay Eddy vs. Fort Sheppard Eddy (%)
	Airport Bar (%)	Waneta Eddy (%)	
Total Abundance	**224**	**-76**	-39
Richness	9	**-63**	-4
Oligochaeta Abundance	**427**	**-100**	-29
Sphaeriidae Abundance	17	**-92**	-10
Chironomini Abundance	998[a]	**-94**	**-84**
Orthocladiinae Abundance	**1,996**	**-99**	-96[a]
Tanytarsini Abundance	**1,473**	**-99**	**-100**
Metal-Sensitive Invertebrate Abundance	179[a]	**-93**	-65

Notes:

(a) Results of tests were nearly significant ($p < 0.057$ for Chironomini abundance Birchbank vs. Airport Bar; $p < 0.055$ for Orthocladiinae abundance Kootenay vs. Fort Sheppard; $p < 0.054$ for metal-sensitive invertebrate abundance Airport Bar vs. Waneta).

Effect sizes are expressed as the percent difference relative to the reference site.

Effect sizes representing significant differences are bolded.

Effect sizes for abundance variables were calculated using geometric means.

Line of Evidence 3: Multivariate Analysis

Multivariate analysis using a non-parametric ordination method (NMDS) showed that Waneta Eddy and Maglios were widely separated from the three reference sites and other exposure sites (Figure 4.19) (Golder 2007a). Other exposure sites clustered with the reference sites, suggesting no substantial deviation in benthic community structure from the reference site communities. The variation along Axis 1 suggests that the differences in community structure between the communities at Waneta Eddy and Maglios, and other sites, was largely exhibited as lower abundances of most taxa at the former two sites.

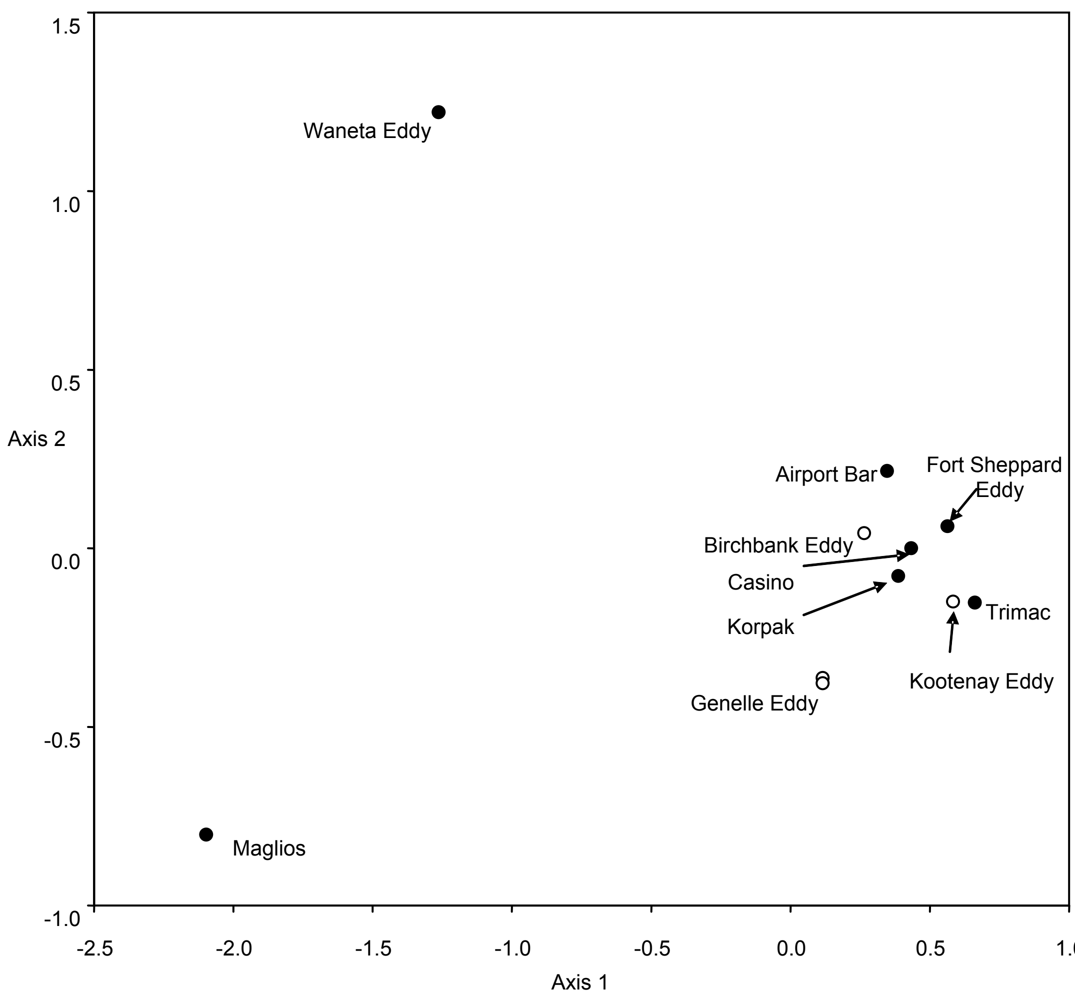
Axis 1 was significantly positively correlated with both macrophyte cover and percentage fine sediments (Spearman rank correlations; $p < 0.001$, both correlations) (Figure 4.20). There were no significant correlations between Axis 1 and water depth or Axis two and any of the three habitat variables analyzed (water depth, macrophyte cover, percentage fine sediments).

Visual examination of scatter plots suggested that, although there is evidence of the effect of habitat variation on ordination results, an additional factor was responsible for the difference in community structure between Waneta Eddy and Maglios, and the other eight sites. Axis I scores for Waneta Eddy and Maglios fell well below the relationship between Axis 1 scores of other sites versus both macrophyte cover and percentage fine sediments. Both of these factors could be considered surrogates for available food and nutrients in the sediment (Figure 4.20). This can be interpreted as reduced abundances of Axis 1-associated taxa below the level that would be expected based on the low macrophyte cover and coarser sediments observed at these sites.

In summary, results of this analysis indicate that benthic invertebrate communities of Waneta Eddy and Maglios were different from those of all other sites (including all reference sites). The differences between these two groups of sites could not be explained by habitat variation.

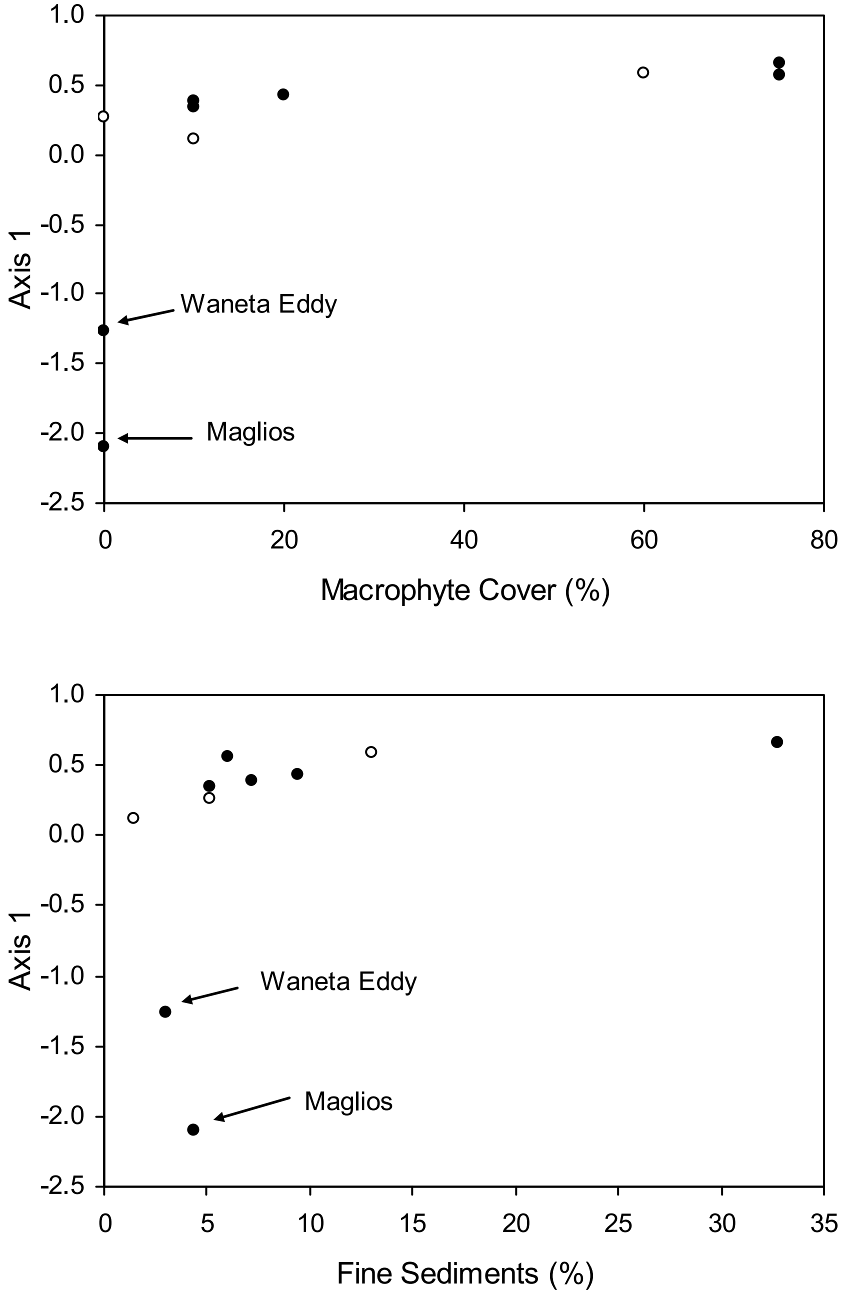
To further determine the availability of PCOC for uptake from sediments by aquatic organisms, and to provide possible explanations for increased toxicity and variations in community composition at some of the downstream sites (namely Maglios, Fort Sheppard Eddy and Waneta Eddy) a sequential extraction procedure was used.

Figure 4.19 NMDS Ordination of Sites Sampled in the Columbia River, September 2003



Notes:
Open symbols: reference sites.
Filled symbols: exposure sites.

Figure 4.20 Scatter-plots of Significant Correlations between Axis 1 Scores and Habitat Variables



Notes:
Open symbols: reference sites.
Filled symbols: exposure sites.

Sequential extraction is a commonly accepted methodology for assessing potential metal bioavailability in fluvial bottom sediments. The procedure, derived by Tessier et al. (1979), involves the partitioning of metals into five fractions that correspond to the binding of metals to different substances within the sediments. The five fractions, in order of increasingly tight bonds to substrates are:

1) Fraction 1 (exchangeable) – Exchangeable metals (extracted with magnesium chloride) - This fraction represents metals that are most likely to desorb and re-enter the water column.

2) Fraction 2 (carbonate) – Metals bound to carbonates leached with acetate/acetic acid adjusted to pH 5 with continuous agitation – This fraction represents metals that desorb with changes in pH.

3) Fraction 3 (iron/manganese oxide) – Metals bound to iron and manganese (extracted with hydroxyl amine hydroxide) – Metals bound to iron or manganese oxides will be released under anoxic conditions.

4) Fraction 4 (organic matter) – Metals bound to organic matter (extracted with nitric acid and ammonium acetate to prevent adsorption of extracted metals) – This fraction represents metals bound to various forms of organic matter such as living organisms, dead and decaying organisms, coatings on mineral particles, etc. Under oxidizing conditions, organic matter can be degraded, leading to the release of soluble metals. It should be noted that the organic fraction also includes sulphides, which also release metals if redox conditions are altered.

5) Fraction 5 (residual) – Residual metals (digested with aqua regia) – This fraction represents metals bound in primary and secondary minerals, held within the crystal structure. These metals are not expected to be released into solution under conditions normally encountered in nature.

The information on the fractions of metals provides an indication of the relative availability of metals for uptake from sediment to biota (bioavailability). For example, metals in the “exchangeable” and “carbonates” fractions (fractions 1 and 2, respectively) are more readily released back into solution; therefore, these fractions can be assumed to be more available for uptake by aquatic biota. In contrast, metals in the “iron and manganese oxides” fraction (fraction 3) are released only under anoxic conditions. Therefore, metals in this fraction are not as available for uptake by aquatic biota in oxygenated conditions. Under oxidizing conditions, organic matter (fraction 4) can be degraded, leading to release of soluble metals. Metals in the “residual” fraction (fraction 5) can be assumed to be unavailable for uptake by aquatic biota.

Although the sequential extraction information provides an indication of the potential bioavailability of metals in sediments from the sampling sites, it is not a direct measure of bioavailability. Actual uptake from sediment will depend upon several factors that include, but are not limited to, the chemical fractions where a particular metal is found. Other factors that affect bioavailability include physical properties of sediments such as grain size, the burrowing and feeding behaviour of benthic invertebrates, and the extent to which sediments are exposed to periodic drying and re-wetting due to flow regulation.

Cadmium concentrations were below detection limits in the majority of the sequential extraction fractions at most of the sample sites (Golder 2007e). Therefore no conclusions could be drawn regarding the potential for cadmium to be bioavailable at the sample sites. The effect of cadmium concentrations on aquatic organisms is expected to be minimal. Total cadmium concentrations did not exceed the PEL.

At all sites, chromium concentrations in the exchangeable and carbonate fractions were below detection limits (Golder 2007e). The majority of chromium was found to be bound to the residual fraction (between 65 and 75% at the downstream sample sites). The PEL was not exceeded at any of the sampling sites and the potential for release is very low because of the high proportion held in the residual fraction. Thus, there is minimal potential for effects on aquatic biota from chromium.

Silver concentrations were all below detection limits at the upstream reference sites. At the downstream sites, silver was mostly bound to the residual fraction (between 38 and 65%). Concentrations of silver in the other fractions were mostly below detection limits. The sequential extraction results, combined with the relatively small differences between upstream reference concentrations and downstream concentrations, indicate that the potential for effects on benthic communities from silver are minimal.

With the exception of samples taken at Waneta Eddy (where thallium was bound mostly to the residual and iron/manganese oxide fractions), all thallium concentrations were less than detection limits for all fractions; therefore, there can be no interpretation of the potential bioavailability of this PCOC.

The sequential extraction data showed that the highest percentages of three of the PCOC, namely arsenic, lead and zinc, were bound to the iron/manganese oxide fraction at most of the sites (Golder 2007e). Therefore, under anoxic conditions, there is a potential for the release of these PCOC into the water column. In particular, there would be a potential for release of sufficient lead and zinc concentrations at Maglios, Fort Sheppard Eddy and Waneta Eddy to exceed effect concentrations.

Anoxic conditions are very unlikely in the mainstem of the Columbia River because of the generally coarse nature of the sediments, the low organic matter content, and the high velocity and flow at these sites. However, anoxic conditions within specific, small areas such as backwater areas with low-flow and an accumulation of organic matter may develop (e.g., in the backwater area along the western shoreline adjacent to the Fort Sheppard site).

At the downstream sample sites, the proportion of total PCOC concentrations in the exchangeable and carbonate fractions (those most available for uptake) was less than 10% for arsenic, chromium, copper, mercury and zinc and between 1% and 31% for lead and nickel (Golder 2007e). Lead was present in approximately equal proportions between the exchangeable and carbonate fractions at upstream sites (13-16%), but the proportion shifted towards the carbonate fraction at downstream sites (19-31% carbonate vs. 1-2% exchangeable), with the exception of Waneta Eddy where the proportion was 5% carbonate and 1% exchangeable. The proportion of nickel in the exchangeable fraction ranged from 6% at Casino Fan to 15% at Korpak. The proportion of nickel in the carbonate fraction was consistently low (5-7%) across all sites.

The significance of the somewhat higher proportion of lead and nickel in the more available fractions depends upon the potential for exceeding effects thresholds. Nickel concentrations at downstream sites were similar to or slightly higher than at reference sites; therefore, the effect of nickel's presence in the more available fractions will depend on whether effect thresholds are exceeded. Lead concentrations, however, were high at the downstream sample sites, particularly at Fort Sheppard and Maglios. This suggests a higher potential for effects of lead at these sites.

Chromium and nickel were associated mostly with the residual fraction of the sediments. This fraction represents metals bound to primary and secondary minerals held within the crystal structure that are not expected to be released into solution. Total chromium concentrations exceeded the ISQG but not the PEL and nickel concentrations were very similar to upstream reference concentrations. Therefore, effects on benthic organisms from these two PCOC are unlikely.

Mercury was also associated primarily with the residual fraction; however, inorganic mercury concentrations are not the primary factor contributing to the uptake and toxicity of mercury in sediments. The methylated form of mercury is the dominant factor, and the sequential extraction technique does not measure this form of mercury.

Copper concentrations were high at the downstream sample sites, particularly at Maglios and Waneta; however, the potential for biological uptake of copper is greater at the Maglios site. At Waneta Eddy, the majority of the copper was bound to the unavailable residual fraction. At the Maglios site, the highest proportion of copper was in the organic matter fraction. Copper in the organic matter fraction would be bound to various forms of organic matter such as living and dead organisms and coatings on mineral particles. If oxidizing conditions prevailed in the sediments, the organic matter could be degraded, leading to the release of copper into the water column.

The sequential extraction data provided additional context for understanding the potential relationship between PCOC at the three sites and effects shown in toxicity tests and in community composition. The overall potential for bioavailability of the PCOC, and thus effects on aquatic biota, was higher at Maglios and Fort Sheppard than at Waneta Eddy. Waneta samples had higher percentages of copper, lead, thallium and zinc bound to the residual fraction of the sediments, making them effectively unavailable for uptake by aquatic organisms. Metals existed more in the iron/manganese oxide and organic matter fraction in samples from Maglios and Fort Sheppard suggesting a potential for uptake should redox conditions fluctuate at these sites.

In summary, the sequential extraction data indicate that there is a potential for effects from copper, lead and zinc at the Maglios, Fort Sheppard and Waneta Eddy sites. Copper release from the organic matter fraction in the presence of oxidizing conditions could produce effects at Maglios and Fort Sheppard; however, a higher percentage of copper in the residual fraction at Waneta would suggest a lower overall potential for release than at other sites. Lead release from the iron/manganese oxide fraction in the presence of reducing conditions or via release from the carbonate fraction if the pH shifts into the acidic range could occur; however, a higher percentage of lead in the residual fraction at Waneta would suggest a lower overall potential for release than at other sites. Although effects from zinc cannot be ruled out because the total concentrations are much higher than the PEL, the potential for effects is much lower than total concentrations would indicate because of the relatively high proportion of zinc found either in the residual or iron/manganese oxide fractions at all three sites.

Magnitude of Response for the Benthic Invertebrate Lines of Evidence

The magnitude of response of benthic invertebrates in toxicity tests as well as in the field was evaluated using criteria presented in Table 4.27. The demarcation between low and moderate magnitude was based, in part, upon guidance provided by Environment Canada for the EEM program (as explained above for periphyton) (Environment Canada 2002). The methods were developed for interpretation of data gathered using the Sediment Quality Triad approach (Chapman and Anderson 2005) and on professional judgment. The EEM "critical effect size" for field measurements of the benthic invertebrate community (two standard deviations from the reference mean) was used to demarcate between low and moderate magnitude. The demarcation between moderate and high magnitude responses in benthic invertebrate community metrics was based upon Chapman and Anderson (2005), precedent in EEM studies (Kovats pers. comm. 2006), and professional judgement.

Table 4.27 Magnitude Criteria for the Benthic Invertebrate Lines of Evidence

Line of Evidence	Method of Assessment of the Line of Evidence	Evidence of Negligible to Low Magnitude ○	Evidence of Moderate Magnitude ⊙	Evidence of High Magnitude ●
Sediment Toxicity	Statistical comparisons of toxicity endpoints between reference and exposure sites.	Less than 20% reduction in each toxicological endpoint.	Statistically significant ($p < 0.05$) and more than 20% but less than 50% reduction in one or more toxicity endpoints relative to reference sites.	Statistically significant ($p < 0.05$) and more than 50% reduction in one or more toxicity endpoint relative to reference sites.
Benthic Invertebrate Community	Statistical comparisons of benthic community variables between reference and exposure sites.	No statistically significant differences in benthic community variables between reference and exposure sites.	Statistically significant reduction ($p < 0.05$) in one or more benthic community variables relative to reference sites and that reduction is >2 standard deviations from the reference mean.	Statistically significant reduction ($p < 0.05$) in most or all benthic community variables relative to reference sites and those differences are >3 standard deviations from the reference mean.
Benthic Invertebrate Community	Multivariate analysis.	Reference and exposure sites cluster together on ordination plot.	Reference and exposure sites form clusters that partially overlap on ordination plot.	Reference and exposure sites cluster separately on ordination plot.

The Maglios and Waneta sediments produced high magnitude responses in sediment toxicity tests (Table 4.28). It was anticipated that effects would be more pronounced in the 20-day test, because of the longer exposure period. This was observed in Maglios and Waneta Eddy sediments (Golder 2007a). However, there were some notable differences between the results of the 10- and the 20-day tests. Effects on growth were in opposite directions in Trimac sediments (positive in the 10-day test; negative in the 20-day test) and positive effects on growth were less pronounced in the 20-day test in Airport Bar and Fort Sheppard Eddy sediments. There is no obvious explanation for these differences, although declining water quality over time is a possibility because the tests were run without renewal of overlying water.

Table 4.28 Magnitude Rating for Toxicity Test Line of Evidence

Sample Type	Site	Percentage Effect on Survival(a)	Rating for Effect on Survival	Percentage Effect on Growth(a)	Rating for Effect on Growth
Reference	Kootenay Eddy	12	○	22	○
Reference	Genelle Eddy	-29#	⊙	-26ns/#	○/⊙
Reference	Birchbank Eddy	17	○	4	○
Exposure	Korpak	-1	○	3	○
Exposure	Maglios	-100*	●	-	●
Exposure	Casino	17	○	10	○
Exposure	Airport Bar	17	○	47	○
Exposure	Trimac	4	○	-46*	⊙
Exposure	Fort Sheppard Eddy	-29	○	36	○
Exposure	Waneta Eddy	-67*	●	-81*	●

Notes:
Statistically significant differences between a reference site and the other two reference sites are identified by #.
ns/# indicates that removal of an outlier identified by diagnostic tests resulted in no significant difference.
- = not applicable.
* indicates a significant difference from the reference sites.
(a) Percentage effect was calculated relative to the mean of the three reference sites.

The results for Genelle Eddy indicate that sediments at this reference site had a negative effect on the test organisms, both on survival and growth (Table 4.28) (Golder 2007a). Examination of sediment chemistry and habitat data did not identify any potential causes that could account for this result. The percent sand content was similar at all three reference sites. Furthermore, since the laboratory controls were also sand (100% silica sand), the substrate at Genelle cannot be the only reason for the significant effect on survival relative to the laboratory control.

The Waneta site had high-magnitude responses in benthic invertebrate community characteristics according to lines of evidence 2 and 3 (site-by-site comparisons of field community composition and abundance and multivariate analysis of all sites together) (Table 4.29). The Maglios site did not have sufficient replication to allow site-by-site comparison; however, multivariate analysis showed that it also had high-magnitude responses (Table 4.29). The Fort Sheppard site showed moderate response in site-by-site comparisons but not in the multivariate analysis. All of the other sites had responses that were rated as low to negligible.

Table 4.29 Magnitude Rating for Site-by-Site and Multivariate Analysis of Field-Based Benthic Invertebrate Community Lines of Evidence

Site	Site Comparisons	Multivariate Analysis
Reference Sites		
Kootenay Eddy	○	○
Genelle Eddy	–	○
Birchbank Eddy	○	○
Exposure Sites		
Korpak	–	○
Maglios	–	●
Casino	–	○
Airport Bar	○	○
Trimac	–	○
Fort Sheppard Eddy	⊙	○
Waneta Eddy	●	●

Notes:
– = not available.
Magnitude:
● strong response.
⊙ moderate response.
○ weak response.

Natural habitat characteristics were important variables influencing the benthic invertebrate community (Golder 2007a). The sampling sites could be separated into two groups based on habitat characteristics. Sites at Kootenay Eddy and Fort Sheppard Eddy had greater macrophyte cover and were located in deeper water than most other sites. Sites at Genelle Eddy, Birchbank Eddy, Korpak, Maglios, Casino and Airport Bar were in shallower waters and had low macrophyte cover. Sites at Trimac and Waneta Eddy did not easily fit into these groups. The site at Trimac was in shallower water; however, it had greater macrophyte cover than most of the other sites. Waneta Eddy had no macrophyte growth but was considerably deeper than all other sites.

All sites in the Columbia River were similar in terms of field-measured water quality variables (Golder 2007a). Dissolved oxygen concentration was moderate, ranging between 7.8 and 8.9 mg/L. Conductance was in the low to moderate range, varying from 130-180 µS/cm. Water in this portion of the Columbia River was slightly basic, with pH ranging from 8.4-8.7. Water temperature varied within a narrow range.

Sediment particle size and carbon content were similar at most sites (Golder 2007a). Sediments at most sites consisted primarily of sand. Carbon content was generally below the detection limit, with measurable total carbon concentrations only at Kootenay Eddy and Trimac. Sediment characteristics at Trimac were distinct from those at other sites, having the largest proportion of clay and the highest carbon content. Also, some of the highest proportions of Harpacticoida and Ostracoda populations were present at the Kootenay Eddy and Trimac sites.

Uncertainty in the Benthic Invertebrate Lines of Evidence

The uncertainty associated with the toxicity test line of evidence is moderate rather than high because of some concerns with measurement error (Golder 2007a). Mean survival in laboratory controls using the standard substrate (silica sand) ranged from 58-82%, with three of the five mean values below the acceptance criterion of 70% survival (Environment Canada 1997). During the 10-day test, mean biomass values of larvae in silica sand laboratory controls were also below the acceptance criterion of 0.6 mg dry weight per organism (Environment Canada 1997). Compared to the laboratory controls, higher survival and biomass were achieved in most reference site sediments. The low survival and growth in the laboratory controls may have been due to the physical nature of the silica sand used as the control sediment. The chironomid larvae were fed throughout the tests; therefore, food availability was not a factor.

Normally, results outside acceptance criteria indicate that the test should be repeated. However, in light of the reference sediment data, which are valid and generally conform to the expectation of no toxicity or a low level of toxicity, the toxicity data were retained as a line of evidence.

The uncertainty associated with the natural variability of the measures of the benthic invertebrate community is low because the sampling design was in accordance with EEM criteria for statistical power (Table 4.19). Furthermore, the design produced an adequate representation of a gradient in PCOC concentrations and habitat features. The gradient design included three upstream sites and seven sites downstream of the Teck Cominco smelter, which were intended to represent a gradient in the concentration of metals in bottom sediments. The ten sites also represented gradients in habitat features (e.g., water depth, sediment particle size distribution) that may influence the benthic community; these gradients were taken into consideration when interpreting field study results. Furthermore, responses by individual benthic invertebrate variables, as well as results of multivariate analysis, were consistent in identifying locations with adversely affected benthic invertebrate communities

Uncertainty related to the relative bioavailability of PCOC from sediments was addressed by performing sequential extraction of sediments from all of the sampling sites. The results were concordant with the toxicity test data and with the benthic invertebrate community data. The sites with the highest proportion of metals in potentially available fractions were Maglios, Fort Sheppard and Waneta. These were the same sites where toxicity was observed and where there were at least some statistically significant differences in the benthic invertebrate community.

Potentially confounding anthropogenic stressor sources along the gradient of smelter-related PCOC include storm-water discharges from the city of Trail, Trail Creek and Ryan Creek. Storm-water discharges from Trail occur within the initial dilution zone of the smelter. These discharges may confound the interpretation of data from the Korpak and Maglios sites. Stressors within storm-water discharge can include nutrients, metals, and organic compounds. Trail Creek is affected by urban runoff from Rossland and Warfield and by input from Haley Creek, which is influenced by drainage from legacy waste materials adjacent to the Teck Cominco Fertilizer Operations. In addition, during the timeframe of the benthic invertebrate studies, a small number of direct household sewer connections to Trail Creek were still in use (subsequently eliminated by the City of Trail). Trail Creek input is most likely to confound the interpretation of data from the Korpak site. Ryan Creek contains elevated PCOC concentrations, including cadmium and zinc, possibly related to a combination of natural mineralization in the watershed, historic mining activity in the upper portion of the watershed. Ryan Creek input is most likely to confound the interpretation of data from the Korpak site.

The support for Conceptual Model 1 was moderate because at least two lines of evidence indicated direct effects (at Waneta and Maglios), most potential confounding variables were quantified and they did not account for all of the observed responses (Table 4.19). The use of laboratory and field-based evidence for response of benthic invertebrates in concert with concurrent chemistry data provided a wider basis for interpretation of the potential for effects from exposure to PCOC. Furthermore, several natural habitat variables that can account for the observed benthic invertebrate community characteristics were measured and included in the statistical analysis. However, confounding anthropogenic stressors such as flow regulation were not included in the analysis.

The data provided moderate-to-weak support for Conceptual Model 2. There was moderate support for the presence of physical effects on habitat due to historic slag discharge (Table 4.19). There was weak support for indirect effects via changes in food chain interactions or via the effect of multiple stressors acting together (Table 4.19).

The moderate score for support of the predicted physical effects of slag deposition was based upon significant changes in the benthic invertebrate community at sites with higher slag content (Maglios and Waneta). However, the relative contribution of physical effects versus direct effects of the PCOC in the sediments could not be determined.

There was weak support for the predicted indirect effects via changes in other levels of the food chain, although support could not be assessed at all sampling sites because sites were not always the same for attached algae and benthic invertebrates. For example, strong currents at the attached algae sampling areas of New and Old Bridge prevented the successful collection of benthic invertebrate sites. Additionally, the lack of depositional habitat at Stoney Creek and Beaver Creek attached algae sampling sites prevented the collection of benthic invertebrates at these locations. The Korpak and Fort Sheppard sites had both periphyton and benthic invertebrate samples taken. The Korpak site had low periphyton abundance relative to upstream reference sites; however, this site clustered together with upstream reference sites when benthic invertebrate community data were assessed. There was some (albeit inconsistent) evidence for responses in the benthic invertebrate community at Fort Sheppard; however, the periphyton community at this site was not significantly different than upstream reference sites.

The combination of the lack of evidence for combined effects of multiple stressors and the difficulty in distinguishing among potential causes led to the conclusion that there was weak support for the multiple stressor effects predicted by Conceptual Model 2. There is insufficient scientific understanding to develop hypotheses of multiple stressor effects in the study area (e.g., the combined effect of PCOC, flow regulation and nutrient addition). However, the gradient sampling design assisted with distinguishing responses to some of the other stressors in the AOI. For example, upstream reference sampling sites were within the expected gradient of response to the Zellstoff Celgar pulp mill discharge. Therefore, if there was a distinct spatial pattern of responses of benthic invertebrates to the pulp mill discharge, one or all of the upstream sampling stations would be expected to be statistically distinct (e.g., would appear as separate clusters during multivariate analysis). This was not the case; the reference sites were clustered with all of the exposure sites except Maglios and Waneta. Responses to stressors that overlap with the smelter-related gradient of PCOC concentrations were more difficult to distinguish. For example, the near-field exposure sites within the smelter-related gradient (Maglios and Korpak) were also within the zone of influence of storm-water discharges from the city of Trail and input from tributaries such as Trail Creek which is affected by the former Teck Cominco fertilizer plant. Some of the significant differences in the benthic invertebrate community observed at Maglios may be due to these other stressors, or to combined effects of multiple stressors. However, if combined effects were occurring, significant differences would be expected at the Korpak site as well; in fact, this site was not distinguishable from reference sites.

The assessment of future risks to benthic invertebrates is limited to the period for which operation (inputs and outputs) of the existing smelter can reasonably be predicted; i.e., 10-20 years. As discussed for periphyton, climate change will not affect the main stem Columbia River as much as in other areas over the next 10-20 years because of the storage capacity in the Columbia River system due to impoundments. In addition, the terms of the Columbia River Treaty govern how river flow is managed. This assessment assumes no change in the terms of the Treaty. Therefore, changes in river flows and volumes beyond currently observed hydrograph variations are not anticipated for the10-20 year period identified for this assessment. Furthermore, changes in PCOC concentrations or distribution of slag caused by changes in flow beyond those currently observed are not predicted.

Summary of Evidence for Direct and Indirect Effects on Benthic Invertebrate Communities

All lines of evidence indicate that the benthic invertebrate communities at the Maglios and Waneta sites had a response of high magnitude. These two sites had the highest visually estimated slag content in the sediments. The Waneta site had among the highest concentrations of PCOC, although other sites often had comparable or greater concentrations of PCOC. The benthic community at the Fort Sheppard site had a moderate response when compared to upstream sites; however, toxicity tests and benthic community lines of evidence indicated a low response. The benthic invertebrate communities at all other sites downstream of the smelter had a low magnitude response.

4.5.3 Step 5: Assessment of Causation for Benthic Invertebrate Lines of Evidence

The lines of evidence for evaluation of Conceptual Model 1 (direct effects of PCOC on benthic invertebrates; physical effects on benthic habitat) are scored for causation (Table 4.30).

Table 4.30 Causation Scores for Benthic Invertebrate Lines of Evidence for Direct Effects: A = Physical Habitat Effects; B = Effects of PCOC

Causal Criterion	Line of Evidence					
	Effect on Survival in Toxicity Tests	Effect on Growth in Toxicity Tests	Site-by-Site Comparisons of Benthic Community Characteristics		Multivariate Analysis	
			A	B	A	B
Spatial Correlation	+	+	+	+	+	+
Temporal Correlation	n/a	n/a	0	0	0	0
Biological Gradient/Strength	+	+	+	+	+	+
Plausibility: Mechanism	+	+	+	+	+	+
Plausibility: Stressor-Response	0	0	+	+	+	+
Consistency of Association	-	-	+	0	+	0
Experimental Verification	0	0	n/a	n/a	n/a	n/a
Specificity of Cause	0	0	0	0	0	0
OVERALL STRENGTH OF EVIDENCE	o	o	⊙	⊙	⊙	⊙

Notes: See Table 4.15 for key to individual causation scores.
● strong overall strength of causal evidence.
⊙ moderate overall strength of causal evidence.
o weak overall strength of causal evidence.
n/a = not available.

This reasoning behind the causation scores for the toxicity test results is presented below.

- *Spatial Correlation*: The spatial correlation criterion was assigned a score of "+" corresponding with "compatible" because effects on survival and on growth were at least partly in accordance with the amount of slag, the total PCOC concentrations, and the relative bioavailability (as indicated by sequential extraction data) at each site. However, there were some exceptions, including Fort Sheppard, where effects on survival and growth were low despite elevated slag and PCOC concentrations, and a higher proportion of copper, lead and zinc in fractions from which metals can be released.
- *Biological Gradient/Strength:* The link between % slag, total PCOC concentrations, and relative bioavailability and toxicity test results was not monotonic. There was not a consistent relationship between sites with elevated slag or PCOC concentrations and a higher proportion of potentially available PCOC and toxicity. Toxicity was highest at the Waneta site, where sediment chemistry and percentage slag were concordant with the toxicity test results, but where potential bioavailability was lower than at Maglios or Fort Sheppard. The Maglios site had high percentage slag, elevated total PCOC concentrations, and a higher proportion of PCOC in the more available fractions (particularly copper); however, the Fort Sheppard site, which also had a high slag content, elevated total PCOC concentrations and a higher proportion of PCOC in the more "available" fractions, did not have high toxicity. The score for this criterion was "+", corresponding with "weak or other than monotonic or inconsistent responses".
- *Plausibility: Mechanism:* There are plausible mechanisms for the effect of PCOC on benthic invertebrate communities, usually via effects on the more metal-sensitive taxa (Wentzel et al. 1977, Winner et al. 1980). The score assigned for this criterion was "+" for all measures, which corresponds with "plausible."

- *Plausibility: Stressor/Response:* The score for this criterion was “0” for “ambiguous” because there a lack of evidence for the expected stressor/response curve (i.e., toxicity versus slag, total PCOC content, or proportion in the more “available” fractions).
- *Consistency of Association*: There was a lack of consistency in the evidence among sites along the gradient of slag content, total PCOC concentration or proportion of PCOC in the more “available” fractions. The score assigned for this criterion was “-” because of the observed exceptions to association with slag, total PCOC or proportion of PCOC in the more “available” fractions.
- *Experimental Verification*: This criterion received a “0” score because toxicity test results were ambiguous. Toxicity was not always observed where expected.
- *Specificity*: None of the responses could be considered to be specific to the effects of slag or PCOC. One of the most important confounding variables was substrate particle size. A score of “0” was assigned for this criterion corresponding with “one of many” potential causes.

In summary, toxicity test results provided low-to-moderate evidence of a causal link to smelter-related emissions. There was low evidence of causation except at the Waneta and Maglios sites. The strongest links were at the Waneta site, where sediment chemistry and percentage slag were concordant with the toxicity test results. The Maglios site also had high percentage slag and elevated PCOC concentrations; however, there were other sources of PCOC and the potential for other chemical stressors (such as pesticides) in the immediate vicinity of this site.

The reasoning behind the causation scores for the statistical results is presented below.

- *Spatial Correlation*: The spatial correlation criterion was assigned a score of “+” corresponding with “compatible” for both physical effects of slag and effects of PCOC. Site-by-site comparisons showed that the two sites with higher slag content (Fort Sheppard and Waneta) were statistically different from Airport Bar and upstream reference sites. However, multivariate analysis did not show Fort Sheppard in the same “cluster” as Waneta. Concentrations of most PCOC were highest at Waneta, followed by Maglios, Fort Sheppard and then Korpak. The proportion of copper, lead and zinc in the more “available” fractions was highest at Maglios, Fort Sheppard and Waneta (in that order). There was a statistical spatial correlation at the two sites with the highest total PCOC concentrations (Waneta and Maglios); however, there was no indication of a correlation at the other sites with elevated total PCOC (Fort Sheppard and Korpak). Since there was some evidence of a relationship between slag content and total PCOC content and the benthic invertebrate community, a “+” score was assigned. The evidence was not strong enough to warrant a “++” score.
- *Temporal Correlation*: Evaluating temporal correlation was challenging because some of the previous studies used different sampling methods (e.g., artificial substrates). In addition, there were few sites in common among studies. Past data from artificial substrate sampling showed that average benthic invertebrate abundance was relatively high at the Birchbank, downstream Stoney Creek, Korpak, and Waneta sites, and much lower at the New Bridge site (Golder 2003a). However, the composition of benthic invertebrate communities varied considerably among the five sites. At Birchbank, and downstream Stoney Creek sites, the majority of invertebrates were dipterans and trichopterans, whereas trichopterans dominated at New Bridge and Waneta, and Diptera were more abundant than the other orders at Korpak

(Duncan 1999, McElligott et al. 2001). Species richness and density were slightly lower at downstream sites than reference sites. The past studies reflected benthic invertebrate communities in erosional habitats whereas the 2003 study reflected communities in depositional habitats. Past studies did not address directly the physical effects of slag. Because of the difficulty comparing among different sampling methods and sites, a score of "0" for "uncertain" was assigned to the temporal correlation criterion for both physical effects of slag and effects of PCOC.

- *Biological Gradient/Strength:* The relationship between % slag, total PCOC concentrations and proportion of PCOC in the more "available" fractions in sediment and the benthic invertebrate community was not monotonic. The % slag was highest at Waneta, followed by Maglios and then Fort Sheppard. The total PCOC concentrations were highest at Waneta, followed by Maglios, Fort Sheppard and Korpak. The highest proportion of PCOC in the more "available" fractions occurred at Maglios and Fort Sheppard. Based upon these gradients, it would be expected that the Fort Sheppard site (and possibly the Korpak site) would also have had statistically distinct benthic communities. However, only one statistical line of evidence showed the Fort Sheppard site to be significantly different and none of the statistical analyses showed the Korpak site to be significantly different. The score for this criterion was "+", corresponding with "weak or other than monotonic or inconsistent responses" for both physical effects of slag and effects of PCOC.

- *Plausibility: Mechanism:* There are plausible mechanisms for the effect of PCOC on benthic invertebrate communities, usually via effects on the more metal-sensitive taxa (Wentzel et al. 1977, Winner et al. 1980). A plausible mechanism for physical effects of slag would be a change in the food web structure due to the lower-quality substrate provided by slag. The score assigned for this criterion was "+" for all measures, which corresponds with "plausible."

- *Plausibility: Stressor/Response*. There was some evidence of stressor/response but only at the sites with the highest slag content and the highest concentrations of PCOC (Waneta, Maglios and Fort Sheppard). The statistical analysis did not reveal a gradient of response according to % slag or PCOC concentration; rather, there were either effects or no effects. Therefore, the score assigned for this criterion was "+" for concordant, but with the proviso that the data do provide evidence of a threshold for effects, and are not sufficient to develop a stressor/response curve.

- *Consistency of Association*: There were several exceptions to an association between elevated total PCOC concentrations and proportion in the more "available" fractions and statistically significant responses in the benthic invertebrate community. For example, all downstream sites had copper concentrations above sediment quality guidelines (in many cases substantially above); however, the only sites with a statistically significant response in pair-wise comparisons were Waneta and Fort Sheppard. Therefore, a score of "0" for "many exceptions to the association" was assigned for the effects of PCOC. The effects of slag were evident at the two sites with the highest slag content (Maglios at 40% slag and Waneta at 90% slag). There was also some evidence of effects at Fort Sheppard with 30% slag and no evidence of effects at the other sites with slag content ranging from 0-10%. Therefore, a score of "+" was assigned for the physical effects of slag.

- *Experimental Verification*: There was no experimental verification of field data via the use of field experiments or mesocosms.

- *Specificity*: There were several natural variables that were shown to be significantly correlated with the benthic invertebrate community, notably depth and the presence of macrophytes. There were also confounding stressors present; e.g., stormwater outfalls directly upstream of Maglios and Korpak. Therefore, a score of "0" was assigned for specificity for both physical habitat effects and effects of PCOC.

Comparisons among sites provided low evidence of a causal link between PCOC concentrations and responses and moderate evidence of a causal link with physical habitat effects due to slag deposition. Site-by-site comparisons were only possible on a subset of sites. Therefore, there is high uncertainty with respect to the presence of a biological gradient, consistency of association and spatial correlation with PCOC concentrations. Sites with the highest concentrations of particular PCOC did not always have significant differences. However, significant differences greater than the critical effect size were detected at the two sites with higher slag content (Fort Sheppard and Waneta).

Multivariate analysis showed moderate evidence of a causal link with PCOC concentrations and slag content at the Maglios and Waneta sites. These two sites were in a very distinct cluster. The other sites were arranged along the full length of the first axis; they were "clustered" only with respect to the second axis.

The analysis of benthic invertebrate community data showed that natural variables strongly influenced the benthic invertebrate community. This finding contributed to the scores assigned for spatial correlation, biological gradient, consistency of association and specificity.

In summary, the strongest evidence for a causal link with the smelter occurred at the Waneta site, followed by the Maglios site. Evidence for a causal link with the smelter at other sites was much weaker. Therefore, Conceptual Model 1 appears to apply to a limited extent within the AOI.

Indirect effects on the benthic invertebrate community as per Conceptual Model 2 are not indicated in the available data. The periphyton community was altered in the immediate vicinity of the Teck Cominco smelter effluent discharge; however, there were no benthic invertebrate data available from this site. The nearest site to the near-field periphyton sites (at Maglios) may have demonstrated a combination of direct and indirect effects. However, the PCOC concentrations in the sediments and the percentage slag composition at Maglios indicate that direct effects may dominate. Indirect effects via changes in fish populations (thus changing feeding rates on benthic invertebrates) are unlikely given the lack of moderate or high-magnitude responses in the fish receptor species.

4.5.4 Step 6: Risk Characterization for Benthic Invertebrates

The risk management objective for benthic invertebrates is:

> "Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on the diversity of aquatic plant and animal communities in the Columbia River and its tributaries."

The assessment endpoint is benthic invertebrate community composition.

As explained above for periphyton, the SALE summary tables apply only to Conceptual Model 1. A narrative risk characterization was produced for Conceptual Model 2.

Conceptual Model 1

The combination of magnitude, causation, and uncertainty scores was used to produce a recommendation regarding the need for consideration of risk management options (Table 4.31). Risk from direct physical effects on benthic invertebrate habitat via slag deposition was also considered (Table 4.31).

A recommendation to proceed to risk management at the Maglios and Waneta sites (Table 4.31) indicates that the risk management objective is not being met at those sites for the benthic invertebrate assessment endpoint. A recommendation to proceed to the consideration of risk management options does not imply that active remediation is required at that site. Options can include monitoring, not only of the benthic invertebrate community but also of the connection between the benthic invertebrate community and the fish community. This would provide additional information regarding the relative importance of addressing the issue of elevated slag content and elevated PCOC concentrations. Furthermore, risk management options may include further investigation of causation, particularly at the Maglios site, where sources of non-smelter stressors are known to exist.

The Fort Sheppard site produced conflicting evidence, leading to the "yes, but confirm with more data" answer regarding the need to proceed to evaluation of risk management options. Although sediment toxicity tests and multivariate analysis showed low-magnitude responses with either low or moderate uncertainty, site comparisons between Fort Sheppard and Airport Bar (which had much lower PCOC concentrations in the sediments) indicated moderate-magnitude responses with low uncertainty. There was also moderate evidence of direct effects on habitat caused by slag deposition at Fort Sheppard.

There is moderate confidence in the risk characterization and the recommendation that evaluation of risk management options is required at Maglios and Waneta and perhaps required at Fort Sheppard because:

- several lines of evidence were examined not only for magnitude but also for causation and uncertainty;
- sampling was conducted along a gradient of exposure to PCOC and slag, including areas of highest expected exposure in well-known, longer-term depositional areas;
- all of the depositional areas with the finer sediments expected to be associated with higher concentrations of PCOC that were identified during exploratory surveys of the AOI were sampled during the formal sampling program; and
- natural variability in benthic invertebrate measures was addressed satisfactorily via the sampling design; but
- there were conflicting lines of evidence at the Fort Sheppard site;
- there were other, uncharacterized sources of stressors at Maglios; and
- uncertainty was moderate for the toxicity test lines of evidence.

No future increases in smelter-related stressors are expected; therefore, consideration of risk management options should focus on confirmation of results at Maglios and Waneta, further characterization of the risk at Fort Sheppard, and further investigation of causation at Maglios and, if necessary, at Fort Sheppard.

Table 4.31 SALE Summary Table for Benthic Invertebrates

Site (Downstream of Smelter)	Sediment Toxicity						Benthic Invertebrate Community Similarity to Reference						Direct Effects on Habitat Caused by Slag Deposition			Proceed to Evaluation of Risk Management Options?
	Survival			Growth			Site Comparisons			Multivariate Analysis						
	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	
Korpak	○	⊙	??	○	⊙	??		-		○	⊙	?	○	⊙	??	No
Maglios	●	⊙	??	●	⊙	??		-		●	⊙	?	●	⊙	??	Yes
Casino	○	⊙	??	○	⊙	??		-		○	⊙	?	○	⊙	??	No
Airport Bar	○	⊙	??	○	⊙	??	○	○	⊙	?	○	⊙	?	⊙	?	No
Trimac	○	⊙	??	⊙	⊙	??		-		○	○	?	○	⊙	??	No
Fort Sheppard Eddy	○	⊙	??	○	⊙	??	⊙	○	⊙	?	⊙	⊙	??	⊙	??	Yes, but confirm with more data
Waneta Eddy	●	⊙	??	●	⊙	??	●	●	⊙	?	●	⊙	??	⊙	??	Yes

Notes: - = not applicable.

Magnitude:

- ● strong response.
- ⊙ moderate response.
- ○ weak response.

Causation:

- ● strong overall strength of causal evidence.
- ⊙ moderate overall strength of causal evidence.
- ○ weak overall strength of causal evidence.

Uncertainty:

- ? low uncertainty (high statistical power, full gradient design, all important natural variables accounted for).
- ?? moderate uncertainty (moderate statistical power, control/impact rather than full gradient design; most natural variables accounted for).
- ??? high uncertainty (low statistical power, important natural variables not accounted for).

Conceptual Model 2

Indirect effects on the benthic invertebrate community as per Conceptual Model 2 are not indicated in the available data. The periphyton community was altered in the immediate vicinity of the Teck Cominco smelter effluent discharge; however, there were no benthic invertebrate data available from this site. The nearest site to the near-field periphyton sites (at Maglios) may have demonstrated a combination of direct and indirect effects. However, the PCOC concentrations in the sediments and the percent slag composition at Maglios indicate that direct effects may dominate. Indirect effects via changes in fish populations (thus changing feeding rates on benthic invertebrates) are not indicated because there are no observed effects on fish health or fish populations that can be related to the Teck Cominco smelter in the AOI (see below).

The evidence for indirect effects on benthic invertebrates is not strong enough to lead to a recommendation for risk management. However, uncertainty with respect to indirect effects is high, particularly at the Maglios and Waneta sites. Therefore, the examination of risk management options should include consideration of both direct and indirect effects at these sites.

4.6 Fish

The assessment endpoints for fish in the mainstem Columbia River are:

- habitat quality;
- growth, condition and reproductive capability of the fish receptor species;
- presence, survival and reproductive success of white sturgeon; and
- habitat quality for white sturgeon.

Step 2 of the SALE process addresses the habitat-related assessment endpoints. There is a separate habitat quality endpoint for white sturgeon because of their status as a red-listed species. Steps 3 and 4 address the fish health and population assessment endpoints (the second and third endpoints in the above list).

These assessment endpoints were evaluated for direct effects of smelter-related emissions, as per Conceptual Model 1, as well as indirect effects as per Conceptual Model 2.

4.6.1 Step 2: Effects Due to Smelter-Related Change in Physical Habitat (All Fish Species)

The historic discharges of slag from the Cominco lead smelter and nutrient-enriched effluent from the Teck Cominco phosphate fertilizer plant affected the physical habitat of fish in the Columbia River by changing the nature of the substrate and by stimulating the growth of periphyton and macrophytes respectively. Slag along the river edges, in backwater areas and in depositional areas, may have affected spawning, rearing and feeding habitats both directly and via changes in the food supply provided by benthic invertebrate community.

Since cessation of slag discharge, the slag deposits have been scoured and redistributed, occurring primarily at the Fort Sheppard and Waneta eddies, plus scattered smaller areas such as the Maglios benthic invertebrate sampling site. The percentage composition of slag is still sufficient to alter directly the nature of the physical habitat in these areas; however, affected habitats represent a very small proportion (<0.1%) of total habitat in the AOI. In order to place the current level of habitat alteration into context, a brief description of general and white sturgeon habitat within the AOI is presented below.

General Fish Habitat

Fish habitat within the AOI has been described as part of a recurring fish community indexing program conducted by Golder for B.C. Hydro (Golder 2002a, 2003b, 2004a, 2005a 2006b). Fish sampling reaches sampled during this indexing program encompass the AOI, and are divided into upper, middle and lower sections. The upper section extends from the Hugh Keenleyside Dam to river km 23 near the mouth of Champion Creek; therefore, this section is entirely upstream of Teck Cominco. The middle section extends from Champion Creek to river km 40, which is just downstream of the smelter and adjacent to the community of Glenmerry. The lower section extends from Glenmerry to the U.S. border, approximately 45 km downriver from the Hugh Keenleyside Dam.

The upper section of the AOI contains three main fish habitat types: (1) the first 8 km of deep water, with average thalweg (the line defining the lowest points along the length of a river bed or valley) depths ranging from 18-20 m, sand/silt substrates and frequent armouring of the shoreline with rip rap; (2) the next 6 km of shallow water extending to Kinnaird Bridge, with typical thalweg depths of 2-6 m, high water velocities, boulder/cobble substrates and common shallow-water habitats; and (3) the final 9 km extending to Champion Creek with thalweg depths of 6-10 m, moderate to high flow velocities with a singular, relatively straight channel confined between steep, eroding valley walls, and a low availability of shallow nearshore habitats (Golder 2002a).

The middle section of the AOI also contains three main fish habitat types: (1) the first 4 km from Champion Creek to the vicinity of Sullivan Creek with a braided depositional island complex, moderate velocities, shallow depth (1-4 m), cobble/gravel substrates and an abundance of shallow nearshore habitats; (2) the next 11 km extending to the smelter and the city of Trail characterized by a narrow deep channel, moderate to high velocities, thalweg depths from 6-12 m and limited shallow-water habitats; and (3) the final section extending to km 40 at Glenmerry with thalweg depths ranging from 3-8 m, moderate velocities (with local sections of low and high velocities), cobble/boulder substrate, localized gravel areas associated with side-bar formation and alluvial outwash fans of tributaries, and moderate availability of shallow-water habitat (Golder 2002a). The Rock Island area is a unique feature within the lower section, where a transverse escarpment of bedrock produces a localized area of deep turbulent habitat.

The lower section of the AOI extends from Beaver Creek to the U.S. border and has two main habitat types. The section from Beaver Creek to upstream of Fort Sheppard Eddy has generally shallow depths with the thalweg at 3-8 m, moderate velocities with localized sections of high and low velocities, cobble/boulder substrates with localized areas of gravel associated with side-bar formation and alluvial outwash fans and moderate availability of shallow-water habitat (Golder 2002a). The section from the Fort Sheppard Eddy to the border, with the exception of the two large eddy pools at Fort Sheppard and Waneta, is shallow, with high velocity and boulder/cobble substrate. Rapids are present above and below Fort Sheppard Eddy and immediately above Waneta Eddy. Thalweg depths range from 3-8 m. The two eddies provide localized areas of lower water velocity and greater depth, with maximum depths of approximately 50 m at Fort Sheppard and 20 m at Waneta (Golder 2002a). Shallow-water habitat in this section is limited.

All reaches of the Columbia River within the AOI are characterized by the almost complete absence of fine sediments. The only exceptions to this are in small backwater areas that occur in the lee of sand and gravel bars or alluvial fans.

Fish distribution data in the AOI shows that the two areas with the most extensive slag deposition (Fort Sheppard and Waneta eddies) are used by a variety of fish species for feeding and staging, including mountain whitefish, lake whitefish, rainbow trout, walleye, burbot, sucker species, redside shiner, sculpin species, northern pikeminnow and, occasionally, yellow perch and smallmouth bass (Golder 2002a, 2003b, 2004a, 2005a 2006b). In addition, both areas are used by adult and juvenile white sturgeon (Golder 2003b, 2005a).

The Pend d'Oreille River, near its confluence with the Columbia River is the only documented white sturgeon spawning area in the AOI (R.L. & L. 1996). This spawning area is not within the Waneta Eddy but occurs in the high velocity Pend d'Oreille River plume.

Relative abundance of several fish species is greatest in the lower section of the AOI (which includes Fort Sheppard and Waneta areas plus the Beaver Creek area). Data from 2001 to 2005 show that walleye, burbot, lake whitefish and sculpin species were always more abundant in the lower section (Golder 2002a, 2003b, 2004a, 2005a 2006b). Mountain whitefish were always more abundant in the upper section. If white sturgeon were captured at all, they were most likely to be captured in the lower section; however, they were captured in all three sections in two of the five sampling years.

Fish were found in four specific habitat types in the Fort Sheppard area (Golder 2002a, 2003b, 2004a, 2005a 2006b):

- A2 – cobble/boulder and large boulder; armoured shorelines that produce backwater areas; moderate to low velocity; instream cover provided by backwater areas, and substrate roughness.
- A4 – gently sloping banks with small and large boulders often embedded in finer materials; shallow depth offshore; generally moderate to high velocities, instream cover provided by pocket eddies behind boulders.
- D2 – low-relief, gently sloping bank with shallow water depths offshore; gravel and cobble substrate; low-moderate current velocity; areas with higher velocity produce riffle areas, instream cover provided by substrate roughness often associated with bar formations and shoal habitat.
- Eddy – large areas of counter current flows with depths generally <5 m produced by major bank irregularities; high quality areas for adult and subadult life stages; high availability of instream cover.

Slag deposits are found in varying degrees in each of these habitat types; however, there are insufficient observations to evaluate whether any of the four habitats contain more slag than the others. Generally, wherever current velocities are low enough to allow deposition (e.g., in low-velocity areas in the lee of cobble/boulder substrate or in the eddy), slag can be present. Sediment from benthic invertebrate sampling stations in A4 habitat at Fort Sheppard contained 30% slag (Golder 2005a).

The presence of slag at Fort Sheppard and Waneta, combined with the extensive use of these sites by fish, produces the potential for direct and indirect effects on fish from slag-related habitat alteration. Direct effects may include altering the nature of the substrate used for spawning such that fish either no longer use the area, or eggs and larvae have lower survival in the area. Direct effects may also include abrasion caused by contact with the slag particles, which tend to retain their angular form even after weathering. Indirect effects may include alteration of food source. The benthic invertebrate community has lower abundance and fewer species at the Waneta site than at other sites. The differences in the benthic invertebrate community may, in part, be related to the slag content (which can be as high as 90%) (Golder 2005a). The lower abundance and diversity of benthic invertebrates may, in turn, affect fish that use the Waneta site for feeding; however, the relative importance of the Waneta Eddy to overall fish food production is low, as explained below.

Food production within the eddies would be insufficient to support the numbers of fish that use these areas. Most of the food consumed by fish that reside in the eddies originates from upstream sources (e.g., mysid shrimp entrained in dam outflow or invertebrate drift). As such, these eddies are less important as food-producing areas than as lower velocity feeding, holding and over-wintering habitats. This is further supported by the low contribution of eddy habitats to the total available habitat and the high abundance of fish that use habitats outside of the eddies.

Nutrients

Effluent from the Teck Cominco fertilizer operation high in phosphate and ammonium was discharged into the Columbia River until 1994. Effluent from the fertilizer operation low in phosphorous and ammonia continues to be discharged as part of the "Combined IV" outfall of Teck Cominco. Fertilization of Arrow Lake (which started in 1999) and Kootenay Lake (1991 or 1992) may contribute additional nutrients to the Columbia River; however, it is expected that most of the dissolved nutrients added in these upstream reservoirs would be taken up by biota in those reservoirs. Increased zooplankton populations are transported downstream and enter the Columbia River food-web causing a potential indirect enrichment effect. Other anthropogenic sources of nutrients include treated sewage effluent and stormwater discharges, and non-point sources from agricultural land, fertilized urban parkland and golf courses.

Historic nutrient additions created luxuriant growth of periphyton and several macrophyte beds along the shoreline of the Columbia River. Since the cessation of phosphate release from the fertilizer plant, macrophyte beds have become much more infrequent and periphyton biomass is much reduced. Other causes for the reduction in periphyton and macrophyte growth may include flow regulation that periodically leaves periphyton and macrophytes above the water line or deeply immersed.

Non-Smelter Related Effects on Habitat

The operation of the three dams (Hugh Keenleyside, Brilliant and Waneta) within the AOI and the operation of two other main-stem dams (Mica and Revelstoke) upstream of the AOI have directly affected fish habitat. Dams block access to spawning or foraging sites, eliminate spring flooding of traditional spawning or rearing habitats, trap nutrients on which downstream forage fish depend and reduce downstream turbidity, making fish (such as juvenile sturgeon) more visible to predators. Other dam-related changes include altering seasonal temperature patterns, and creating increased concentrations of dissolved gases (Total Gas Pressure [TGP]) in the water column. The dams have fragmented the Columbia River into long impoundments connected by short flowing sections. All of these alterations have had significant negative impacts on all resident riverine fish populations, including white sturgeon (Hildebrand et al. 1999).

The effects of some of the dam-related stressors are being monitored and addressed. For example, the yearly fish indexing program conducted for B.C. Hydro monitors year-to-year variation in fish distribution, abundance, and growth (Golder 2002a, 2003b, 2004a, 2005a 2006b). The effects of flow regulation on mountain whitefish reproductive success have been studied (R.L. & L. 1997a, b, 1999, 2000). TGP levels in the river have decreased since the early 1990s as a result of operational changes and upgrades at the dams and construction of the Arrow Lakes Generating Station at Hugh Keenleyside Dam (CRIEMP 2005). The B.C. TGP water quality objective of 110% is met most of the year, and exceeded only on occasions when spill volumes are greatest

(CRIEMP 2005). Studies conducted by B.C. Hydro and the Columbia Power Corporation have shown considerable reductions in TGP and associated risks to fish (CRIEMP 2005). Abatement of TGP must comply with the conditions of the 1964 Columbia River Treaty between the United States and Canada (Goldschmid 2001). Dam operators participate in fish habitat programs such as the Columbia Basin Fish and Wildlife Compensation Program. Operators have also participated in the Water Use Plan for the Columbia River. The Water Use Plan includes seasonal flow strategies for mountain whitefish and rainbow trout (WUP Consultative Committee 2005). The WUP also includes a recommendation to pursue a high flow option on an opportunistic basis, or turbidity augmentation, for improving white sturgeon recruitment via a hypothesized link between increased velocity and turbidity and reduced predation on larval and juvenile sturgeon. This recommendation is presented without consensus from the WUP participants.

EEM studies conducted for the Zellstoff Celgar pulp mill have shown a decrease in the area and levels of sediment contaminants between 1994 and 1999 (CRIEMP 2005). Dioxin and furan levels in sediment downstream of the pulp mill have met provincial sediment quality objectives since 1998, although sediments in the immediate vicinity of the mill (within 120 m) remain higher than the objective. The most recent toxicity test data (2002) indicate no effluent toxicity to rainbow trout or the water flea *Ceriodaphnia*, but some effects on the algae *Selenastrum* (IC25 of 19-21% effluent) (Environment Canada National EEM Database). Historic discharges from the mill resulted in a fibre mat containing wood fibre, fly-ash and chemicals. Toxicity testing of sediments and the fibre mat materials in the near-field immediately downstream of the pulp mill shows that survival and growth of laboratory test organisms has improved compared to previous tests (CRIEMP 2005). Periphyton studies have shown that periphyton communities are similar near and far from the pulp mill discharge and that benthic invertebrate communities are diverse, although samples downstream of the mill had lower density relative to those collected further downstream near Genelle, indicating possible impacts on benthic invertebrate communities from mill effluent (CRIEMP 2005).

There are several sources of localized habitat disturbance in the AOI. Construction of transmission corridors (such as natural gas pipeline corridors) can create localized habitat effects via sedimentation. Highway and railway bridges, water intake and discharge structures, armouring of shoreline, culverts directing tributary flow, and residential or commercial buildings along the river banks with associated erosion and slumping can cause alterations in local flow velocities, changes in substrate characteristics including sedimentation and blockage of fish passage.

Summary of Direct Effects on Fish Habitat

- The remnant pockets of slag deposition in the AOI directly affect fish habitat quality, and these changes in habitat occur in areas that are used by a variety of fish species. The relative amount of habitat affected by slag deposition is small (<0.1% of the total habitat in the AOI).
- There is no longer any evidence of wide-spread nutrient enrichment effects on fish habitat (via stimulation of periphyton and macrophyte growth) in the AOI; however, entrainment of zooplankton (primarily mysids) in dam outflows introduces an important additional food source downstream.
- The operation of dams in the AOI is an important source of direct effects on fish habitat. Dam operators have successfully reduced some effects (e.g., decreased TGP). However, other flow-related issues remain problematic.

- Historic discharges from the Zellstoff Celgar pulp mill created a localized fibre mat area and current discharges may still be affecting benthic invertebrate density (and hence fish food supply) in the near-field.
- The relatively high number of human activities in the AOI can create many localized habitat disturbances; however, the relative significance of these disturbances cannot be assessed with the current data.
- Yearly monitoring of fish populations (such as the fish indexing program) is an important tool for evaluating the status of fish populations as they respond to overall fish habitat effects in the AOI.

4.6.2 Steps 3 and 4: Evaluation of Magnitude and Uncertainty in Field and Laboratory Data for Mountain Whitefish and Prickly Sculpin

Lines of evidence for the assessment endpoints related to fish are presented first for the two non-listed receptor species, mountain whitefish and prickly sculpin, and then for the listed receptor species, white sturgeon.

Sites selected for the assessment of the health of mountain whitefish and prickly sculpin were those that contained similar habitats and, based on previous studies conducted by Golder, were expected to contain adequate numbers of the two receptor species (Golder 2007d). Fish were sampled in four study areas on the lower Columbia River: two exposure areas (downstream of the smelter effluent outfalls in the near-field and in the far-field) and two reference areas (upstream of the smelter) (Figure 2.1). The reference areas were:

- *Reference Area A:* between Kinnaird Bridge and the mouth of Champion Creek; and
- *Reference Area B:* from just upstream of Sullivan Creek to just upstream of Murphy Creek, including the Birchbank Eddy.

The lines of evidence examined for Steps 3 and 4 of the SALE analysis were:

- direct measurement of mean length (total length for sculpin, fork length for whitefish), body weight, carcass weight and age estimates among sites, size-at-age (i.e., length-at-age and weight-at-age), condition (body weight vs. length), relative liver size, relative gonad size, and fecundity (whitefish only);
- derivation of a pathology index for captured mountain whitefish and prickly sculpin; and
- distribution and population characteristics measured during the Columbia River Fish Indexing Program (2001 to 2005) and compared with earlier studies conducted in the early 1990s.

Review of Results of Step 1 of SALE: Comparison of PCOC Concentrations in Fish Tissue with Effects Concentrations

In Step 1 of SALE, concentrations of PCOC in fish tissue were compared to literature-based effects concentrations. Zinc was the only PCOC that exceeded effects benchmarks in mountain whitefish and prickly sculpin specimens collected in 2004. Earlier data examined for the Problem Formulation showed that copper also exceeded effects benchmarks in all of the fish species examined.

Comparison of Concentrations of PCOC in Mountain Whitefish and Prickly Sculpin Upstream and Downstream of the Teck Cominco Smelter

Concentrations of PCOC in mountain whitefish and prickly sculpin from upstream and downstream of the smelter were compared in order to obtain an understanding of the relative exposure of these fish.

Three metals exhibited significantly higher concentrations in mountain whitefish sampled from the sites downstream of the smelter (Golder 2007d). These metals were cadmium (in male fish), cobalt (in female fish) and lead (in both sexes). Mean concentrations of cadmium in males were relatively similar between the near- and far-field areas; however, the maximum concentration was higher in the far-field area. Mean cobalt levels in female whitefish were slightly higher with distance downstream of the smelter. Whitefish from the near-field area exhibited higher mean concentrations of lead than fish at other locations. Both sexes at this site also exhibited a much higher level of variation, with concentrations (wet weight) ranging from 0.001 to 0.109 µg/g in females and 0.001 to 0.145 µg/g in males.

Prickly sculpin sampled from the near-field area, downstream of the smelter, exhibited significantly higher mean concentrations compared to the upstream sites for most metals analyzed in 2004 (Golder 2007d). These metals were arsenic, cadmium, chromium, cobalt, copper (males only), lead, selenium (females only), sulphur (males only), thallium and zinc, and in almost all cases male fish exhibited the higher concentrations in the near-field area. The exception was for lead and thallium, where considerably higher concentrations were found in both sexes in the near-field area.

Most of the metals with higher concentrations in the near-field area demonstrated a partial or full decline to reference concentrations in the far-field area. The only exception was zinc, where the mean concentrations in females were relatively similar at both downstream sampling sites.

Mean mercury concentrations were relatively similar upstream and downstream of the smelter, although higher concentrations were found in female sculpin from Reference Area A. Similarly, mean silver concentrations were highest in prickly sculpin sampled from Reference Area A.

In summary, there was some limited evidence for increased exposure of mountain whitefish downstream of the smelter; however, the high variation in PCOC concentrations is indicative of the relative mobility of this species compared to prickly sculpin. There was more consistent evidence that prickly sculpin downstream of the smelter had higher exposures to PCOC than upstream prickly sculpin, particularly in the near-field area. These results are consistent with the small home-range and limited mobility of this species.

Line of Evidence 1: Fish Health Parameters in Mountain Whitefish and Prickly Sculpin

Measures of growth and energy storage in non-reproductive tissues showed statistically significant responses in female mountain whitefish and female prickly sculpin ($p < 0.05$) (Golder 2007d). Female sculpin from the near-field and female whitefish from the near-field and far-field areas had significantly higher condition factors than fish from upstream reference areas (Tables 4.32 and 4.33 and Figure 4.21). There were no significant differences among sites in males of either species. Female sculpin from the near-field area were significantly longer and heavier relative to fish from both reference sites and had greater length-at-age and weight-at-age ($p < 0.05$) (Table 4.32 and Figure 4.22). There were no significant differences in length, weight, length-at-age or weight-at-age in male sculpin or male and female mountain whitefish in either near-field or far-field.

There were no significant differences in mean age among sites in prickly sculpin (Tables 4.32 and 4.33)(Golder 2007d). Age estimates for mountain whitefish were not available due to indistinct otolith banding resulting from mild winters; therefore, site differences in size-at-age could not be assessed.

Table 4.32 Summary of Responses in Measured Fish Health Parameters in Prickly Sculpin

Parameter	Near-field Area				Far-field Area			
	Male Statistical Result	Male % Difference	Female Statistical Result	Female % Difference	Male Statistical Result	Male % Difference	Female Statistical Result	Female % Difference
Length	0	0	+	18	0	1.8	0	0.6
Weight	0	-1.2	+	78	0	7.3	0	7.1
Age	0	3.0	0	31	0	-9.1	0	-13
Condition factor	0	0	+	7.1	0	3.4	0	0.9
Relative liver size	0	-7.8	-	-34	+	20	0	11
Relative gonad size	-	-22	-	-16	-	-22	0	3.1
Length-at-age	0	4.8	+	2.5	0	4.7	0	0.6
Weight-at-age	0	36	+	17	0	38	0	4.9

Notes:
0 = no change.
+ = significant increase.
- = significant decrease.

Table 4.33 Summary of Responses in Measured Fish Health Parameters in Mountain Whitefish

Parameter	Near-field Area				Far-field Area			
	Male Statistical Result	Male % Difference	Female Statistical Result	Female % Difference	Male Statistical Result	Male % Difference	Female Statistical Result	Female % Difference
Length	0	1.3	0	-5.8	0	-4.5	0	-2.9
Weight	0	0.4	0	-9.4	0	-8.2	0	-0.3
Condition factor	0	-3.6	+	4.2	0	4.4	+	6.3
Relative liver size	-	-12	0	2.0	0	-4.9	0	3.0
Relative gonad size	0	-18	0	-8.3	0	1.6	0	2.5
Fecundity	n/a	n/a	0	-1.5	n/a	n/a	0	8.5

Notes:
0 = no change.
+ = significant increase.
- = significant decrease.

Figure 4.21 Condition Factor vs. Fork Length for Female Mountain Whitefish Collected from the Columbia River, Fall 2004

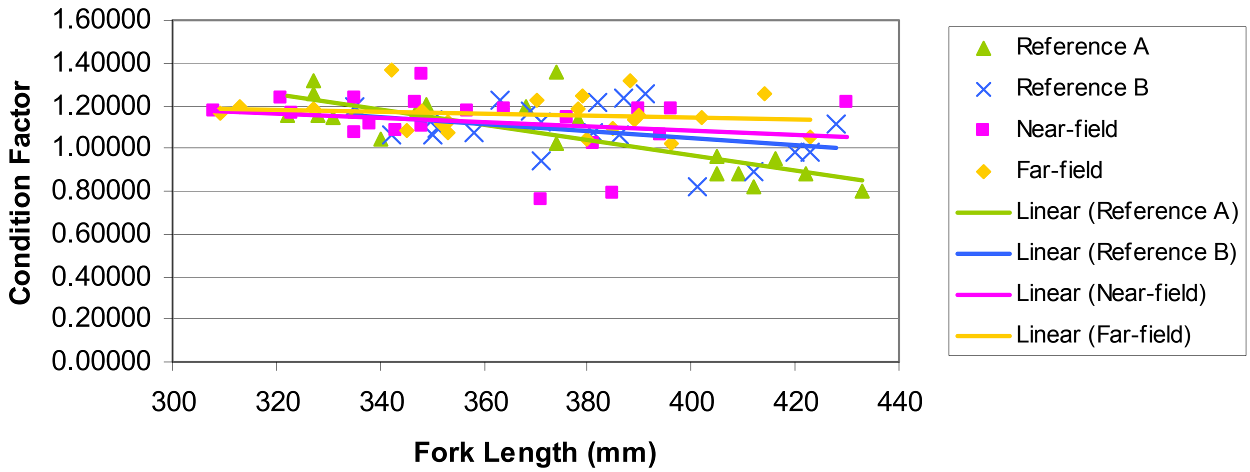
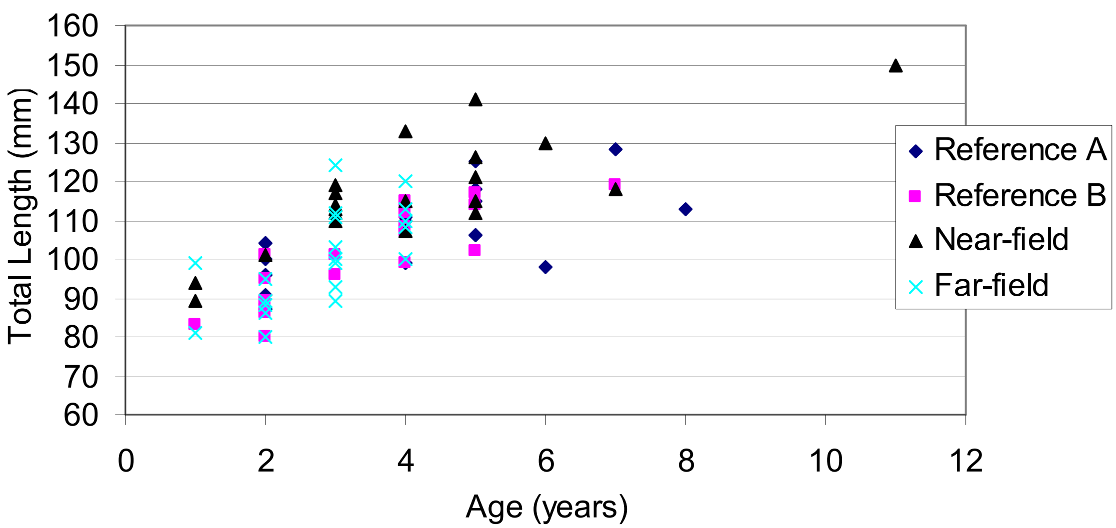


Figure 4.22 Total Length at Age for Female Prickly Sculpin Collected from the Columbia River, Fall 2004



Measures of reproductive capability showed a statistically significant response in prickly sculpin, but not in mountain whitefish. Relative gonad weights (Gonad Somatic Index [GSI] values) in female sculpin were significantly lower ($p < 0.05$) in the near-field area, and in both the near-field and far-field in male sculpin (Table 4.32, Figure 4.23). The GSI of male and female mountain whitefish, as well as female fecundity, did not differ among sites (Table 4.33, Figure 4.24). Due to limited gonadal development, sculpin fecundity estimates were not available. Female sculpin are unique in that they invest very little energy into reproductive tissue during the early fall (GSIs are ~1-2%); instead, most energy is invested during the winter and early spring (GSIs are ~30-40%) when ambient water temperatures are low, feeding activity would be expected to be diminished, and contaminant concentrations would be relatively higher (Gray 2003; Galloway et al. 2003; Brasfield 2007).

The pattern of changes in relative liver weights (Liver Somatic Index [LSI] values) was similar in both male and female sculpin and whitefish (Tables 4.32 and 4.33) (Golder 2007d). Overall, LSI values decreased from the reference areas to the lowest values observed at the near-field area, and by the far-field area, values were approaching or were greater than those observed at the reference areas. Only female sculpin and male whitefish from the near-field area had LSI values that were statistically smaller ($p < 0.05$) than those of upstream reference fish. Far-field male sculpin had statistically larger LSI values ($p < 0.05$) than upstream fish.

Figure 4.23 Mean Gonad Somatic Index for Prickly Sculpin Collected from the Columbia River, Fall 2004

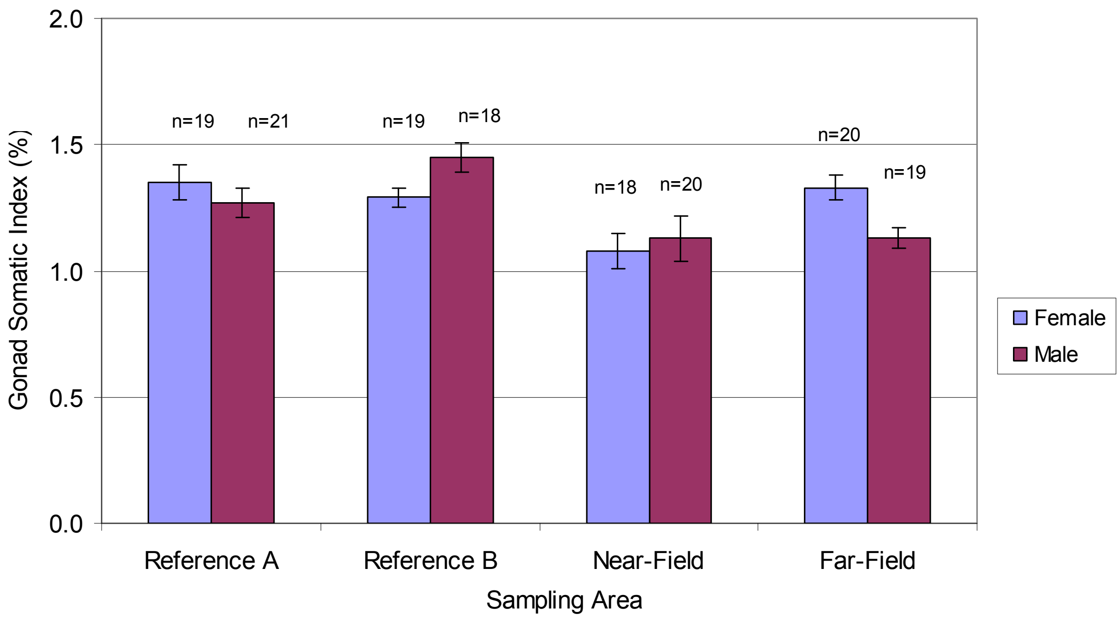
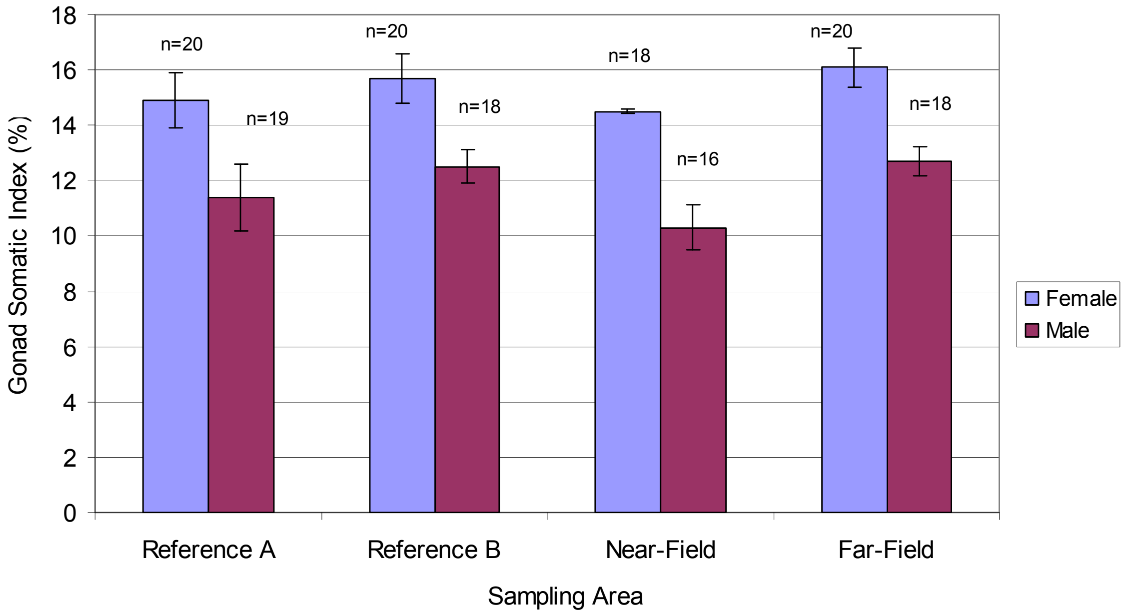


Figure 4.24 Mean Gonad Somatic Index of Mountain Whitefish Collected from the Columbia River, Fall 2004



Line of Evidence 2: Pathology Index

A pathology index (PI) was calculated based on the Health Assessment Index (HAI) developed by Adams et al. (1993). Fish exposed to environmental contaminants or stresses frequently show visible external and/or internal signs of disease as abnormal conditions in tissues or organs. Because the incidence of pathological conditions may be related to degradation of the aquatic environment (Adams et al. 1993), a pathological examination was conducted for both species collected during the 2004 fall fish survey on the Columbia River. The fish were examined for parasites and non-specific abnormalities such as growths, lesions and deformities.

The 14 parameters in the pathology examination were assigned a numerical value based on the condition or appearance of the tissue/organ (Golder 2007d). Normal conditions have a value of zero and abnormal conditions have a higher value, to a maximum of 30. For nine parameters, the presence of an abnormal condition was assigned a value of 30. For the other five parameters, the severity of the abnormality was rated as low (value of 10), moderate (value of 20) or high (value of 30) (Golder 2007d). The PI for each fish was the sum of the values for each of the 14 parameters. Therefore, the higher the PI for a fish, the higher the number or severity of abnormalities. A mean PI was then calculated for the prickly sculpin and mountain whitefish populations (sexes separate) from each of the exposure and reference sites.

There was no evidence of increased pathology in prickly sculpin or mountain whitefish captured downstream of the Teck Cominco smelter. Mean PI values for female prickly sculpin from the exposure areas were generally similar to the mean PI values for fish from the reference areas (Figure 4.25) (Golder 2007d). The mean PI for males at each exposure site was intermediate to the two reference area PI values. Prickly sculpin exhibited few anomalies, and those that did show pathological symptoms did so with a low to moderate degree of abnormality. As a result, mean PI values were considered low for both exposed and unexposed prickly sculpin. Mean PI values in mountain fish from the exposure areas were lower than in the reference areas (Figure 4.26) (Golder

2007d). The male fish from each site exhibit higher mean PI, ranging from 21.7-47.5, compared to the females (mean PI range of 7-29). The PIs were highest in fish sampled from Reference Area B while the lowest PIs were seen in fish sampled from the near-field area.

Figure 4.25 Mean Pathology Index for Prickly Sculpin Sampled from the Columbia River in Fall 2004

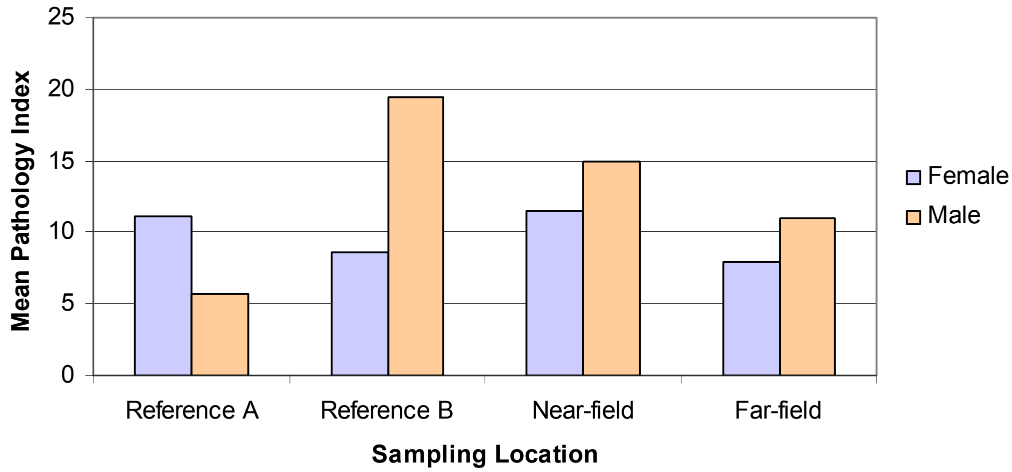
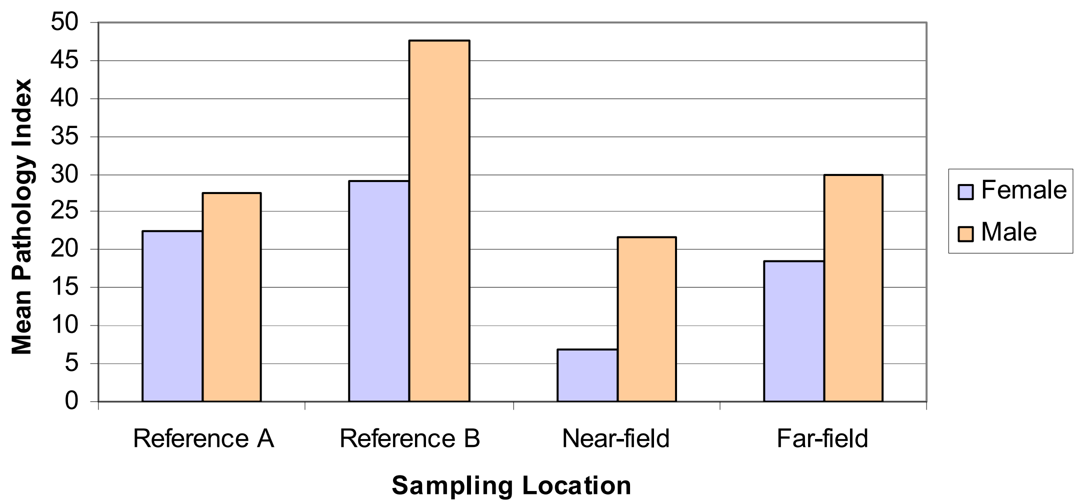


Figure 4.26 Mean Pathology Index for Mountain Whitefish Sampled from the Columbia River in Fall 2004



Line of Evidence 3: Fish Indexing Program Information on Population Characteristics

Data on mountain whitefish population characteristics have been gathered over several years (2001 to 2005), together with data on the two other most abundant sport fish, rainbow trout and walleye (Golder 2006b). The key findings for mountain whitefish are presented below, with information on rainbow trout and walleye provided for context. Data for sculpin species are also discussed.

Interpretation of results relative to the location of the smelter was based upon the three main sampling sections of the Columbia River used in the fish indexing program, plus the Kootenay River between the Brilliant Dam and the confluence with the Columbia River. The three sampling sections were the Upper, Middle and Lower sections. The Upper section extends from the Hugh Keenleyside Dam to river km 23 near the mouth of Champion Creek; this section is entirely upstream of the Teck Cominco smelter. The Middle section extends from Champion Creek to river km 40, which is just downstream of the smelter and adjacent to the community of Glenmerry. The Lower section extends from Glenmerry to the U.S. border.

Percent composition among sport fish species showed no definite trends over time. Mountain whitefish were always the most abundant sport fish recorded in 2001 to 2005 and were also the most abundant sport fish in the early 1990s (Golder 2006b). Between 2001 and 2005, the percent composition of mountain whitefish within the sport fish catch had no definite trends, ranging from 52% in 2001 to 35% in 2003. These changes in percent composition likely reflect seasonal fluctuations in relative abundance levels rather than changes in population abundance (Golder 2006b). Rainbow trout percent composition ranged from 30-42%, also with no definite trends. In the early 1990s (1990 to 1994), mountain whitefish had a higher percent composition (62%), while rainbow trout had a lower percent composition (19%). Walleye percent composition (11%) fell within the range observed from 2001 to 2005 (5-22%); however, there was a general increasing trend in the relative number of walleye over time.

Percent composition of sport fish varied among sampling sections (Golder 2002a, 2003b, 2004a, 2005a, 2006b). Mountain whitefish consistently made up a larger proportion of the sport fish catch in the Kootenay and Upper Sections. Rainbow trout made up a larger proportion of the catch in the Middle and Lower sections. Walleye usually made up a larger proportion of the catch in the Middle and Lower sections; however, distribution of this species among sections was highly variable year-to-year.

Percent composition among non-sport fish species also showed no definite trends over time. Sculpin species were the most abundant non-sport fish species recorded during the 2003 to 2005 fish indexing studies, and were second or third-most abundant in the 2001 to 2002 sampling years (Golder 2006b). In the early 1990s (1990 to 1994), redside shiner and sucker species were the most abundant non-sport fish, and sculpin were the third-most abundant.

Sculpin species were at least twice as abundant in the Lower section of the AOI relative to the Kootenay, Upper or Middle sections (Golder 2006b). This pattern was consistent over time.

Catch-rates for mountain whitefish have decreased every year since 2001 (as have rainbow trout catch-rates but not walleye). A possible reason for this decrease is a change in sampling method. Changes were made to the electrical field used during electroshocking to reduce the frequency of electroshocking-induced injuries. This reduced the number of mountain whitefish and rainbow trout that became immobilized, thereby reducing their catch-rates (Golder 2006b). Walleye, which react differently to the electrical current, still became immobilized, allowing the samplers to more easily capture and/or identify them. The changes to the electrical field also resulted in smaller fish being less affected by the electrical current, decreasing their catch-rates. This reduced catch-rates for rainbow trout and mountain whitefish but did not affect walleye catch-rates because smaller walleye are not abundant in the system. Another possible reason for the decrease in catch-rates could be related to differences in flow. Flow not only affects sampling efficiency but is a primary determinant of fish distribution and abundance in nearshore habitats (Golder 2006b).

Data for catch-rates for the early 1990s were not available; therefore, comparisons with the 2001 to 2005 data could not be made.

Catch-rates upstream and downstream of the smelter varied with fish species. Catch-rates for mountain whitefish were higher in the upstream sections (Kootenay, Upper, Middle) than the section downstream of the smelter (Lower) in all sampling years (2001 to 2005) (Golder 2002a, 2003b, 2004a, 2005a, 2006b). Catch-rates for other fish species were greatest in the lower section of the AOI (which includes the Fort Sheppard and Waneta areas plus the Beaver Creek area). Walleye, burbot, lake whitefish, and sculpin species were always more abundant in the lower section according to data from 2001 to 2005.

Results in 2005 suggest a possible transition to a population structure similar to that observed in the early 1990s as younger age-classes were less evident during 2005 than from 2001 to 2004 (Golder 2006b). Sampling during 2004 and 2005 indicated a predominance of larger mountain whitefish within the overall population, while studies conducted from 2001 to 2003 showed a predominance of smaller and younger individuals (Table 4.34) (Golder 2006b). Rainbow trout also exhibited a shift in length-frequency distribution; the number of larger fish increased each year from 2001 to 2005. This observed change in length-frequency also could be the result of changes made to the sampling methods, as discussed above.

Table 4.34 Percent Composition of Smaller (<250 mm Fork Length) Versus Larger (>250 mm Fork Length) Mountain Whitefish by Sampling Section Within the AOI (Golder 2006b)

Year	Size-Cohort	Percent of Total Mountain Whitefish Catch (includes observed fish)				
		Kootenay Section	Upper Section	Middle Section	Lower Section	All Sections
2005	≥250 mm FL	18	35.7	13.9	8.6	76.2
	<250 mm FL	1.2	7.4	6.9	8.3	23.8
	Total	19.3	43.1	20.8	16.9	100
2004	≥250 mm FL	19.3	27.5	9.5	9.4	65.7
	<250 mm FL	3.9	13.5	8	9	34.3
	Total	23.2	41	17.5	18.4	100
2003	≥250 mm FL	7.4	18.8	8.5	8.8	43.5
	<250 mm FL	2	34.9	9.2	10.6	56.5
	Total	9.3	53.6	17.7	19.4	100
2002	≥250 mm FL	6.8	16.5	4.8	6.9	35
	<250 mm FL	3.5	37.1	11.8	12.6	65
	Total	10.3	53.6	16.6	19.5	100
2001	≥250 mm FL	2.6	13.4	8.9	10.2	35.1
	<250 mm FL	2	42.9	10.9	9.2	64.9
	Total	4.5	56.3	19.8	19.3	100

Note: FL = fork length.

The factors influencing the shift in size distribution appeared to be operating in the upper sampling areas, with no obvious spatial association with the smelter. Differences in size distribution of mountain whitefish, as well as the shift toward larger fish, occurred in the Kootenay and Upper sampling sections, but not in the Middle and Lower sections, where there was a relatively equal split between smaller and larger fish in all sampling years (Table 4.34). The smelter is located just upstream of the boundary between the Middle and Lower sections. Mountain whitefish were more abundant in the Kootenay and Upper sampling sections in all sampling years.

Habitat differences may be the dominant factor influencing percent species composition, catch-rates and size-distribution upstream-to-downstream in the AOI. The habitat in the upstream sections of the AOI is different than lower sections. The upstream sections have fewer backwater areas, a more uniform shoreline configuration with few/minor bank irregularities, and less overhead cover provided by depth and woody debris than in downstream areas (see description in Section 4.6.1). The depositional areas upstream have substrates consisting predominantly of sand/silt, low current velocities offshore, and generally absent instream cover whereas downstream depositional areas have coarse substrates (gravels/cobbles), low-moderate current velocities offshore with occasional riffle areas and instream cover provided by the substrate roughness.

Observations made by sampling crew members during the 2001 to 2005 studies indicated that mountain whitefish appeared healthy and typically exhibited a robust body form, while the “thin body” form that was commonly recorded in catches from the early 1990s was rarely observed.

Population estimates were variable with no consistent trend among species (Golder 2006b). The 2005 population estimates for mountain whitefish were higher than all previous years (2001 to 2004), but all estimates exhibited wide confidence intervals due to the low number of recaptured fish (Table 4.35, Golder 2006b). Population estimates for rainbow trout were lower in 2005 than in 2001 to 2004 but were higher than estimates from the early 1990s. Population estimates for walleye suggested an increase in walleye abundance each year from 2002 to 2004 and a decrease from 2004 to 2005.

Population estimates were for the overall population within the entire AOI; therefore, comparisons between upstream and downstream of the smelter were not possible.

Table 4.35 Comparison of Population Estimates Derived for Mountain Whitefish, Rainbow Trout and Walleye in the AOI, 2002 to 2005 (Golder 2006b)

Year of Study	Modified Schnabel			Sequential Bayes Algorithm			Program MARK			No. Tag Recaptures
	Mean	Lower (2.5%)	Upper (97.5%)	Mode	Lower (2.5%)	Upper (97.5%)	Mode	Lower (2.5%)	Upper (97.5%)	
Mountain Whitefish										
2002	52,515	40,949	67,281	53,553	42,947	71,022	5,639	4,864	6,560	18
2003	37,347	25,664	54,363	38,777	28,304	62,003	4,328	3,733	5,034	8
2004	33,305	22,886	48,480	34,497	25,228	55,192	9,711	8,453	11,180	17
2005	35,019	24,225	50,633	36,315	26,640	57,410	11,023	9,720	12,528	18
Rainbow trout										
2002	14,204	12,375	16,302	14,374	12,189	17,337	11,470	9,969	13,236	144
2003	8,636	7,387	10,097	8,691	7,589	10,203	10,130	8,846	11,629	123
2004[(a)]	8,005	6,403	10,010	8,147	6,751	10,359	10,544	9,187	12,127	79
2005	6,591	5,435	7,993	6,696	5,674	8,205	9,565	8,422	10,888	87
Walleye										
2002	10,590	5,776	17,650	11,543	7,412	26,095	3,797	3,253	4,450	11
2003	18,352	13,194	25,529	18,897	14,304	28,090	9,381	8,186	10,778	33
2004	15,051	12,043	18,811	15,308	12,615	19,568	15,380	13,451	17,621	76
2005	10,707	8,144	14,079	10,979	8,698	15,003	9,160	8,061	10,433	50

Note:

(a) Differences in recapture rates between the two size-classes of rainbow trout (i.e., fish ≥ 250 mm fork length and fish <250 mm fork length) prevented the generation of an "all size-classes combined" population estimate using the modified Schnabel and sequential Bayes Algorithm estimation techniques. Data represent the sum total of the two size-class population estimates.

Survival rate was lower in mountain whitefish than in rainbow trout or walleye from 2001 to 2005. Mountain whitefish from 2001 to 2005 had a survival rate of 20% while catch-curve analysis showed the population had an inter-year survival rate of 43% for the same time period. Rainbow trout from 2001 to 2005 had a survival rate of 44%, while catch-curve analysis showed the population had an inter-year survival rate of 54% for the same time period. Walleye had an inter-year survival rate of 32% between 2001 to 2005. A catch-curve survival rate was not calculated for walleye. Survival rate estimates were not available for the early 1990s; therefore, comparisons with the 2001 to 2005 estimates could not be made.

Magnitude of Response in Fish Health Parameters for Mountain Whitefish and Prickly Sculpin

The criteria for judging the magnitude of effects on fish health (Table 4.36) were based on the EEM definitions of critical effect size for GSI, LSI and condition factor (Lowell et al*.* 2005). Critical effect sizes for age and size-at-age have not been developed for the EEM program due to uncertainties in techniques used to age some species of fish (Lowell et al*.* 2005). Therefore, for age and growth-related parameters in the present study, the generic benchmark provided by Suter et al. (1995) of 20% for aquatic measures was used to discriminate between negligible-to-low magnitude (referred to as *de minimis* by Suter et al*.* (1995)) and moderate magnitude. The criterion for discriminating between moderate and high magnitude for all fish health parameters except condition parameters was set arbitrarily at 40%. The criterion for high magnitude response in condition was set arbitrarily at 30%, in accordance with the lower critical effect size for this parameter of 10%.

A numeric or statistical magnitude criterion for the pathology index (PI) is not available from the EEM program. A simple definition of low magnitude was used; that is if the PI for exposed fish is less than or equal to the PI for reference fish, then the magnitude of response is low. The definition of moderate magnitude defaulted to the Suter et al*.* (1995) definition of *de minimis* risk (20% change from reference). The definition of high magnitude followed the same arbitrary reasoning as used for the other fish health parameters; if the PI for exposed fish was >40% higher than reference fish, then the response would be rated as high.

Table 4.36 Magnitude Criteria for the Fish Health Lines of Evidence

Line of Evidence	Method of Assessment of the Line of Evidence	Evidence of Negligible to Low Magnitude ○	Evidence of Moderate Magnitude ◉	Evidence of High Magnitude ●
Fish Health Parameter	Statistical comparison of fish health parameters between reference and exposed fish.	Statistical difference ($p < 0.05$), but magnitude of any statistical difference is less than: 25% for GSI and LSI, 10% for condition; 20% for age, length and weight.	Statistical difference ($p < 0.05$), and magnitude of any statistical difference is greater than 25% but less than 40% for GSI and LSI; greater than 10% but less than 30% for condition; greater than 20% but less than 40% for age, length and weight.	Statistical difference ($p < 0.05$) and magnitude greater than 40% for GSI, LSI, age, length and weight and greater than 30% for condition.
Pathology Index (PI)	Comparison of mean PI between reference and exposed fish.	PI of exposed fish less than or equal to PI for reference fish.	PI for exposed fish at least 20% greater but less than 40% greater than PI for reference fish.	PI for exposed fish at least 40% greater than PI for reference fish.
Fish Population Characteristics	Qualitative comparison of upstream versus downstream of the smelter, plus comparison of 2001 to 2005 sampling period (post-Kivcet smelter) with 1990 to 1994 period (pre-Kivcet smelter).	No difference or no consistent trend in percent composition, catch-rates, size-distribution, or population estimates between upstream and downstream sampling sections or over time.	Some, but inconsistent evidence for: shifts in percent composition and size distribution over time and/or upstream versus downstream of the smelter; declines in catch-rate upstream versus downstream of the smelter and/or over time; declines in population estimates over time.	Definite and consistent shift in percent composition and/or size distribution with time and/or upstream versus downstream of the smelter; definite and consistent decline in catch-rate upstream versus downstream of the smelter and over time; definite decline in population estimates over time.

The population characteristics were judged qualitatively by comparing spatial trends upstream and downstream of the smelter and over time. Spatial trends were evaluated by comparing the Kootenay, Upper and Middle sampling sections (upstream of the smelter) with the Lower section (downstream of the smelter). Temporal trends were evaluated by comparing the 2001 to 2005 data with data from the early 1990s (prior to installation of the Kivcet smelter with accompanying decreases in metal discharge plus the cessation of discharge of slag to the river).

The magnitude of all responses in prickly sculpin and mountain whitefish was low except for LSI and condition factor in near-field female sculpin (Table 4.37). Although there were several statistically significant differences in female sculpin health measures, most of these differences did not exceed the critical effect size that demarcated moderate from low magnitude (Tables 4.32 and 4.33). The critical effect size of 25% for LSI was exceeded in near-field female sculpin (-36%). The percent decrease in LSI fell into the moderate magnitude category. The decrease in relative gonad size (-22%) was just below the critical effect size of 25% in near-field and far-field male sculpin. The condition factor of near-field female sculpin was 78% higher than reference. This percent difference fell into the high magnitude category.

The magnitude of response was low for all fish health parameters in mountain whitefish (Table 4.38).

Fish population characteristics showed few relationships upstream versus downstream of the smelter or over time (Table 4.39). There was a moderate magnitude difference in catch-rate of mountain whitefish, with higher catch-rates upstream of the smelter. There was a moderate-magnitude shift to larger fish in the more recent sampling years for mountain whitefish and rainbow trout; however, this shift did not occur in all of the years from 2001 to 2005.

Table 4.37 Magnitude Rating for Fish Health Lines of Evidence for Prickly Sculpin

Site	Length		Weight		Age		Condition Factor		LSI		GSI		Pathology Index	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Near-field	○	○	○	●	○	○	○	○	○	◉	○	○	○	○
Far-field	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Note: LSI = Liver Somatic Index; GSI = Gonad Somatic Index.

Table 4.38 Magnitude Ranking for Fish Health Lines of Evidence for Mountain Whitefish

Site	Length		Weight		Age		Condition Factor		LSI		GSI		Pathology Index	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Near-field	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Far-field	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Note: LSI = Liver Somatic Index; GSI = Gonad Somatic Index.

Table 4.39 Magnitude Ranking for Fish Population Characteristics

Comparison	% Composition			Catch-Rate		Size Distribution		Population Estimate	
	Mountain Whitefish	Other Sport Fish	Sculpin species	Mountain Whitefish	Other Sport Fish	Mountain Whitefish	Other Sport Fish	Mountain Whitefish	Other Sport Fish
Upstream vs. Downstream of Smelter	○	○	○	◉	○	○	○	○	○
1990 to 1994 vs. 2001 to 2005	○	○	○	Data not Available	Data not Available	◉	◉	○	○

Note:

Magnitude:

- ● strong response.
- ◉ moderate response.
- ○ weak response.

Uncertainty in Fish Health Lines of Evidence for Prickly Sculpin and Mountain Whitefish

The uncertainty associated with variability of fish health measurements is low-to-moderate. The sampling design followed the guidance provided by Environment Canada (2002) for sample size per site to produce adequate statistical power (Table 4.19). Thus, there is reasonable confidence that the data were sufficient to detect differences from reference measurements. However, the control/impact design does not address the presence of gradients in potentially confounding natural or anthropogenic variables, apart from the use of one near-field and one far-field sampling area. It is unlikely that these two downstream sites, plus the two upstream reference sites, fully represented gradients in habitat features (e.g., water depth and velocity, substrate characteristics, bankform characteristics, instream cover, and abundance of periphyton and benthic invertebrate food sources) that may influence fish health. Also, these four stations did not represent the full extent of gradients in non-smelter stressors, such as temperature and dissolved gas conditions due to dam operation, or nutrient enrichment due to pulp mill discharge. The lack of full coverage of gradients is of most concern regarding interpretation of mountain whitefish data because of the mobility of this species. Mountain whitefish can be expected to be exposed to the full range of variables in the AOI during their life cycle because of their tendency to undergo migrations to different areas for spring feeding, summer feeding, prespawning, spawning and overwintering (Nelson and Paetz 1992). The lack of a full gradient design is of less concern for prickly sculpin, since sculpin remain within a localized area for their entire life cycle, as shown by stable isotope studies (Gray et al. 2004) and life history studies. For example, Hill and Grossman (1987) showed that the home range size of a closely related species, the mottled sculpin (*Cottus bairdi*), was 30 m.

The uncertainty associated with variability of fish population characteristics is also low-to-moderate. Some sampling methods were different between the two main time periods (1990 to 1994 and 2001 to 2005). However, the fish indexing program from 2001 to 2005 sampled the same sections of river during the same times of year and collected the same information. The only significant change in sampling method during the 2001 to 2005 period was the change in electrical current used for electroshocking. All data were evaluated by the same senior fisheries biologist (L. Hildebrand).

The evidence provides a low-to-moderate level of support for Conceptual Model 1. Two fish health measures indicated direct effects (for prickly sculpin on relative liver size and weight). There were higher catch-rates of mountain whitefish upstream of the smelter and there has been a shift to larger mountain whitefish and rainbow trout in more recent sampling years. Some potential confounding variables were quantified or described with a narrative. The observed responses in prickly sculpin at the near-field site could be due to some of the other variables (e.g., storm-water discharges from the City of Trail); therefore, the validity of the conceptual model is in question. However, the full range of confounding natural and anthropogenic stressors was not included in the analysis. Furthermore, the interaction between direct physical effects on habitat caused by slag and responses to the PCOC was not assessed statistically.

The evidence provides weak support for the indirect effects via food chain interactions predicted by Conceptual Model 2. The observed differences in weight and liver size in near-field sculpin may, in part, reflect an indirect effect from smelter-related emissions because near-field periphyton biomass at the Old Bridge was elevated (providing a larger food supply and thus faster growth). However, benthic invertebrate abundance was not uniformly elevated relative to upstream in the near-field fish sampling area (although the invertebrate data are for depositional habitats whereas sculpin feed primarily in erosional habitats). Another possible indirect mechanism for the larger sculpin in the near-field is reduced intra-specific competition because of metal-related reduced survivorship of young sculpin. The reduced competition would result in compensatory increases in growth and condition in the young fish that survive. Indirect effects of this kind were reported by Ryan and Harvey (1980) for moderately acidified lakes with elevated metals; however, metal concentrations were considerably higher than in the Columbia River. The fact that sculpin at the far-field area had larger liver somatic indices (LSIs) than fish from the reference areas suggests that food (e.g., benthic invertebrates) may be more abundant in the far-field area. Interestingly, the highest abundance of benthic invertebrates was observed at Fort Sheppard Eddy (>150,000 organisms/m^2), which is located immediately downstream of the fish sampling stations (see Golder 2005a, page 27, Figure 2).

Conceptual Model 2 also postulates that there will be multiple stressor effects on fish health (i.e., effects of several stressors acting together such as metals plus flow regulation). There is insufficient scientific understanding to develop hypotheses of how multiple stressors may interact to produce effects on fish health; therefore, it is difficult to evaluate the strength or weakness of evidence for multiple stressor effects in the study area. The use of prickly sculpin assisted with distinguishing responses to some of the other stressors in the AOI because they remain within a relatively small area and thus reflect exposure to local sources. Hence, the fish health indicators measured in sculpin from the upstream reference sampling sites would reflect exposure to upstream stressors such as the Zellstoff Celgar pulp mill discharge, whereas fish health indicators measured in sculpin from the near-field site would reflect exposure to the smelter discharges plus storm-water discharges from the City of Trail and other sources such as Trail Creek (affected by the Teck Cominco fertilizer plant). Sculpin at the far-field site were exposed to lower smelter-related metal concentrations, as demonstrated by the lower body burdens of metals measured in sculpin collected from this site. The spatial pattern of responses of sculpin appears to correspond most with Conceptual Model 1 (direct effects of exposure to near-field metal concentrations) rather than indirect effects or effects of multiple stressors. However, this statement is highly uncertain.

There is little-to-no support for Conceptual Model 2 from the evidence on the health of mountain whitefish. Periphyton biomass was higher at the Old Bridge, but much lower at the New Bridge and Korpak. This lower periphyton biomass, accompanied by low benthic invertebrate abundance in some or all of the near-field may have contributed to the slight (but non-significant) decline in condition factor and the larger decline in relative liver size in male mountain whitefish in the near-field. However, there is also little evidence supporting the idea that there may be metabolic imbalance in mountain whitefish in the near-field because higher condition factors were not accompanied by lower gonad size. The mobility of this species makes interpretation of the response very difficult.

Data on fish population characteristics provide weak support for Conceptual Model 2. The higher catch-rates upstream of the smelter are more likely related to differences in habitat upstream and downstream. The shift to larger fish in later sampling years may be related to a reduction in recruitment of young which, in turn, may be related to changes in food web characteristics downstream of the smelter. However, the change in sampling method is a significant confounder that can account for the apparent shift.

The assessment of future risks to fish health and fish populations is limited to the period for which operation of the existing smelter can reasonably be predicted, i.e., 10-20 years. As discussed for periphyton and benthic invertebrates, climate change will not affect the main stem Columbia River as much as in other areas over the next 10-20 years because of the storage capacity in the Columbia River system due to impoundments. In addition, the terms of the Columbia River Treaty govern how river flow is managed. This assessment assumes no change in the terms of the Treaty. Therefore, changes in river flows and volumes beyond currently observed hydrograph variations are not anticipated for the10-20 year time period identified for this assessment. Furthermore, changes in PCOC concentrations or distribution of slag caused by changes in flow beyond those currently observed are not predicted.

4.6.3 Step 5: Assessment of Causation for Mountain Whitefish and Prickly Sculpin

The magnitude of response in fish health parameters was low for all but weight and LSI in prickly sculpin in the near-field area. Therefore, the causation analysis focused on these two parameters.

The overall pattern of responses in fish health parameters in the present study was not consistent with general fish response patterns postulated by Munkittrick and Dixon (1989), Gibbons and Munkittrick (1994), Jaworka et al. 1997, Adams et al. (1999) and Munkittrick et al. (2000). The closest similarity to the general patterns suggested by these authors was to the "metabolic redistribution" pattern put forward by Gibbons and Munkittrick (1994). This pattern reflects a change in the ability of the fish to process energy, resulting in decreased energy expenditure (e.g., for reproduction) but increased storage (e.g., increased condition factor and liver weight). The near-field female sculpin showed a statistically significant decline in GSI and increase in condition; however, these changes were not greater than the critical effect size. The increased weight of female sculpin was above the critical effect size, but this was not accompanied by a critical increase in liver size. Furthermore, there was no consistency between male and female sculpin results.

The observed responses in fish health were not consistent with the three main response patterns observed at pulp and paper mill sites during Cycle 2 and Cycle 3 EEM programs (Lowell et al. 2005). Response to chemical stress has been associated with induction of detoxification enzymes, increased liver size, increased frequency of histopathological lesions, impairment of some reproductive parameters and a decrease in species richness in the fish community with an alteration of the distribution of feeding guilds (Adams et al. 1999). The three response patterns observed in the EEM program were: (1) nutrient enrichment associated with increased gonad and liver weight and often increased condition and growth rate; (2) nutrient limitation together with chemical toxicity associated with decreased gonad and liver weight, and decreased condition and growth rate; and (3) nutrient enrichment coupled with metabolic disruption associated with increases in condition and liver weight and decreases in gonad weight (Lowell et al. 2005).

The results of the first cycle of the metal mining EEM program are not yet analyzed; therefore, it is not known whether general response patterns to metals will be similar to those observed for pulp mills. Furthermore, it is not known whether generalizations will be possible because responses vary with the type of metal, fish species, and type of receiving waters. Currently available studies of field populations of fish exposed to elevated metals indicate that generalizing may be difficult.

McFarlane and Franzin (1978) studied populations of white sucker in lakes affected by a smelter complex at Flin Flon, Manitoba. They found that the white suckers occupying a lake contaminated by Zn, Cu and Cd showed greatly increased growth in length and weight, increased fecundity, and earlier age of maturation, but reduced spawning success, reduced larval and egg survival, smaller egg size, and reduced longevity compared with reference lake suckers. Metal concentrations in the McFarlane and Franzin (1978) study ranged from 10-20 µg/L copper, 0.5-0.6 µg/L cadmium and 211-245 µg/L zinc. Concentrations in the Columbia River post-Kivcet ranged from 0.4-3 µg/L copper, 0.03-1.9 µg/L cadmium and 1.1-67 µg/L zinc with the higher concentrations occurring at the New Bridge site.

Munkittrick and Dixon (1988a, b) found that white sucker populations in lakes contaminated with copper and zinc from mine wastes showed the opposite pattern to what would have been expected based upon McFarlane and Franzin's (1978) work. Instead of finding increased growth and fecundity due to less competition from young fish, the most obvious effect was retarded growth of sexually mature females. The metal-enriched sediments reduced productivity of benthic invertebrates and created a food shortage that interacted with the energy demands of oogensis in maturing females to reduce growth rates.

Swanson (1982) found that lake whitefish and white sucker populations in a lake with elevated uranium, chromium, radium-226 and lead-210 concentrations had the following characteristics: (1) missing juvenile and older size and age classes in whitefish; (2) a slower growth rate in both species; (3) lower fecundity in both species; and (4) later age of maturity in both species. These results were attributed to poorer overall nutrition in the affected lake and possible physical effects on a major spawning habitat area caused by precipitation of aluminum and uranium hydroxides produced by acid drainage from an abandoned uranium tailings area.

Field studies of yellow perch in the Rouyn-Noranda mining region of Quebec as well as the Sudbury region, (which is affected by nickel smelters) have shown a variety of effects (Campbell et al. 2003). Both direct and indirect effects were observed in perch collected from the more contaminated lakes along a gradient of metal concentrations (particularly copper, nickel and cadmium). Metal concentrations in the lakes where effects were observed were considerably higher than in the Columbia River (e.g., cadmium concentrations were 1-2 orders of magnitude higher). The perch had higher accumulation of metals, especially in liver and kidney, and this exposure was accompanied by morphological changes in gill, kidney, thyroid and gonad tissues. In addition, juvenile fish had a decreased capacity to secrete cortical and thyroid hormones that are key for regulation of intermediary metabolism and osmoregulation and had reduced condition and survivorship. Food web-mediated indirect effects on yellow perch were caused by an impoverished littoral benthic community in lakes with elevated metals, leading to adult perch continuing to rely on zooplankton. This failure to complete diet shifts to larger-sized prey produced stunted fish. Campbell et al. (2003) suggested that a combination of direct and indirect effects was responsible for other effects that were first observed in juvenile perch but which persisted in adults, such as reduced condition factor, reduced GSI, and changes in liver metabolic enzymes and energy stores. The authors went on to postulate that such effects could lead to impaired spawning and recruitment and thus contribute to the under-representation of young age classes in the perch populations in metal-exposed lakes. Levesque et al. (2003) observed direct metal effects on adult yellow perch in the Rouyn-Noranda region along a gradient of cadmium, zinc, copper, lead and nickel concentrations. These effects included increased gill histopathology, reduced sex steroid production, delayed gonadal recrudescence and cortisol impairment.

As can be seen by the brief review above, there may be no general pattern of response in fish to metals. Therefore, the evidence for causation of the specific responses noted in prickly sculpin in the present study was examined without any expectation of consistency with other studies.

The response pattern for sculpin in the present study is greater length and weight, increased condition, and smaller relative gonad (GSI) and liver size (LSI); however, only weight and LSI in females exceeded critical effect sizes. Increased weight can be associated with nutrient enrichment; however, as Campbell et al. (2003) point out, this depends upon the fish species, the aquatic system (lake or river) and the characteristics of the food web. As noted previously during the discussion of support for Conceptual Model 2, the observed differences in near-field sculpin may, in part, reflect an indirect effect from smelter-related emissions because near-field periphyton biomass at the Old Bridge was elevated (providing a larger food supply and thus leading to faster growth). However, benthic invertebrate abundance was not uniformly elevated relative to upstream in the near-field fish sampling area (although the invertebrate data are for depositional habitats whereas sculpin feed primarily in erosional habitats). Another possible indirect mechanism for the larger sculpin in the near-field is reduced intra-specific competition because of metal-related reduced survivorship of young sculpin (Ryan and Harvey 1980); however, metal concentrations in the near-field were much lower than in the Ryan and Harvey study.

Smaller relative liver size has been associated both with nutrient limitation (defined broadly to include some combination of limited availability of food, appetite suppression or internal alteration of food absorption) and exposure to metals (Lowell et al*.* 2005; Norris et al. 2000; Rajotte and Couture 2002). The periphyton study conducted for this risk assessment showed that the near-field area, if anything, provides a greater periphyton food base than other reaches of the river (Golder 2007c). There is experimental evidence for metal effects on liver size. A laboratory study using adult rainbow trout (*Oncorhynchus mykiss*) exposed to 10-25 μg/L $CdCl_2$ revealed a dose-related decrease in LSI values and liver glycogen content (Ricard et al*.* 1998). Larsson et al*.* (1984) also reported decreased liver sizes in perch (*Perca fluviatilis*) held in the laboratory and exposed to a mixture of metals. Levesque et al*.* (2002) found chronic exposure to sub-lethal concentrations of metals altered seasonal changes in liver glycogen and triglycerides as well as enzymes involved in lipid, carbohydrate and protein metabolism.

The decreased LSIs in prickly sculpin from the near-field are unlikely to be due to nutritional deficiencies, but may be related to the effects of metals on the metabolic capacity of the liver (i.e., altered ability to store and use glycogen). However, exposure of sculpin to metals in the near-field area is much lower than the exposures that caused effects in laboratory studies.

Indirect effects on sculpin health caused by smelter-related physical changes in habitat would now be limited to deposits of slag remaining from the period when slag was discharged to the river. Past nutrient discharges from the Teck Cominco fertilizer plant would not be expected to have lingering effects on physical habitat. Observations of slag content obtained during the sediment and benthic invertebrate sampling program indicate that there are small pockets of slag deposition in the near-field area. However, these pockets of slag are small relative to the total amount of sculpin habitat and occur in depositional areas whereas sculpin occupy erosional areas. Therefore, it is unlikely that there is spatial correlation between the presence of slag and effects on sculpin health.

The only population-level information for sculpin in the AOI was percent composition within the overall fish community as measured during annual fish indexing surveys from 2001 to 2005. The evaluation of causation for % composition is included in the discussion below.

On balance, there is weak evidence for a cause/effect link between the larger weight and lower LSI in female sculpin from the near-field area and the smelter (Table 4.40). This conclusion is based upon the following reasoning:

- *Spatial Correlation*: There was spatial correlation between effects and relative exposure (as measured by fish tissue concentrations) in the near-field area, but not with presence of slag; % composition of sculpin within the overall fish community increases downstream of the smelter; therefore, there was no indication of direct effect of PCOC or slag-related physical effects on habitat quality relative to upstream;

Table 4.40 Causation Scores for Prickly Sculpin Lines of Evidence for Direct Effects: A = Physical Habitat Effects; B = Effects of PCOC

Causal Criterion	Distribution (% Composition)		Fish Health Parameters		Pathology Index	
	A	B	A	B	A	B
Spatial Correlation	0	0	0	+	---	---
Temporal Correlation	0	0	n/a	n/a	n/a	n/a
Biological Gradient/Strength	0	0	0	+	-	-
Plausibility: Mechanism	0	0	+	+	0	+
Plausibility: Stressor-Response	0	0	0	0	---	---
Consistency of Association	0	0	0	-	-	-
Experimental Verification	0	0	n/a	n/a	n/a	n/a
Specificity of Cause	0	0	0	0	0	0
OVERALL STRENGTH OF EVIDENCE	○	○	○	○	○	○

Notes: see Table 4.15 for key to individual causation scores.
● strong overall strength of causal evidence.
⊙ moderate overall strength of causal evidence.
○ weak overall strength of causal evidence.
n/a = not available.

- *Temporal Correlation*: There are no earlier health data available for sculpin and the distribution data show no definite temporal trend;
- *Biological Gradient/Strength:* There was a response greater than critical effect size in only two parameters and only in females; the effects declined with distance from the smelter as did levels of PCOC in water and fish tissue, but not in sediment; and there were no effects on distribution upstream versus downstream of the smelter;
- *Plausibility: Mechanism:* There is a questionable mechanism for effects on weight (because of conflicting information on abundance of food organisms); there is a plausible mechanism for metal effects on liver size; there is a plausible mechanism for slag effects via indirect effects on food organisms;
- *Plausibility: Stressor/Response:* The literature indicates that effects on liver size are observed at metal concentrations that are much higher than observed in the near-field area and sculpin do not live in habitats where slag deposits occur;
- *Consistency of Association*: There was no consistency with any of the observed or postulated “patterns” of response to metals or other stressors; there were many exceptions to an association between fish health parameters and proximity to the smelter or PCOC concentrations in water, sediment or fish tissue;
- *Experimental Verification*: There were no laboratory tests done on sculpin for this study; and
- *Specificity*: Many other environmental or biological factors could explain the responses observed in female sculpin.

An analysis of causation for mountain whitefish population characteristics was conducted because some population characteristics differed between upstream and downstream sampling sections and/or there has been a change over time (Table 4.41). Causation was not evaluated for mountain whitefish health parameters because all responses were less than the critical effect size.

Evaluating causation for population-level characteristics when whole-organism characteristics showed no critical effect may appear to be unnecessary, since whole-organism responses are understood to be more sensitive and an earlier sign of exposure to and effect of chemical stressors (Hodson 1990). However, given the potential interaction between physical and chemical stressors and the level of uncertainty associated with Conceptual Model 2, a causation evaluation for population-level characteristics was conducted.

Table 4.41 Causation Scores for Effects on Mountain Whitefish Population Characteristics: A = Physical Habitat Effects; B = Effects of PCOC

Causal Criterion	Population Characteristics							
	(% Composition)		Catch-Rate		Size Distribution		Population Estimate	
	A	B	A	B	A	B	A	B
Spatial Correlation	---	---	---	0	---	0	n/a	n/a
Temporal Correlation	---	---	---	0	---	0	---	---
Biological Gradient/Strength	-	-	-	-	0	0	-	-
Plausibility: Mechanism	+	+	+	+	+	+	+	+
Plausibility: Stressor-Response	---	---	0	0	---	---	---	---
Consistency of Association	-	-	-	-	-	-	-	-
Experimental Verification	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Specificity of Cause	0	0	0	0	0	0	0	0
OVERALL STRENGTH OF EVIDENCE	○	○	○	○	○	○	○	○

Notes: See Table 4.15 for key to individual causation scores.
● strong overall strength of causal evidence.
⦿ moderate overall strength of causal evidence.
○ weak overall strength of causal evidence.
n/a = not available.

Percent Composition

Mountain whitefish have continued to have the highest percent composition within the fish community throughout the period evaluated (1990 to 1994; 2001 to 2005). This is true for all sampling sections of the AOI, both upstream and downstream of the smelter. Therefore, all causation criteria for percent composition received a low score, with the exception of "plausible mechanism," since there are plausible mechanisms for smelter-related emissions to cause changes in the fish community composition (e.g., via changes in food abundance or availability or via effects on the more sensitive fish species within the community).

Catch-Rate

- *Spatial Correlation:* The higher catch-rate of mountain whitefish in upstream sampling sections does not correspond with the location of the smelter. The highest catch-rate for mountain whitefish is in the "Upper Sampling Section", which extends from the Hugh Keenleyside Dam to just above the confluence with Champion Creek. Catch-rates decrease both in the Middle and Lower sections. Therefore, the spatial correlation criterion was assigned an "uncertain" score of "0" for PCOC and an "incompatible" score for physical effects on habitat caused by slag. The difference between the score for PCOC exposure and exposure to habitat change caused by slag is based upon the fact that the remaining proportion of habitat affected by slag is small relative to total habitat.

- *Temporal Correlation:* As discussed above, the decrease in catch-rates noted in more recent sampling years may be due to a change in sampling methods; therefore, the temporal correlation criterion was also assigned an "uncertain" score of "0" for exposure to PCOC. The score for temporal correlation with physical effects on habitat caused by slag is "incompatible" because if slag were affecting catch-rates, the effect should have been greater (with lower catch-rates) in the early 1990s.
- *Biological Gradient:* The change in catch-rate with time occurred in all sampling sections, not just downstream of the smelter; therefore, the biological gradient score was "none" (-).
- *Plausible Mechanism:* The mechanisms for a smelter-related effect on catch-rate may include behavioural avoidance (due to detection of metals in the water by fish), changes in food abundance caused by the smelter-related PCOC or slag deposits, or direct toxicity. Since there are several plausible mechanisms, but none have been demonstrated in the study area, the score was "plausible" (+).
- *Plausible Stressor/Response:* Despite the existence of several plausible mechanisms, there was ambiguous evidence of a stressor-response relationship between exposure to conditions downstream of the smelter and catch-rate, since there was no consistent spatial or temporal relationship between exposure to smelter-related stressors and catch-rate. Therefore, the stressor-response relationship was given a score of "0" (ambiguous).
- *Consistency:* Similarly, the lack of consistency across the sampling sections and over time resulted in a score of (-) for consistency (which equates to many exceptions to the association with the smelter).
- *Experimental Verification:* There was no experimental verification of a relationship between catch-rate and exposure to smelter-related stressors; therefore, this criterion was assigned a score of "not available".
- *Specificity:* There are many possible causes of changes in catch-rates with time or sampling area; therefore, the specificity criterion was assigned a score of "0".

Size Distribution

- *Spatial Correlation:* The shift in size distribution of mountain whitefish back to a predominance of larger fish occurred within the overall population, both upstream and downstream of the smelter. The factors influencing size distribution appear to be operating both upstream and downstream of the smelter, with no obvious spatial correlation with the smelter discharges. The observed change in length-frequency could be the result of changes made to the sampling methods, as discussed above. Therefore the spatial correlation criterion was assigned a score of "0", corresponding with an uncertain spatial relationship.
- *Temporal Correlation:* The temporal correlation criterion was also assigned a score of "0" because the fluctuations in size distribution from 1990 to 1994 and 2001 to 2005 do not coincide with the reductions in exposure to PCOC or slag discharge after installation of the Kivcet smelter in 1995.
- *Biological Gradient:* The shift to larger fish did not follow a spatial or temporal gradient of exposure to smelter-related stressors; therefore, the biological gradient criterion had a score of "0".

- *Plausible Mechanism:* There is a plausible mechanism for exposure to PCOC or historic habitat degradation caused by slag causing a shift to larger fish via effects on recruitment of young and the "metabolic disruption" patterns observed at some sites with elevated metal concentrations (see discussion above).
- *Plausible Stressor/Response:* The lack of any spatial or temporal correlation and the lack of any gradient of response provided no evidence of a stressor-response relationship, resulting in an "inconcordant" score (---).
- *Consistency:* The score for consistency was based upon the lack of any evidence for consistent association between exposure to smelter-related stressors and the response (-).
- *Specificity:* There are many causes of shifts in size distribution in fish populations; therefore the specificity score was "0".

The lack of a consistent temporal trend in population estimates produced an "inconsistent" score for temporal correlation. Spatial correlation could not be evaluated because population estimates were derived for the entire mountain whitefish population in the AOI, not individual sampling sections. There was no evidence of a response over the temporal gradient of smelter-related emissions, which declined after the installation of the Kivcet smelter in 1995; therefore, the biological gradient criterion was given a score of "0". There are plausible mechanisms for the effects of metals on fish populations (either via direct toxicity or via changes in food organisms), thus a score of (+) was assigned to this criterion. However, the population estimates provided no evidence of a stressor-response, leading to a score of (---) for this criterion. There was no consistency of association between population estimates and exposure to the smelter-related stressors, producing a score of (-). There are many possible causes of variation in population estimates (score of "0").

As discussed above, habitat differences may be the dominant factor influencing percent species composition, catch-rates and size-distribution upstream-to-downstream in the AOI.

4.6.4 Step 6: Risk Characterization for Mountain Whitefish and Prickly Sculpin

The risk management objective for mountain whitefish and prickly sculpin was:

> "Minimize, now and in the future, smelter operation-related direct and indirect effects within the AOI on fish populations in the Columbia River and its tributaries."

The assessment endpoints for this objective were:

- growth, condition and reproductive capability of the fish receptor species in the Columbia River;
- population characteristics of the fish receptor species in the Columbia River, including distribution within the AOI, relative abundance, and age and/or size distribution; and
- fish habitat quality in the Columbia River.

The two receptor species were chosen to represent the overall fish community in the Columbia River. It is assumed that if the risk management objective is met for these two species, then it will also be met for all other fish species in the AOI. This assumption is based upon the following reasoning:

- mountain whitefish have been shown to have higher concentrations of PCOC in their tissues than walleye or rainbow trout and similar concentrations to largescale sucker; therefore, it is unlikely than any other large-bodied species would have greater exposure to the PCOC in the AOI;
- mountain whitefish have historically been demonstrated to be the most sensitive large-bodied fish species to the stressors present in the AOI and historically have exhibited a number of responses to these stressors (which included, but were not limited to smelter-related PCOC and slag) in the early 1990s;
- if mountain whitefish, as the most sensitive large-bodied species, no longer show significant responses that exceed critical effect benchmarks, then other large-bodied species would not be expected to show significant responses; and
- prickly sculpin, because of their fidelity to relatively small home ranges and their food habits, would be expected to have exposures to PCOC that are as high as (or higher) than other small-bodied fish species in the AOI.

The uncertainty associated with these assumptions was addressed by examining data available from fish indexing studies for walleye and rainbow trout for relative abundance, percent composition in the fish community, age and size-distribution, population estimates and survival rates. These data showed no spatial or temporal trend that would indicate effects from smelter-related stressors (see discussion of fish population characteristics above; Golder 2006b).

Conceptual Model 1

The evidence for direct effects of PCOC on fish health or fish populations and the evidence for direct effects on habitat caused by slag deposition does not support Conceptual Model 1; therefore, the risk management objective is being met and consideration of risk management options is not required (Table 4.42).

The largest uncertainty associated with the prickly sculpin risk characterization is with respect to the direct effects of slag deposition on prickly sculpin habitat as well as population characteristics. Observations of slag content of sediments were limited to depositional habitats. Prickly sculpin primarily use erosional habitats. It is assumed that slag will not be present in large amounts in erosional habitats; however, there is a potential for small pockets of slag to accumulate around the coarser substrates favoured by sculpin. Additional data on the relative occurrence of slag in erosional areas of the AOI have been collected subsequent to the completion of this ERA. These data are still in the process of being assembled and interpreted. Once this interpretation is complete, the potential for effects of any slag deposition in erosional habitat on habitat quality (e.g., via changes in food organism abundance or diversity) can be evaluated.

A smaller area of uncertainty relates to the possibility of effects on prickly sculpin at the Maglios benthic invertebrate site. Further work with prickly sculpin at this site would only be warranted if benthic invertebrate impacts are confirmed and are shown to be causally related to the smelter, and if the zone of smelter-related impact is large enough to encompass the home range of a sub-population of prickly sculpin. The fish health work (if any) should be on prickly sculpin (if they occur in the area) because the site is so small that exposure to wide-ranging large-bodied species would be insignificant.

Table 4.42 SALE Summary Table for Prickly Sculpin and Mountain Whitefish

Receptor Species	Fish Health			Fish Population Characteristics			Direct Effects of Slag on Habitat			Proceed to Evaluation of Risk Management Options?
	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	
Prickly Sculpin	o→⊙	o	?	o	o	??	o	o	??	No
Mountain Whitefish	o	o	?	o	o	?	o	o	?	No

Notes:

Magnitude:

- ● strong response.
- ⊙ moderate response.
- o weak response.

Causation:

- ● strong overall strength of causal evidence.
- ⊙ moderate overall strength of causal evidence.
- o weak overall strength of causal evidence.

Uncertainty:

- ? low uncertainty (high statistical power, full gradient design, all important natural variables accounted for).
- ?? moderate uncertainty (moderate statistical power, control/impact rather than full gradient design; most natural variables accounted for).
- ??? high uncertainty (low statistical power, important natural variables not accounted for).

The uncertainty associated with the mountain whitefish risk characterization is less than for prickly sculpin because of the presence of several years of population-level data as well as fish health data that demonstrate improvement since the discharge of PCOC decreased and the discharge of slag ceased. As discussed above, it is unlikely that other large-bodied fish species have been at greater risk than mountain whitefish. Therefore, there is no compelling argument for further monitoring or evaluation of large-bodied fish species in the AOI relative to direct risks from smelter-related stressors.

There is also no compelling argument for monitoring in anticipation of possible future increases in discharge of PCOC. Discharge of PCOC in the treated effluent continues to decline; this decline is reflected in water quality data. This assessment has been based on data collected from a relatively recent time period (i.e., primarily 1994 to 2005). This time period included rapid and dramatic reductions in releases of PCOC to air and water. These improvements have resulted in current PCOC release rates that are lower than they have been at any time since metallurgical operations began. The ERA therefore provides an assessment of ecological risks under conditions of low PCOC release rates. Of course, the current influence of past higher PCOC release rates is also captured in the ERA (e.g., current PCOC concentrations in soils and sediments today reflect inputs from releases over previous decades).

In the foreseeable future, releases of PCOC to air and water from the Teck Cominco metallurgical plants may generally be expected to remain at their current low levels, or to decline somewhat further. Of course, there will be fluctuations in the amounts of various PCOC released, as the primary smelter feed sources (zinc and lead concentrates from various mines) change, but these variances will be maintained within the limits specified in current permits under the B.C. Environmental Management Act. Key metallurgical plants at Trail (zinc electrolytic and melting, silver refinery and lead smelter) have all undergone expansion and updating in the past several decades. These plants currently operate at or near full capacity and there are currently no plans for major production capacity increases in Trail. However, changes in available feeds, changes in technology, and changes in the suite of products made at Trail are likely to occur in the future, just as they do for other major industrial facilities. Any such changes will be only be made upon consideration of potential environmental risks and in consultation with key stakeholders.

There is considerable confidence in the risk characterization and the recommendation that consideration of active risk management options is not required because:

- several lines of evidence examined not only for magnitude but also for causation and uncertainty indicate that the risk management objective is currently being met;
- the uncertainty associated with the risk characterization is low for mountain whitefish;
- the uncertainty associated with the risk characterization for prickly sculpin can be addressed by some additional evaluation of slag effects in erosional habitats plus confirmatory monitoring of fish health measures;
- sampling was conducted in areas of expected maximum exposure to PCOC from the smelter and exposure was confirmed;
- mountain whitefish and prickly sculpin are good representatives of the fish community due to their level of exposure and (in the case of mountain whitefish) their documented sensitivity;
- natural variability in fish health measures was addressed satisfactorily via the sampling design;
- variability in mountain whitefish population characteristics has been documented for several years both before and after smelter-related discharges decreased; and
- no future increases in smelter-related stressors are expected.

Conceptual Model 2

The lack of any direct response of the fish receptors to the smelter-related stressors reduces, but does not eliminate the likelihood of indirect effects as per Conceptual Model 2. The effects on benthic invertebrates at Maglios and Waneta may reduce the local food supply, especially for small-bodied fish. However, there is no evidence of effects on fish populations; therefore, effects via changes in competition or predator-prey interactions are highly unlikely.

The data on fish distribution, abundance and fish health do not indicate the need for management of risks from indirect effects. Uncertainty is not as great for indirect effects on fish as it is for the other receptors because of the extensive monitoring that has been conducted in the AOI on fish habitats, distribution and abundance. Effects of stressors from other anthropogenic sources such as pulp mills and dams are being addressed by mitigation and monitoring programs conducted by the operators.

4.6.5 Steps 3 and 4: Assessment of Magnitude and Uncertainty of Field and Laboratory Data of White Sturgeon

The white sturgeon is a SARA-listed species that is the subject of considerable effort aimed towards understanding its current status, the contributing factors for its current status, and recovery. The White Sturgeon Recovery Initiative (WSRI) began in 2000 with an agreement signed by Fisheries and Oceans Canada, B.C. Ministry of Environment and B.C. Hydro. The WSRI brings together the interests of over 25 partners, including government, First Nations and American tribes, industry, environmental groups and others to the challenge of preventing the extinction of this species in the Upper Columbia River (WSRI 2004).

The current study relied upon the WSRI and others (such as B.C. Hydro and B.C. Ministry of Environment publications) for data on white sturgeon health and population status in the AOI. Lines of evidence available from these sources were:

- habitat characteristics and smelter-related effects on habitat;
- distribution and habitat use;
- population dynamics; size and age distribution; and recruitment;
- spawning activity;
- contaminant concentration in sturgeon tissue;
- incidence of external anomalies in adults and juveniles;
- toxicity tests using juvenile sturgeon; and
- genomics studies.

Smelter-Related Effects on White Sturgeon Habitat

Past studies of white sturgeon have documented several areas of high use by adult white sturgeon. These areas are from the Hugh Keenleyside Dam to Norns Creek, the confluence of the Columbia and Kootenay Rivers (Kootenay Eddy), Fort Sheppard Eddy and Waneta Eddy (R.L & L 1994, 1998, 2001). Juvenile white sturgeon exhibited a distribution pattern similar to adults within the AOI and are most commonly found downstream of the Hugh Keenleyside Dam and the Fort Sheppard Eddy.

Smelter-related effects on these high-use areas are restricted to direct and indirect effects caused by slag deposition at Fort Sheppard and Waneta Eddies. No other physical effects on habitat are expected in these areas, although historic effects included stimulation of aquatic plant growth by nutrient-rich discharges from the Teck Cominco fertilizer plant (see discussion of past nutrient effects above). With the exception of occasional forays into shallow water to feed, sturgeon would be exposed to slag deposited in deeper water, since they spend the majority of their time in mean depths ranging from 12.5-19.5 m (Golder 2003b, 2005b).

The only spawning area for white sturgeon in the AOI is at the confluence of the Pend d'Oreille and Columbia Rivers (Hildebrand et al. 1999). Observations by divers in this spawning area indicate that substrates in the egg deposition zone are coarse, angular and not heavily embedded in finer substrates (WSRI 2002). This suggests that slag does not accumulate in substrate interstices; therefore, slag effects on spawning habitat are not apparent. Flushing flows provided by the relatively natural freshet patterns that still occur in the Pend d'Oreille system help maintain substrate interstices and would scour and transport slag and other fine materials out of the area.

Sand is the dominant substrate recorded at juvenile white sturgeon capture and observation locations (Golder 2003c, 2005b). The majority (n=17; 53%) of juvenile white sturgeon recorded on underwater video footage in 2002 were observed over sand/silt substrate, with 14 of the 17 individuals associated with slag depositions. These 14 individuals were observed over undulating sand and slag substrate ("low relief dunes") in Waneta Eddy (Golder 2003c). The "dunes" were 0.1-0.2 m in height and may provide velocity refugia and areas of food settlement. In 2003, underwater video footage recorded 1,010 juvenile white sturgeon, 31 adult white sturgeon and 286 fish of other species in Waneta Eddy (Golder 2005b). The juvenile white sturgeon were observed interspersed with adults, lying on the river bottom aligned facing into the current, exhibiting relatively little movement and in very close proximity to each other.

Indirect effects on feeding habitat because of slag-related effects on benthic invertebrates at Fort Sheppard and Waneta are a possibility; however, as noted above, the eddies are not primary food-producing areas for fish within the AOI. Stomach content analysis of age-1 and age-2 hatchery juvenile white sturgeon collected in November showed that all had fed almost exclusively on *Mysis relicta* (Golder 2005b). Mysids were introduced into the Columbia River (Arrow Lakes Reservoir and Kootenay Lake) and in the Pend d'Oreille River (Lake Pend d'Oreille) as a food source for kokanee. More recent stomach content data show that, while juveniles still feed primarily on mysids in the northern portion of the AOI, juveniles feeding further downstream consume a greater variety of prey items including amphipods and chironomid larvae (Hildebrand, pers. comm.). It is not known if the dominant benthic invertebrates found in Waneta Eddy (*Bezzia*, *Hydra* and fingernail clams) and Fort Sheppard (tubificids, nematodes and fingernail clams) are important juvenile sturgeon prey items.

Slag or sandy deposits may affect the ability of tube-dwelling amphipods to colonize the Fort Sheppard and Waneta areas. In other studies, tube-dwelling amphipods were the primary prey of juvenile white sturgeon (Sprague et al. 1993). Other prey items included other amphipod species, chironomid larvae, mayfly nymphs and mysids. Small quantities of fish bones were found in some stomachs of juvenile sturgeon. In a 1988 study, McCabe et al. (1993) also found tube-dwelling amphipods to be the most important prey item in the Columbia River downstream of Bonneville Dam. Small amounts of fish were found in the stomachs of larger juveniles.

Distribution and Habitat Use

Historical white sturgeon spawning habitat may have been situated in systems that had a high suspended sediment load such as the upper Columbia River or the lower Pend d'Oreille River (Hildebrand et al. 1999). White sturgeon are broadcast spawners and the eggs and post-hatch larvae are relatively large and black in colour. Post-hatch larvae undergo a passive downstream migration to rearing habitats. Turbid water conditions during egg incubation and early pelagic larval stage would provide protection from visual-dependent predation and also for the early benthic feeding stage of sturgeon fry (Hildebrand et al. 1999). Historical locations of rearing, feeding and overwintering habitats were likely distributed throughout the Columbia River and lower reaches of larger tributaries. Prior to dam construction in the United States, white sturgeon likely relied heavily on runs of spawning salmon as an important seasonal food source (Hildebrand et al. 1999).

Current adult and juvenile white sturgeon distribution in the AOI is restricted and localized. As noted above, the highest numbers are observed in the 7-km long section below Keenleyside Dam and the Columbia Kootenay confluence (Kootenay Eddy), Fort Sheppard Eddy and Waneta Eddy. This distribution reflects the availability of deep (>15 m) water areas with lower velocity (Hildebrand et al. 1999). White sturgeon are found in these four areas throughout the year. Three of the four primary areas are associated with major inflow sources (tributary confluences or dam tailwaters).

The four high-use areas used by adult and juvenile white sturgeon also support high densities of other fish species that likely provide a food source. In high-use areas directly below dams, entrained fish and zooplankton (mysids) represent an important food source (Hildebrand et al. 1999). Winter is a critical period for fish survival, as food resources are limited. The elimination of salmon runs into the AOI has implications for sturgeon survival, spawning frequency and fecundity. Sturgeon in the AOI tend to select calm water habitats in the winter period, likely to reduce energy expenditures.

Highly-fluctuating flows during the winter period can adversely affect the overwintering habitat for white sturgeon, and can affect behaviour and gonad maturations. Winter flows in the upper AOI below the Keenleyside dam have increased substantially from pre-regulated conditions. The effects of this increase in terms of increased energy expenditures by sturgeon in the winter are unknown, but may have implications to fish growth and spawning success (Hildebrand et al. 1999).

Larval white sturgeon are most vulnerable to predation at the swim-up stage and during drift downstream. Factors that increase the time larvae spend in the drift (e.g., slower current velocity due to reduced discharge from upstream dams) or increase their visibility to predators (e.g., increased water clarity due to upstream impoundments) would reduce survival (Hildebrand et al. 1999). Larval white sturgeon are also the most vulnerable life stage to gas bubble trauma caused by high TGP, a physically-induced syndrome that involves the growth of gas bubbles internal or external to the animal.

Recent studies have been conducted by BC Hydro, Columbia Power Corporation, and the Washington Department of Fish and Wildlife in the Columbia River immediately downstream of the Waneta white sturgeon spawning area near the Canada/U.S. border. The objectives of these studies were to assess the development, condition, behaviour (hiding/drift patterns), and relative abundance of early life stages of white sturgeon and to determine their distributions, locate hiding habitats, and define the parameters of these habitats. Relatively large numbers of drifting larval sturgeon have been captured including both the “free embryo” stage where the larvae go into their hiding phase as well as the “early larvae” stage when larvae come out of hiding and start exogenous feeding (Golder 2009a). Both stages were recovered up to approximately 1.5 km downstream from the Canada/U.S. border. Concurrent studies on the Canadian side of the border were conducted to establish the timing of spawning at Waneta (Golder 2009b, 2010). A larval drift sampling station established upstream of Waneta confirmed that the larvae captured as far downstream as just upstream from Northport originated from the Waneta spawning area. The river bottom from the Waneta spawning area downstream for approximately 1.5 km was examined using underwater video gear and the parameters of substrate type and interstitial space availability were rated as a means of assessing the suitability of free embryo hiding habitat. The results indicated this area contained habitats with moderate to high substrate rankings which may support a high use of this area by free embryos during the hiding phase.

Adult and juvenile white sturgeon do not move extensively throughout the AOI. Tagging, radiotelemetry, and sonic telemetry data show that most sturgeon move less than 10 km (Hildebrand et al. 1999). Movements out of the high-use areas to nearby shallower habitats occur at a greater frequency during the spring-summer period. These movements are attributed to feeding activities (Hildebrand et al. 1999).

Population Dynamics: Size and Age Distribution, Recruitment, and Growth

Estimates of the white sturgeon population in the upper Columbia River have remained between 1,100 and 1,400 fish (Hildebrand et al. 1999; UCWSRI 2007). Recaptured percentages of marked fish increased from 5% in 1990 to 53% in 1995, indicating low abundance, limited recruitment and low rates of immigration or emigration (Hildebrand et al. 1999; Golder 2005b). Ageing studies indicated that most of the fish recaptured were greater than 30 years old (UCWSRI 2007).

The length-frequency distribution of white sturgeon in the upper Columbia River has shifted from a population comprised predominantly of juvenile fish in the early 1980s to one currently dominated by adult fish (Hildebrand et al. 1999). The reported size distribution of white sturgeon in Lake Roosevelt was similar to the population in Canada (UCWSRI 2002).

White sturgeon have spawned and hatched successfully in the Waneta area from 1993 to 2005 (Golder 2004c, 2006c). There were no spawning studies conducted in 2006.

Recent information provided by studies conducted by the Washington Department of Fish and Wildlife indicates that every year since 1995, there has been recruitment of wild juvenile sturgeon to the portion of the population that resides on the U.S. side of the border (L. Hildebrand pers. comm. 2007). Approximately 6% of the catch was shown to be wild fish, in contrast to data from the Canadian side where wild juveniles are rarely captured. Although the observed level of recruitment is not considered sufficient to maintain the population, the data indicate that there were at least some successful spawning events in most if not all years since 1995. The two years with the highest number of wild juveniles recruited into the population were 1997 and 2000; these years were high-flow years. However, the third-highest numerical abundance in the over all catch was from 2001, which was a record low-flow year. Therefore, while the data are very significant with respect to establishing that a low level of annual recruitment of wild juveniles has occurred, it is too early to draw conclusions regarding the factors that resulted in these recruitment signals.

Currently, a large number of sturgeon ageing materials are being re-aged from birth year 1960 onwards. This study will help determine the accuracy and precision of the ageing conducted to date and help establish if current recruitment has also occurred on a low but consistent basis from the onset of recruitment failure in the late 1960s to early 1970s to 1995. This re-ageing process is expected to be completed in late 2010.

Because the white sturgeon population in the AOI appeared to be ageing with low levels of recruitment, the WSRI includes the introduction of hatchery-reared juveniles to the river.

Recaptured juvenile sturgeon have been in good condition with high growth rates (Golder 2005b). Growth rates for the Columbia River juvenile white sturgeon were substantially higher than growth rates observed in juveniles released and recaptured in the Kootenay River (Golder 2002b, 2005b). Results of monitoring in 2001, 2003 and 2004 showed that hatchery-reared juveniles adapted quickly and very well to natural conditions. Decreases in weight between release and recapture were not observed in any individual captured. The growth rates indicate suitable prey availability and high feeding success. Growth rates and the condition of juveniles observed upon recapture suggest that food availability should not limit survival (Golder 2005b).

Spawning

Spawning in the AOI has only been recorded below Waneta Dam at the Pend d'Oreille-Columbia confluence. An additional spawning area has been confirmed just outside of the AOI, at Northport, Washington, USA. The number of individual spawning events in the Waneta area varies from year-to-year, and is related to discharge, temperature, and prey abundance (Golder 2002b, 2004c, 2006c). The AOI is a low nutrient system; therefore, gamete development and maturation takes longer than in higher nutrient systems such as the lower Columbia River, where salmon are available as prey. As a result, despite their long lifespan, the number of times female white sturgeon in the AOI are able to spawn may be severely limited (Golder 2002b). Consequently, females that develop mature gametes may spawn despite less than ideal physical conditions during the spawning season, since the energetic benefits gained from gamete re-absorption may not be sufficient to offset losing the chance to spawn (Golder 2002b). This may have been one of the reasons why 2001 had a higher number of spawning events than expected given highly unstable flow conditions and less than optimal water temperatures that year.

From 1993 to 2001, spawning occurred at a later time each year (Hildebrand et al*.* 1999, Golder 2002b). This trend did not correlate with the number of spawning events and was not a covariate of temperature or discharge variables (Golder 2002b). Because the spawning population is aging, older spawners may take longer to respond to spawning cues, or may not be meeting the nutrient input threshold required to complete maturation of the egg mass and cue ovulation as the overall biomass of the population increases (Golder 2002b).

The trend to later spawning times did not continue in 2003 to 2005 (Golder 2004b, 2004c, 2006c). The 2003 to 2005 results suggest that the hypothesis of a continual progression to a later average spawning time may not be valid.

There were two consistent patterns in white sturgeon spawning from 1993 to 2005 (Golder 2004b, 2004c, 2006c). The first pattern was that the onset of spawning occurred during the descending limb of the Pend d'Oreille River hydrograph. The second pattern was that spawning began at water temperatures between 14 and 16^{o}C.

There may be a relationship between discharge and the numbers of white sturgeon eggs collected during spawning studies (Golder 2004b). This relationship was initially thought to represent a positive correlation of discharge with spawning timing, frequency and intensity (Hildebrand et al. 1999). An alternative hypothesis is that egg distribution and dispersal is either greater or more uniform during high discharge periods or eggs are more frequently displaced and therefore at higher risk of capture during high flow volumes (Golder 2004b). Thus, the relationship may simply reflect an increase in egg capture efficiency of the egg collection mats used during these surveys at higher discharges. The most recent spawning survey results suggest another possible hypothesis. Most of the eggs captured in 2005 were at two locations, one on a lateral cobble bar extending out into the main channel, and the other just downstream of the cobble bar. Factors that affect either the degree to which Pend d'Oreille River discharge is confined to the south bank and diverted over the cobble bar or the physical location of spawning in the Waneta dam discharge plume may, in turn, alter the capture efficiency at the other spawning location and, consequently, the total number of eggs captured in a given water year (Golder 2006c).

A 2005 study of predation on white sturgeon eggs documented the species composition and relative densities of potential egg predators in the vicinity of the white sturgeon spawning area and the Waneta Eddy (Golder 2006c). This study confirmed that largescale suckers consume white sturgeon eggs. In addition to largescale suckers, other potential egg predators in the Waneta area included walleye, sculpin, smallmouth bass, rainbow trout and northern pikeminnow.

The predation study also assessed the effect of White Sturgeon Flow Augmentation Program (WSFAP) flows. The WSFAP flows are implemented under a commitment of the Project Approval Certificate for the Waneta Dam Upgrade Project. Under conditions of the WSFAP, when mean daily Pend d'Oreille flows are below 708 m^3/s, Waneta Dam provides minimum discharges of 283 m^3/s during the day (0600h to 2400h) in an effort to attain the minimum white sturgeon spawning velocity target of 0.8 m/s or greater in the upper portion of the spawning area. The WSFAP also requires the release of a minimum flow of 142 m^3/s during the night (2400h to 0600h) to help discourage predation on incubating sturgeon eggs. This flow supplementation program was developed in 1996 to meet obligations under the Fisheries Act as part of the Mitigation and Compensation Plan associated with the Waneta Upgrade Project.

To assess the effect of WSFAP flows on egg predators, catch per unit effort (CPUE) was compared among species. At WSFAP flows near 708 m^3/s, the catch rate of suckers was the highest (133 fish/km), followed by sculpin spp. (22 fish/km), walleye (18 fish/km), smallmouth bass (17 fish/km), rainbow trout (12 fish/km) and northern pikeminnow (19 fish/km) (Golder 2006c). At WSFAP flow near 142 m^3/s, catch rate of sculpin spp. was highest (183 fish/km), followed by smallmouth bass (29 fish/km), sucker species (17 fish/km), rainbow trout (16 fish/km), walleye (9 fish/km) and northern pikeminnow (3 fish/km). The apparent decrease in catch-rate for suckers during a period of decreased flow was contrary to the intuitive expectation that higher flows would deter egg predators from using the area and that egg predator densities would increase during periods of lower velocity at lower discharge levels. Golder (2006c) suggested that the observed reduction in sucker catch-rate may have been due in part to an erroneous assumption that the intervening period (about 3 hours) between sampling sessions at high and low flows was sufficient to allow fish to re-establish after the first sampling pass. A second possible cause is that, during low Pend d'Oreille flows, cooler Columbia River water (about 2.5°C cooler) inundates the spawning area and may discourage fish use. The large increase in sculpin recorded during low flows was more likely due to an increase in sampling efficiency, in that sculpin were easier to see and catch at lower discharge levels (Golder 2006c).

Regardless of the cause of the changes observed at higher and lower flows, the data indicate that there is not a large influx of potential egg predators into the egg deposition area from adjacent areas of the Columbia River during periods of low flow from Waneta Dam (Golder 2006c). This would support a hypothesis that the potential egg predators that are present in the area consist of locally resident fish that may occasionally feed on sturgeon eggs.

The 2005 egg predator study did not produce sufficient data to estimate the effect of egg predation on overall white sturgeon egg mortality rates.

Concentrations of PCOC and Non-Smelter Related Contaminants in Sturgeon Tissue

Concentrations of PCOC were measured in several tissues from one adult, hatchery-reared juveniles from five families (i.e., five different females), one wild spawned juvenile raised in the hatchery and gametes from nine wild broodstock (BCMOE unpublished). Comparison of PCOC concentrations with published effects benchmarks showed that five of the PCOC may exceed effects thresholds. Cadmium exceeded the effects threshold of 2 µg/g wet weight reported by Jarvinen and Ankley (1999) once (in kidney tissue of the adult). Chromium concentrations frequently exceeded the effects threshold of 0.6 µg/g (Jarvinen and Ankley 1999), both in adult tissues and in juveniles. Available data produce a very low effects threshold for silver (0.003 µg/g) (Jarvinen and Ankley 1999). In many cases, silver was less than the rather high limit of detection of 0.05 µg/g; therefore, it is impossible to determine whether concentrations in these samples actually exceeded the low silver threshold. All detectable silver concentrations exceeded this threshold; silver was above detection limit in 4 samples, liver and kidney tissue of the adult specimen and two of the juvenile families.

Copper and zinc concentrations were greater than published effects thresholds in almost all samples. The lowest copper effects threshold in Jarvinen and Ankley (1999) is 0.5 µg/g. The lowest zinc effects threshold in Jarvinen and Ankley (1999) is 4.5 µg/g. Copper and zinc concentrations exceeded the effects threshold in all adult tissues and all of the five families of juveniles. Eggs and sperm did not contain measurable concentrations of zinc. Two gamete samples contained measurable copper concentrations; both of these concentrations exceeded the effects threshold. A significant correlation between increased mortality of white sturgeon embryos and copper concentrations between 0.79 and 2.8 µg/g was observed by Kruse and Scarnecchia (2002). The two measurable copper concentrations in gamete samples were 1.6 and 2 µg/g.

Non-smelter related contaminants found in measurable amounts in white sturgeon samples included several PCB congeners; dioxins and furans; the pesticides chlordane, heptachlor, aldrin, dieldrin, mirex, DDT and flame retardants (polybrominated diphenyl ethers [PBDEs]). PCB concentrations did not exceed published effects thresholds, with the exception of thresholds published in early studies conducted on salmonids by Jensen et al. (1970) and Niimi (1983) (Kruse and Webb 2006). Dioxin and furan concentrations were below published effects thresholds (Kruse and Webb 2006). There are very few data on effects thresholds for the pesticides found in the sturgeon samples. Dieldrin and aldrin concentrations were much lower than any concentration found to have effects (Kruse and Webb 2006). Flame retardants (PBDEs) were found in most specimens; however, there are very few data on the effects of PBDE body burdens on any fish species. PBDEs cause changes in thyroid endpoints, similar to responses to other xenobiotics; however, these changes have not been causally linked to decreased fitness or survival (Brown et al. 2004).

Incidence of External Anomalies in Adult and Juvenile White Sturgeon

External anomalies include deformities, eroded fins, lesions, tumours, diseases and parasites (Kruse and Webb 2006). A search of the Columbia River sturgeon database showed that 2.4% (33 out of 1,380) of the fish in the database had fin deformities. A total of five fish had tumours, lumps or nodes on the body surface. Only two fish had missing or deformed barbells and two fish had deformed or shortened gill plates. In total, less than 1% of fish had deformities to body parts other than the fins; this anomaly rate likely represents background conditions (Kruse and Webb 2006).

In contrast to the above information, Golder (unpublished data) reported that 39% of adult sturgeon captured in 2002, 41% of adults captured in 2003 and 55% of adults captured in 2004 had some type of deformity or parasites. Barbel deformities were the most common type of deformity in 2002. Fin deformities were the most common type of deformity in 2003 and 2004. Differences in fin deformity rates between 2002 and 2003/2004 likely were due to a change in deformity classification methods.

Incidence of fin deformities has varied greatly in recent years. Recaptured hatchery-reared juveniles in 2002 had a high incidence of deformities (Golder 2002b, 2005b). Over 50% of recaptured juveniles in 2002 had pectoral fin deformities. During 2003 and 2004, 50.5% and 43.9% of recaptured juveniles had some type of fin deformity. However, incidence in 2005 and 2006 declined dramatically; the most recent data show an incidence of approximately 3% (L. Hildebrand, 2007, pers. comm.). Deformities appear to be more common in certain families of hatchery-reared sturgeon.

The causes of the pectoral fin deformities are unknown. Potential causes include infection, carry-over of PCOC concentrations in reproductive tissue, or hatchery stressors (e.g., stock density, low genetic diversity, water temperature, handling, transportation or potential contaminants in the hatchery) (Golder 2005b).

The mean daily growth rates of juvenile white sturgeon with pectoral fin deformities were similar to fish without deformities (Golder 2002b, 2005b). This suggests that at least during initial time at-large (i.e., the first two years), the deformities did not appear to have a substantial negative effect on successful feeding in the natural environment. Pectoral fin deformities may have a greater effect during later stages of the life cycle (e.g., when they switch to a more piscivorous diet). The long-term effects of these deformities are unknown.

Toxicity Tests

Early-life stage tests using white sturgeon from yolk-sac fry to free swimming phase showed that full-strength and half-strength effluents from the Teck Cominco smelter were toxic but 1% effluent was not toxic (Bruno 2004). For the full strength Teck Cominco maintenance-period effluent, the LT_{50} (Lethal Threshold for 50% mortality) was four days, while for the half-strength effluent, the LT_{50} was seven days. All sturgeon exposed to the 100% effluent were dead after five days of exposure while all sturgeon in the 50% effluent died within 17 days. Toxicity effects were not evident after exposure to any of the tested concentrations (100%, 1%) of the Zellstoff Celgar effluent. The LT_{50} for sturgeon mortality was not determinable because less than 50% of the fry died in any of the treatments.

Genomics Study

Early life-stage white sturgeon exposed to 100% and 50% maintenance-period effluents from the Teck Cominco smelter showed a marked increase in the transcription level of almost all of the ten genes examined (Edwards and Bruno 2004). These increases were interpreted as showing a shock response to the effluent (Edwards and Bruno 2004). The largest increases in gene expression for the sturgeon exposed to 100% effluent were for a gene linked to exposure to metals and organics, plus genes that code for cell growth and repair proteins. Genes associated with a general stress response and endocrine/receptor functions also were expressed at higher rates. The changes in gene expression indicate that the exposed fish were undergoing large metabolic change, consistent with the mortality rates observed in 100% smelter effluent.

Sturgeon exposed to 50% maintenance-period effluent from the Teck Cominco smelter showed a 2-fold drop in gene expression compared to controls (Edwards and Bruno 2004). The largest suppression occurred for genes that code for proteins essential for cell growth and repair. There were no reported effects of 1% maintenance-period effluent.

The Zellstoff Celgar 100% effluent produced increases in gene activity associated with organochlorine exposure, including dioxin (Edwards and Bruno 2004). The 1% effluent produced no effects. No other concentrations were tested.

The results showed that, in a laboratory setting, undiluted effluents from Teck Cominco and Zellsotff Celgar can affect the expression of some genes in white sturgeon. However, it is not known whether the increased gene expression would cause deleterious effects in whole fish, nor can the results be used to predict whether effects would be observed under environmentally relevant exposures in the Columbia River.

Magnitude of Response in Lines of Evidence for White Sturgeon

The largest magnitude of response in white sturgeon in the AOI is the low recruitment of wild juveniles into the population. The abundance estimate for the Canadian sub-population of white sturgeon found in the LCR-CAN reach was 1157 fish with 95% CI of 414-1900 (Irvine et al. 2007). This estimate is similar to previous studies which have estimated abundance in this reach to range between 980 and 1300 fish (Hildebrand et al. 1999). If the worst case scenario is projected (i.e., 414 fish with a mortality rate of 8.2% and mortality is considered age-independent) there will be less than 50 white sturgeon left in the LCR-CAN reach in 25 years. These estimates did not account for potential compensatory changes in growth and recruitment as the population changed. Recent information that indicates that recruitment of wild juveniles has been occurring since 1995 has changed the understanding of the potential magnitude of effects on the population. Rather than a “no recruitment” situation, there is now an understanding that some recruitment is taking place although it is unlikely that current levels of natural recruitment are sufficient to maintain the population (L. Hildebrand, pers. comm., 2009).

Another major response in white sturgeon in the AOI is the restricted use of habitat because of the presence of dams. Historic habitats are no longer available to the remnant population residing in the AOI. The population primarily uses four areas within the AOI; therefore, maintenance of favourable habitat conditions in these four habitats is vital. This includes favourable depth and flow conditions, temperature within the tolerance range (especially during pre-spawning, spawning and development of eggs), TGP within acceptable limits, availability of velocity refugia, fine substrates, and the availability of food suitable for all life stages.

It is clear that spawning continues to occur at the one remaining spawning area in the AOI (at the confluence with the Pend d’Oreille River); however, the number of females available to spawn in any given year is low. The remnant population may not contain sufficient genetic diversity to be sustainable, even with release of hatchery-reared juveniles, since the hatchery program depends upon broodstock from the same genetically-restricted pool of individuals.

Sample sizes for PCOC concentrations in white sturgeon are far less than required for adequate statistical power (Table 4.19). Important variables that may affect the uptake and effects from PCOC are not quantified. The high detection limit for silver precludes any attempt to compare silver concentrations in sturgeon with published effects benchmarks. Furthermore, effects thresholds in the literature are for teleost fish and may not be applicable to sturgeon. Therefore, data are not available to produce hypotheses regarding direct effects on sturgeon from the observed PCOC concentrations. Given the limited information and uncertainty, it is impossible to either confirm or invalidate Conceptual Model 1 for sturgeon.

In the initial years of the hatchery supplementation program, there was a high incidence of deformities (primarily fin deformities) in hatchery-reared juvenile sturgeon released into the AOI. These deformities were attributed to hatchery rearing/feeding conditions and, in subsequent years, modified fish culture techniques reduced the levels of deformities dramatically and present levels are low (L. Hildebrand, pers. comm., 2009). These deformities do not appear to have caused negative effects on the relative weight or growth of released fish, at least in the first few years in the river (Golder 2006e). The incidence of deformities in wild adult sturgeon in the AOI varies widely from study to study; this variation may have more to do with differences in deformity classification methods than a true variation in the population. The long-term effects of observed deformities on growth and survival are unknown. Responses of early life-stage sturgeon in laboratory toxicity tests to undiluted or 50% smelter effluent were of a high magnitude (100% mortality). However, there was no toxicity at 1% effluent, and environmentally relevant concentrations have not been tested. Furthermore, the tests were conducted on effluents obtained during a maintenance shut-down of the smelter. Therefore, it is very difficult to determine whether the responses observed in the toxicity tests are indicative of what could be expected during normal operation of the smelter and at environmentally relevant concentrations. Additional testing of effluent produced during normal operations and at environmentally realistic concentrations would reduce this uncertainty.

There was a distinct response in gene expression in early-life stage white sturgeon to exposure to undiluted and 50% smelter effluent, but no reported response to 1% effluent. The relevance of the observed response in gene expression to whole-organism or population-level responses under environmentally relevant concentrations is unknown. Environmentally relevant concentrations would be those that reflect the large dilution factor at the effluent discharge point (greater than 1000-fold).

Uncertainty in White Sturgeon Lines of Evidence

There is adequate information to support the current understanding of the status of the white sturgeon population in the AOI. There is an extensive database on white sturgeon distribution, habitat use and spawning in the AOI that has been assembled over more than 10 years of monitoring. Monitoring of the distribution, condition and growth of hatchery-reared juvenile sturgeon has contributed additional data.

Although the status of the population is reasonably well-understood, the causes of the low recruitment failure of wild juveniles are not. There are many candidate causes and these causes almost certainly interact. A series of recruitment failure hypothesis workshops were convened by B.C. Hydro from 2007 to 2008 to rank the various hypotheses and construct pathways to determine how the various proposed impacting mechanisms related to each hypothesis may lead to effects on recruitment (Gregory and Long 2008; L. Hildebrand pers. comm. 2009). A starting list of approximately 100 hypotheses was initially narrowed down to 10-12 and finally to 4 or 5 key hypotheses which will be the focus for further studies. Survival of early life stages from post-hatch to early juveniles (young-of-the-year) has been identified as the most likely bottleneck to recruitment success. Change in flow and flow volume and the effects these changes may have on early hiding and feeding habitats or on predation rates of these early life stages are leading hypothesis but will require further study.

The applicability of Conceptual Model 1 to white sturgeon is highly uncertain (Table 4.19). Direct effects of PCOC on white sturgeon cannot be evaluated from the available information because the information on PCOC concentrations in sturgeon tissue and data on effects thresholds are extremely limited and well below requirements for statistical power (Table 4.19). Slag is scoured from the spawning beds by flushing flows from the Pend d'Oreille River; therefore, direct physical effects of slag on developing eggs are unlikely. Experimental data that test the hypothesis of direct effects were obtained using concentrations that were not environmentally relevant (Table 4.19). There is no consistent relationship between recruitment and PCOC concentrations. Recruitment occurred during earlier periods of smelter operation in the first half of the 20th century where PCOC concentrations were much higher. However, information collected in 2007 by the Washington Department of Fish and Wildlife indicated that recruitment greatly declined in the 1970s and 1980s and then recovered somewhat in the 1990s, coincidental with the decline in PCOC concentrations following installation of the Kivcet smelter, reduction of TGP and Zellstoff modernization (L. Hildebrand pers. comm.).

The applicability of Conceptual Model 2 to white sturgeon is also highly uncertain. There is little supporting evidence for indirect effects on sturgeon via PCOC effects on food items or via competitive or predator-prey interactions. Juvenile white sturgeon grow rapidly in the AOI, largely because they have a ready food supply in the form of mysids introduced to the system to enhance kokanee production. Physical (via slag) or chemical effects on alternative food items (such as tube-dwelling amphipods) may be important for larger juveniles that are switching from mysids to larger prey; however, this is unknown. The major problem for the white sturgeon population in the AOI appears to be survival of young. There are no apparent indirect links between smelter emissions and survival of young; however, the lack of data produces a high uncertainty with respect to the role that PCOC may play in combination with other stressors. In other words, there are insufficient data that test hypotheses regarding multiple stressor effects (Table 4.19).

4.6.6 Step 5: Assessment of Causation for White Sturgeon

Evaluation of a cause/effect link with the smelter for white sturgeon responses in the AOI was performed for the lines of evidence assembled from the literature (Table 4.43).

Distribution and Habitat Use

- *Spatial and Temporal Correlation*: Data on white sturgeon distribution and habitat use do not support the assumption of a spatial or temporal correlation between distribution and habitat use and PCOC concentrations or slag content; therefore, both of these criteria received a score of "---" corresponding with "incompatible". There is no evidence of avoidance of the areas with elevated PCOC by sturgeon; in fact, quite the opposite appears to be the case. Some of the highest numbers of sturgeon are found in Waneta, the location with the highest slag content and some of the highest concentrations of PCOC in the sediment. Sturgeon also congregate at Fort Sheppard, which also has substantial slag content (although there is a wide range) and elevated concentrations of several PCOC in sediment. However, the possibility that mortality may be higher in white sturgeon congregating at these sites cannot be dismissed. After hatch, larval sturgeon enter a drift and hiding phase. Sometimes they hide first and sometimes they drift first (L. Hildebrand, 2007, pers. comm.). The only linkage with PCOC may be if the early life-stage habitats have elevated PCOC concentrations, leading to uptake via food or water; however, this linkage is doubtful because PCOC concentrations were much higher historically (the first half of the 20th Century) when recruitment continued to occur. The primary causes of white sturgeon distribution are the sturgeon's preference for deeper water, lower current velocity and substrates that are made up at least partially of sand. Sturgeon are now known to spawn at Northport (just downstream of the U.S. border) as well as at the confluence with the Pend d'Oreille River (L. Hildebrand, 2007, pers. comm.). These spawning locations provide high flows for long periods of time with high turbidity. These areas are not prone to deposition of slag because they are high velocity areas.

Table 4.43 Causation Scores for White Sturgeon Lines of Evidence for Direct Effects: A = Physical Habitat Effects; B = Effects of PCOC

Causal Criterion	Line of Evidence										
	Distribution and Habitat Use		Population Dynamics, Size and Age Distribution, Recruitment		Spawning Activity		Contaminant Concentration vs. Effects Benchmarks	Incidence of External Anomalies		Toxicity of Effluent	Effects on Gene Expression
	A	B	A	B	A	B		A	B		
Spatial Correlation	---	---	0	0	---	---	+	0	0	0	0
Temporal Correlation	---	---	0	0	---	---	0	0	0	n/a	n/a
Biological Gradient/Strength	-	-	-	-	-	-	-	-	-	+	+
Plausibility: Mechanism	+	+	+	+	+	+	+	+	+	+	++
Plausibility: Stressor-Response	---	---	0	0	---	---	0	0	0	0	0
Consistency of Association	-	-	-	-	-	-	-	-	-	n/a	n/a
Experimental Verification	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	0	0
Specificity of Cause	0	0	0	0	0	0	++	0	0	+++	+++
OVERALL STRENGTH OF EVIDENCE	○	○	○	○	○	○	○	○	○	⦿	⦿

Notes: see Table 4.15 for key to individual causation scores.

● strong overall strength of causal evidence.

⦿ moderate overall strength of causal evidence.

○ weak overall strength of causal evidence.

n/a = not available.

- *Biological Gradient/Strength:* There is no evidence of a gradient in response to PCOC concentrations with respect to white sturgeon distribution and habitat use; therefore, a score of "-" was applied to this criterion. Although it is plausible that elevated PCOC concentrations could affect distribution, e.g., through avoidance behaviour, the distribution of sturgeon is inconcordant with a stressor-response pattern in the AOI.
- *Plausibility: Mechanism:* There are plausible mechanisms for both direct and indirect effects of PCOC and slag on distribution and habitat use. For example, direct toxicity of PCOC could lead to failure of spawning at sites with elevated PCOC concentrations. The physical effects of slag on habitat quality could lead to reduced food supply and thus fewer sturgeon using areas with high slag deposition. Therefore, this criterion was given a score of "+", corresponding with "plausible."*Plausibility: Stressor/Response:* This criterion received a score of "---", corresponding with "inconcordant" for the same reasons as presented above for spatial correlation.
- *Consistency of Association*: There were many exceptions to any indication of an association between distribution and habitat use and PCOC concentrations or slag; therefore a score of "-" was assigned to this criterion.
- *Experimental Verification*: This criterion is not applicable.
- *Specificity*: The score for specificity was "0" because there are several potential causes of the observed distribution of sturgeon within the AOI.

Population Dynamics: Size and Age Distribution, Recruitment

- *Spatial Correlation*: There is an uncertain spatial correlation between PCOC concentrations, slag content and age/size distribution and recruitment; therefore, a score of "0" was applied to this criterion. The PCOC and/or slag content in sediments may be reducing the variety and abundance of food for larval sturgeon as they drift downstream; however, draw-down due to dam operation is a major factor. The area where it is estimated that larval sturgeon settle to feed after absorbing the yolk sac is de-watered every year. This would require the larvae to extend their search for food, thus exposing them to more predation (L. Hildebrand, 2007, pers. comm.). Food for juvenile sturgeon is primarily mysids in the northern portion of the AOI, but shifts to a greater variety farther downstream, including amphipods and chironomids (L. Hildebrand, pers. comm.). The slag deposition areas (Fort Sheppard and Waneta Eddies) are not the primary food-producing areas in the AOI. Therefore, while slag and PCOC may be affecting the abundance and diversity of food organisms in these areas, these effects would not be expected to reduce substantially the overall food supply for juvenile sturgeon in the AOI.
- *Temporal Correlation*: There is an uncertain temporal correlation between age/size distribution, recruitment and PCOC concentrations and/or slag content; therefore, a score of "0" was applied to this criterion. Recruitment occurred during the earlier period of smelter operations in the first half of the 20th century, when PCOC concentrations and slag content were at their highest. However, recent information appears to indicate that recruitment greatly declined in the 1970s and 1980s, recovering somewhat in the 1990s after the installation of the Kivcet smelter and other centred measures. The possibility of a temporal correlation cannot be dismissed, but the evidence is not consistent.
- *Biological Gradient/Strength:* There is no evidence of a gradient in response to PCOC concentrations or slag content with respect to white sturgeon age/size distribution or recruitment; therefore, a score of "-" was

applied to this criterion. Although it is plausible that elevated PCOC concentrations or slag could affect recruitment, e.g., via increased mortality of larval sturgeon, declines in recruitment do not appear to be in accordance with exposure because the greatest responses do not coincide with the highest concentrations (as explained above for temporal correlation).

- *Plausibility: Mechanism:* There are plausible mechanisms for both direct and indirect effects of PCOC and slag on age/size distribution and recruitment. For example, direct toxicity of PCOC could lead to increased mortality of larval sturgeon. The physical effects of slag on habitat quality could lead to reduced food supply and thus a requirement for larval sturgeon to feed in a wider area, exposing them to more risk of predation. Therefore, this criterion was given a score of "+", corresponding with "plausible."
- *Plausibility: Stressor/Response:* This criterion received a score of "0", corresponding with "ambiguous" for the same reasons as presented above for biological gradient and spatial/temporal correlation.
- *Consistency of Association*: There were many exceptions to any indication of an association; therefore, a score of "-" was assigned to this criterion.
- *Experimental Verification*: This criterion is not applicable.
- *Specificity*: The score for specificity was "0" because there are several potential causes of the observed size/age distributions and recruitment.

Spawning Activity

- *Spatial and Temporal Correlation*: There is no apparent spatial or temporal correlation between PCOC concentrations, slag content and spawning activity; therefore, a score of "---" was applied to these criteria. White sturgeon spawning activity occurs every year at the confluence with the Pend d'Oreille River in habitats that are not affected by slag. Exposure to PCOC may be one of the stressors affecting sexual maturation and development of gametes; however, there are no data to support or refute this hypothesis. Spawning has no temporal correlation with the smelter; spawning has continued to occur throughout the life of the smelter with no indication of temporal trends in response to reductions in PCOC concentrations after commissioning of the Kivcet smelter in 1997. The drivers for spawning location are current velocity, turbidity and coarse substrate with interstitial spaces to provide protection of developing eggs and early post-hatch larvae. The most direct, and strongest, linkage with spawning is with flow regulation. Flow regulation has reduced peak flows more than 50% during the spawning period. Flow is a primary determinant of spawning habitat location, as well as turbidity. Turbidity provides cover from visual predators such as walleye. There may be a cumulative effect of flow regulation and the presence of slag. Flow regulation has reduced the spring freshet which, in turn, has reduced the scouring of substrates. The presence of slag can compound this effect via armouring and increased embeddedness of the substrate (the slag fills interstices). This would reduce the suitability of an area for egg incubation and hatching. However, as documented above, the two spawning areas at the confluence of the Pend d'Oreille and at Northport are located in areas with sufficiently high flows that slag deposition does not occur. There may be slag deposition in adjacent habitats (e.g., upstream of the spawning area at the Pend d'Oreille within the Waneta Eddy). However, the actual spawning and incubation habitats are highly unlikely to be affected by the compounding effect of flow regulation and slag deposition.

- *Biological Gradient/Strength:* There is no evidence of a gradient in spawning activity in response to PCOC concentrations because spawning only occurs at Waneta; therefore, a score of "-" was applied to this criterion. Although it is plausible that elevated PCOC concentrations or slag could affect spawning, declines in spawning areas are not in accordance with exposure to PCOC, but rather to changes in flow and flow pattern.
- *Plausibility: Mechanism:* There are plausible mechanisms for both direct and indirect effects of PCOC and slag on spawning. For example, direct toxicity of PCOC could lead to increased mortality of eggs. There is a plausible mechanism for effects of slag on spawning habitat because slag would tend to fill the interstitial spaces, smothering or damaging eggs. However, slag does not occur at the spawning bed in the AOI because of the scouring action of flushing flows from the Pend d'Oreille River in the shallower water along the shoreline. Therefore, this criterion was given a score of "+", corresponding with "plausible."
- *Plausibility: Stressor/Response:* This criterion received a score of "---", corresponding with "inconcordant". This score was based upon the fact that the actual spawning beds are not in areas where slag is deposited, nor where PCOC concentrations in substrate or in the water column are elevated. Furthermore, historic information indicates that spawning occurred during periods of much higher PCOC concentrations in the water column.
- *Consistency of Association*: There was no indication of a consistent association; therefore, a score of "-" was assigned to this criterion.
- *Experimental Verification*: This criterion is not applicable.
- *Specificity*: The score for specificity was "0" because there are several potential causes of the observed pattern of spawning.

Contaminant Concentration vs. Effects Benchmarks

Data on PCOC concentrations in sturgeon tissue are extremely limited and information on effects thresholds in sturgeon are almost non-existent; therefore, it is very difficult to determine the likelihood of a cause/effect link between PCOC body burdens and effects on growth or survival. Therefore, all causation criteria have received scores that correspond with "uncertain", "ambiguous", or "many exceptions to the association", with the exception of plausibility: mechanism, which received a "+" score. There are plausible mechanisms for at least some of the PCOC detected in white sturgeon tissue and effects on either physiological or whole-organism responses. White sturgeon from the AOI have elevated concentrations of cadmium, chromium and zinc relative to sturgeon captured in other locations in other studies; however, PCOC concentrations in eggs are lower than those found in Kootenay River white sturgeon. A family of juvenile white sturgeon with elevated copper, lead and nickel concentrations relative to other families had the lowest incidence of deformities. Cadmium, chromium, copper, silver and zinc concentrations exceeded effects thresholds; however, these thresholds are for teleost fish and are of uncertain applicability to sturgeon. The smelter is one potential source of elevated PCOC concentrations in white sturgeon. The effects of multiple stressors on white sturgeon, including PCOC in white sturgeon tissue, cumulatively may be producing the low recruitment in the population. On balance, a causal link between PCOC concentrations and effects in white sturgeon in the AOI cannot be dismissed because of the potential for cumulative effects of all stressors. However, it is highly unlikely that PCOC are playing a dominant role.

Incidence of External Anomalies

There is an uncertain spatial and temporal correlation between external anomalies in adult and juvenile sturgeon and exposure to PCOC or slag; therefore, these criteria received a score of "0" for uncertain. The primary deformity of interest is fin deformity because fish with deformities to body parts other than fins occurred at a rate likely to represent background conditions. Differences in fin deformity rates in adult sturgeon between study years likely were due to a change in deformity classification methods, rather than to exposure to PCOC or slag. There is no indication of a gradient in response to PCOC concentrations in water, sediment, or tissue and no indication of a gradient in response to exposure to slag depositional areas; therefore, this criterion was assigned a score of "-," corresponding with "none." There are plausible mechanisms for PCOC or slag causing external anomalies, e.g., direct physical injury caused by slag. However, the plausible stressor-response criterion was assigned a score of "0" for "ambiguous" since there were insufficient data to evaluate whether fish with higher PCOC concentrations in their tissues had a higher incidence of fin deformities. There were many exceptions to association between incidence of fin deformities and exposure to PCOC or slag; therefore, this criterion was given a score of "-". The causes of the pectoral fin deformities are unknown. Potential causes include infection, carry-over of PCOC concentrations in reproductive tissue, or hatchery stressors (e.g., stock density, low genetic diversity, water temperature, handling, transportation or potential contaminants in the hatchery). Therefore, this criterion was given a score of "0."

Toxicity of Effluent

Full and half-strength effluent from the Teck Cominco smelter (during a maintenance period) was clearly toxic to early-life stage white sturgeon, but 1% effluent was not toxic. Therefore, a score of "0" was assigned for spatial correlation. Since no tests were conducted at environmentally relevant concentrations, the applicability of this line of evidence to white sturgeon growth and survival in the AOI is highly uncertain and the biological gradient criterion was given a score of "+" for "weak" due to the lack of information on concentrations below 1%. The score for plausible stressor-response was "0" for ambiguous, also because of the lack on information on lower concentrations. There were no repeated tests; therefore, the consistency criterion could not be scored. The criterion for experimental verification was assigned a score of "0," again because of the lack of information on lower concentrations. The specificity criterion was assigned a score of "+++" because toxicity tests are designed to test a specific "cause", in this case full-strength or half-strength and 1% effluent.

The toxicity test line of evidence was given a moderate overall score for causality; however, this score was driven by the clear and strong response in the test at higher effluent concentrations and the plausible mechanisms linking PCOC in the effluent with the observed response.

Effects on Gene Expression

Effects on gene expression received a "0" score for spatial correlation because of the changes in gene expression after exposure to full and half-strength Teck Cominco effluent, but the lack of response at 1% effluent. The data on gene expression are of highly uncertain applicability to wild fish in the AOI that are exposed to much lower effluent concentrations. Therefore, scores for biological gradient, plausible stressor-response and experimental verification are the same as those applied to the toxicity test line of evidence. The plausible mechanism criterion received a "++" score for gene expression since the test, by definition, targets the genetically-based mechanism for effects at higher levels of organism function such as metabolism. The specificity criterion was assigned a score of "+++" because, like toxicity tests, the gene expression test was designed to test a specific "cause," in this case, full-strength or half-strength effluent.

Summary of Causation Assessment

The strength of the evidence for a cause/effect link between PCOC and slag produced by the smelter and white sturgeon lines of evidence in the AOI is weak. Therefore, Conceptual Model 1 has very limited application to white sturgeon in the AOI.

Evidence for indirect effects on white sturgeon (Conceptual Model 2) via changes in food organisms, competition or predator-prey interactions caused by the smelter is also weak. The only potential link may be the effect of slag on the composition of the benthic invertebrate community; slag may affect the abundance of a preferred food item (i.e., tube-dwelling amphipods). However, juvenile white sturgeon have been shown to be growing rapidly in the AOI. Adult sturgeon exist in a nutrient-limited system and no longer have access to salmon as a prey item. Neither of these factors is related to the smelter. There is no evidence that the smelter is affecting other fish species; therefore, the likelihood of indirect effects via changes in competition or predator-prey interaction is negligible.

Evidence for multiple stressor/cumulative effects on white sturgeon where PCOC form part of the cause of observed responses is non-existent; therefore, the applicability of Conceptual Model 2 regarding multiple stressor effects is highly uncertain. Dam operations appear to have had a strong influence on the physical habitat for all life stages of sturgeon. Effects of dams include: altered temperature regime; reduced spawning habitat; reduced nutrients downstream of reservoirs; reduced turbidity (and thus increased predation by visual predators on eggs and early life stages); and substantial changes in fish species assemblages and relative abundance caused by reservoir formation and increased water clarity resulting in a shift to visual feeding (WSRI 2002). The deliberate introduction of walleye and bass into the system also increased the abundance of predators that could potentially feed on early life stages of white sturgeon (WSRI 2002).

4.6.7 Step 6: Risk Characterization for White Sturgeon

The risk management objective for white sturgeon was:

> "Prevent, now and in the future, smelter operation-related direct and indirect effects on threatened and endangered aquatic species in the AOI."

The assessment endpoints for this risk management objective were:

- presence, survival and reproductive success of white sturgeon in the AOI; and
- habitat quality for white sturgeon in the AOI.

Conceptual Models 1 and 2

Conceptual models 1 and 2 are discussed together for white sturgeon, since available lines of evidence address both direct and indirect effects.

Lines of evidence obtained from the literature indicate that several measures of white sturgeon population performance and fish health show moderate or high magnitude responses. However, the causation analysis showed weak and/or highly uncertain linkages between these responses and the Teck Cominco smelter. Uncertainty was low regarding the magnitude of response of many of the measures but high with respect to causation.

Indirect effects on white sturgeon are most likely with respect to the introduction of non-native species such as walleye into the AOI. These visual predators may be a key factor in the lack of recruitment of young into the white sturgeon population, since a combination of increased water clarity caused by dam operation and the presence of an additional visual predator species is likely to have increased predation pressure on white sturgeon larvae, fry and juveniles.

Indirect effects on white sturgeon caused by the Teck Cominco smelter are unlikely, with the possible exception of a reduction in food supply in feeding areas due to the presence of slag or PCOC in sediments. However, juvenile white sturgeon using the Waneta and Fort Sheppard areas grow rapidly, indicating that the food source is sufficient. Available data show that mysids are the primary food of juvenile sturgeon in the upper portion of the AOI; if this food source declined, then the effects of slag and PCOC on benthic invertebrate abundance at Waneta may become important.

Given the current difficulties with maintenance of the white sturgeon population, risk management obviously needs to continue. Continued involvement of Teck Cominco in the White Sturgeon Recovery Initiative research program is recommended, in order that uncertainties regarding the relative risks from PCOC and slag deposits can be defined with more confidence.

5.0 CONCLUSIONS REGARDING THE NEED TO CONSIDER RISK MANAGEMENT

The SALE analysis indicated that the risk management objectives are being met for mountain whitefish and prickly sculpin. Therefore, an evaluation of risk management options is not required for these receptors. However, because there was no sampling reach for prickly sculpin that directly overlapped the Maglios benthic invertebrate site and because there may be direct or indirect effects on prickly sculpin at this site, further fish health work focussing on the Maglios site may be warranted. This would be true only if benthic invertebrate impacts are confirmed and are shown to be causally related to the smelter, and if the zone of smelter-related impact is large enough to encompass the home range of a sub-population of prickly sculpin. There is no compelling argument for further monitoring or evaluation of large-bodied fish species in the AOI relative to direct risks from smelter-related stressors.

The SALE analysis indicated that the risk management objectives were not being met for periphyton in the near-field (New Bridge site) and the benthic invertebrate community at the Maglios and Waneta sites. Therefore, evaluation of risk management options is required for these sites. There are non smelter-related stressors in the vicinity of the New Bridge and Maglios sites. Additional data would help increase the understanding of the role of the non-smelter stressors. The role of slag in the sediment as a physical stressor versus the role of PCOC as chemical stressors may also require clarification at both sites in order to refine risk management options. The additional data could be obtained both from laboratory tests and field investigations. The temporal framework would be better understood with a quantitative evaluation of sediment transport and deposition mechanisms in the AOI; this evaluation would assist in the prediction of the length of time for the current slag deposits to be further transported and/or buried with natural sediment materials.

Follow-up work at Maglios may include fish health work if benthic invertebrate impacts are confirmed and are shown to be causally related to the smelter, and if the zone of smelter-related impact is large enough to encompass the home range of a sub-population of prickly sculpin. The fish health work (if any) should be on prickly sculpin (if they occur in the area) because the site is so small that exposure to wide-ranging large-bodied species would be insignificant.

The risk management objective for white sturgeon is not being met; however, the causal link to the Teck Cominco smelter is weak. The current status of the white sturgeon in the AOI is likely due to cumulative effects from multiple stressors. The relative role of PCOC and slag deposition appears to be minor; however, there is uncertainty regarding this conclusion because of limited data. Continuing participation by Teck Cominco in the White Sturgeon Recovery Initiative appears to be the appropriate response to the current understanding of the situation.

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7.0 ACRONYMS, ABBREVIATIONS AND UNITS

AE	Assessment endpoint
AFDW	Ash-free dry weight
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
AOI	Area of Interest
ARC	Alberta Research Council
B.C. LEL	British Columbia lower effect level
B.C. MELP	British Columbia Ministry of Environment, Land and Parks (re-named to BCMOE)
B.C. MOE	British Columbia Ministry of Environment
B.C. MWLAP	British Columbia Ministry of Water, Land and Air Protection (re-named to BCMOE)
CCME	Canadian Council of Ministers of the Environment
CEV	Chronic effect value
CPUE	Catch per unit effort
CRIEMP	Columbia River Integrated Environmental Monitoring Program
CSR	Contaminated Sites Regulation
°C	Degrees Celsius
cells/cm^2	Cells per square centimetre
cm^2	Square centimetre
d.f.	Degrees of freedom
d/s	Downstream
DFO	Department of Fisheries and Oceans Canada
DL	Detection limit
DO	Dissolved oxygen
EC	Electrical conductivity
EEM	Environmental effects monitoring
ERA	Ecological risk assessment
ERL	Effects range low
ERM	Effects range medium
ES_c	Critical effect size
GPS	Global positioning system
GSI	Gonad Somatic Index

HAI	Health Assessment Index
HCl	Hydrochloric acid
HSD	Honestly significant difference
IC_{25}	Inhibiting concentration causing an effect to 25% of the population
ISQG	Interim Sediment Quality Guideline
km	Kilometre
LOE	Lines of Evidence
LOEC	Lowest observable effect concentration
LSI	Liver Somatic Index
LT_{50}	Lethal threshold for 50% mortality in a population
m	Metre
m/s	Metres per second
m^2	Square metre
m^3/s	Cubic metres per second
MDL	Method detection limit
mg/L	Milligrams per litre
mg/m^2	Milligrams per square metre
mm	Millimetre
MMER	Metal Mining Effluent Regulations
MRV	Minimum reportable value
n, no.	Number in a sample
$no./m^2$	Number of organisms per square metre
NA	Not analyzed
NAD	North American datum
NMDS	Nonmetric multidimensional scaling
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observable effect concentration
ORNL	Oak Ridge National Laboratory
p	Probability
PAC	Public Advisory Committee
PCB	Polychlorinated biphenyl
PBDE	Polybrominated diphenyl ether
PCA	Principal components analysis
PCOC	Potential chemicals of concern

PEL	Probable Effects Level
PI	Pathology Index
QA/QC	Quality assurance and quality control
QC	Quality control
SALE	Sequential assessment of lines of evidence
SARA	Species at Risk Act
SD	Standard deviation
SE	Standard error
$SedQC_{scs}$	Sediment quality criterion for sensitive contaminated sites
$SedQC_{tcs}$	Sediment quality criterion for typical contaminated sites
SQT	Sediment Quality Triad
TAC	Technical Advisory Committee
TDS	Total dissolved solids
Teck Cominco	Teck Cominco Metals Ltd. [now Teck Metals Ltd.]
TGP	Total gas pressure
TP	Technical Procedure
TRV	Toxicity Reference Value
UCWSRI	Upper Columbia River White Sturgeon Recovery Initiative
U/S	Upstream
U.S. EPA	United States Environmental Protection Agency
UTM	Universal transverse Mercator
VEC	Valued Ecosystem Component
WOE	Weight of Evidence
WSRI	White Sturgeon Recovery Initiative
WSFAP	White Sturgeon Flow Augmentation Program
µg/g	Micrograms per gram
µg/L	Micrograms per litre
$µg/cm^2$	Micrograms per square centimetre
µS/cm	MicroSiemens per centimetre

8.0 GLOSSARY

Adverse Effect	A harmful result on the environment or health from specified actions.
Agricultural Land	The use of land for the primary purpose of producing agricultural products for human or animal consumption including, without limitation, livestock raising operations, croplands, orchards, pastures, greenhouses, plant nurseries and farms.
Alluvial	Of or relating to alluvium.
Alluvium	A deposit of fine fertile soil left during a time of flood, e.g., in a river valley or delta.
Antagonistic	Opposing or neutralizing or mitigating an effect by contrary action.
Anthropogenic	Man-made or related to human activities.
Area of Interest	The particular study area being examined within the ERA context. An area of the Columbia River and its tributaries from the Hugh Keenleyside Dam immediately upstream of Castlegar to the U.S. border (56 km).
Assessment Endpoint	What is to be evaluated and protected through the use of ecological risk assessment. It is defined by an ecological entity and a characteristic (e.g., abundance).
Attribute	The characteristic of the entity of concern that is important to protect and which is potentially at risk (e.g., flow velocity at a spawning ground).
B-IBI Scores	Benthic Index of Biotic Integrity scores. The five metric B-IBI uses benthic invertebrate community attributes to assess the biological integrity of a stream ecosystem and provides a general assessment of the stream health in the study area.
Bioaccumulation	The accumulation of a substance in a living organism as a result of its intake both in the food and also from the environment.
Bioavailability	The amount of chemical that enters the general circulation of the body following administration or exposure.
Biomass	The total quantity or weight of organisms in a given area or of a given species.
Biota	The animal and plant life of a region.
Catchment Area	The area from which rainfall flows into a river or other water body.
Causal Relationship/ Causation	A relationship that may produce an effect from a particular cause.
Chronic	Occurring during a relatively long period of exposure, usually a significant portion of the life span of the organism such as 10% or more.
Conceptual Model	A model in which the relationships and pathways between stressors (and the sources of the stressors) and receptors is shown.
Concordance	Agreement with.
Condition Factor	Reflects the nutritional state or "well-being" of an individual fish and is sometimes interpreted as an index of growth rate.
Confounding Factors	Elements that contribute to the overall effect, but are not the direct consequence.

Control	A treatment in an investigation or study that duplicates all the conditions and factors that might affect the results of the investigation, except the specific condition being studied.
Critical Effect Size	A predetermined difference between the reference area and an area exposed to a stressor; the critical effect size corresponds to what would be considered an effect of sufficient magnitude to be of ecological, economic, or social significance.
Direct Effects	Impacts caused by the direct toxic action of stressors including chemicals.
Diversity	The variety, distribution and abundance of different plant and animal communities and species within an area.
Ecological Entity	A general term referring to a species, population, community, ecosystem, valued habitat, etc.
Ecosystem	An integrated and stable association of living and non-living resources functioning within a defined physical location. A community of organisms and their environment functioning as an ecological unit.
Effects Benchmarks	Values derived through toxicological studies and literature searches that represent concentrations (of chemicals or other stressors) at which an effect is observed on a population.
Effluent	Waste discharged into a body of water.
Evapotranspiration	The sum of water vapour fluxes from transpiration of leaves and evaporation from soils and wet leaves.
Fecundity	The potential reproductive capacity of an organism or population, measured by the number of gametes.
Freshet	The occurrence of a water flow resulting from sudden rain or melting snow.
Gamete	A mature haploid reproductive cell (male or female) which unites with another of the opposite sex in sexual reproduction to form a zygote.
Genomics	The study of an organism's entire genome.
Geogenic Source	Originating from soil.
Habitat	The place or environment where a plant or animal naturally or normally lives.
Histopathology	Changes in tissue caused by disease.
Hydrology	The science of the properties of the Earth's water, especially of its movement in relation to land.
Indirect Effects	Effects that occur indirectly, for instance loss of prey due to chemicals will affect predators that are not directly affected by those chemicals.
Intermittent	Occurring at intervals; not continuous or steady.
Interstice	A chink or crevice.
Loading	The amount of a stressor added to the portion of an aquatic system being studied.
Macrophyte	Any plant, especially an aquatic plant, large enough to be discerned by the naked eye.
Mainstem	Main river.

Management Goal	A general statement about the desired condition (or direction of preference) of ecological values of concern.
Management Objective	Specific statement about the desired condition (or direction of preference) of ecological values of concern.
Measure	Measurements used to evaluate the assessment endpoint. Includes Measures of Exposure, Measures of Effect and Measures of Ecosystem and Receptor Characteristics.
Measure of Ecosystem and Receptor Characteristics	A measure that influences the behaviour and location of ecological entities of the assessment endpoint, the distribution of a chemical (or other stressor), and life-history characteristics of the assessment endpoint or its surrogate that may affect exposure or response to the stressor.
Measure of Effect	A measure that describes a change in a characteristic of an assessment endpoint or its surrogate.
Measure of Exposure	A measure of chemical (or other stressor) presence and movement in the environment and its contact with the assessment endpoint.
Mesocosm	A large aquatic enclosure for testing the effects of stressors on communities of aquatic organisms.
Mesotrophic	A term applied to clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients.
Metapopulation	A set of partially isolated populations belonging to the same species.
Minimize	To reduce ecological risks from smelter operations to levels that will protect wildlife and aquatic populations.
Monotonic	Of a sequence or function; consistently increasing and never decreasing, or consistently decreasing and never increasing in value.
Multivariate Analysis	In statistics, describes a collection of procedures which involve observation and analysis of more than one statistical variable at a time.
Non-Point Source	A contaminant source that does not have a single origin.
Oligotrophic	A term applied to clear water lakes and ponds that are relatively poor in nutrients.
Outlier	A data point that falls outside of the statistical distribution defined by the mean and standard deviation.
Parameter	Distinguishing or defining characteristic or feature, especially one that may be measured or quantified.
Pelagic	The upper layers of a water body.
Piscivorous	Feeding on fishes.
Plume	Material spreading from a particular source and travelling through environmental media, such as air or ground water. For example, a plume could describe the dispersal of particles, gases, vapors and aerosols in the atmosphere.
Point Source	A contaminant from a fixed source.
Population Persistence	The population is stable or growing with sufficient birth rates and immigration to maintain a wildlife species population.

Potential Chemicals of Concern (PCOC)	Chemicals identified at the screening stage of the ecological risk assessment that may negatively affect the chosen ecological receptors.
Problem Formulation	The initial step in a risk assessment that focuses the assessment on the chemicals, receptors and exposure pathways of greatest concern.
Receptor	The organism subjected to exposure to chemicals or physical agents.
Red Listed	Endangered species and ecosystems as defined by the Province of British Columbia. Includes any indigenous species, subspecies or plant community that is Extirpated, Endangered, or Threatened in British Columbia. Often used in legislation to refer to certain designated species, which are the subject of prohibitions and regulations under the Species at Risk Act.
Residual Ecological Risk	Ecological risk remaining after natural recovery processes have taken place or after human intervention, such as remediation and re-vegetation.
Rip Rap	Rock or other material used to stabilize a shoreline.
Spatial	Of or concerning space (spatial extent).
Statistical Power	The ability to distinguish a particular level of effect from natural background variability.
Stressor	Something that causes stress; may be biological or chemical in nature.
Surrogate	An ecological entity that is evaluated because it is representative of an assessment endpoint entity that is difficult to evaluate directly.
Synergistic	Increased effectiveness or achievement produced by combined action or co-operation.
Taxa	A taxon (plural taxa), or taxonomic unit, is a grouping of organisms (named or unnamed). Once named, a taxon will usually have a rank and can be placed at a particular level in a hierarchy (kingdom; phylum (animals or plants) or division (plants); class; order; family; genus; species; subspecies).
Temporal	Of or relating to time.
Thalweg	The line defining the lowest points along the lengthy of a riverbed or valley.
Tributary	A creek or small river that drains into a main river.
Trophic Cascade	Effects mediated through interactions between consumer organisms and their food.
Trophic Level	The feeding position of an organism in the food chain.
Uncertainty	Imperfect knowledge concerning the present or future state of the system under consideration; a component of risk resulting from imperfect knowledge of the degree of hazard or of its spatial and temporal distribution.
Urban Land	Areas within municipalities, including residential, commercial-industrial, institutional areas, and urban parks and playgrounds.
Velocity	The measure of the rate of movement in a given direction.
Wildland	Naturally forested lands that in general have not been physically disturbed by human activities.

9.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned. Note that, in addition to a final review by Dr. Peter M Chapman, earlier versions of this report were reviewed by Dr. Larry Kapustka, presently with LK Consultancy.

SWANSON ENVIRONMENTAL STRATEGIES LTD.

GOLDER ASSOCIATES LTD.

Report prepared by:

Stella M. Swanson, Ph.D, P.Biol.
President, Swanson Environmental Strategies

Report reviewed by:

Peter M. Chapman, Ph.D. R.P. Bio.
Principal, Senior Environmental Scientist

Zsolt Kovats, M.Sc.
Associate, Aquatic Ecologist

SS/PC/ZK/kl

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ADDENDUM TO FINAL REPORT ON SEQUENTIAL ANALYSIS OF LINES OF EVIDENCE (SALE)

The following additional information is provided to Section 4.6.5, “Steps 3 and 4: Assessment of Magnitude and Uncertainty of Field and Laboratory Data of White Sturgeon”:

Recent information regarding the toxicity of cadmium, copper and zinc to early life-stage white sturgeon has provided another line of evidence regarding the potential risk to the white sturgeon population from PCOC exposure. Vardy et al. (2010) found that the early juvenile life-stage (40 days post-hatch) of white sturgeon is more sensitive to copper compared to earlier and later life stages, and that the early life-stages of white sturgeon have comparable sensitivity to copper, cadmium and zinc as relatively sensitive salmonid species, such as Chinook salmon.

Concentrations of cadmium, copper and zinc in water at the New Bridge site in 1995 were slightly greater than the Vardy et al. (2010) thresholds for cadmium, copper and zinc (Table 1). Cadmium concentration at the New Bridge site was slightly greater than the effects threshold in 2003. Concentrations have been below the Vardy et al. (2010) thresholds since 2003 at all sampling stations in the AOI, including the New Bridge site. Concentrations at Waneta (which is one of the four remaining habitats for white sturgeon in the AOI) have been at least an order of magnitude below the Vardy et al. (2010) effects thresholds during the entire period of record for this assessment.

Table 1 Comparison of Cadmium, Copper and Zinc Concentrations in the AOI from 1995-2006 with Effects Thresholds for Juvenile White Sturgeon

Metal	LC50 (µg/L)	LC20 (µg/L)	Concentration in Water 1995-2006 (µg/L)		
			New Bridge	Old Bridge	Waneta
Cadmium	-	1.2	0.04 - 2.5	0.05 - 0.4	0.02 - 0.05
Copper	8	6.3	0.5 - 20	0.3 - 2.4	0.4 - 1.1
Zinc	-	107	1.5 - 130	1.2 - 5.7	1.2 - 5.7

Note: Effect thresholds shown are from Vardy et al. (2010).

This information does not change the conclusions of the SALE report regarding the strength of evidence (i.e., weak) for a cause/effect link between PCOC and slag produced by the smelter, and white sturgeon lines of evidence in the AOI.

Reference:

Vardy, D.W., A. Tompsett, J. Oellers, J. Doering, M. Allen, J.P. Giesy and M. Hecker. 2010. Development of toxicity reference values for white sturgeon (*Acipenser transmontanus*) in support of metal related environmental risk assessments. Abstract Number 394. Society for Environmental Toxicology and Chemistry. 31st Annual Meeting North America, Portland, OR.

ERRATUM TO FINAL REPORT ON SEQUENTIAL ANALYSIS OF LINES OF EVIDENCE (SALE)

Table 4.31 providing a summary of the aquatic SALE analysis results for benthic invertebrates contained incorrect information in the final SALE report. The corrected Table 4.31 is provided bellow. The corrections to the table do not change the conclusions of the aquatic SALE report.

Table 4.31 SALE Summary Table for Benthic Invertebrates

Site (Downstream of Smelter)	Sediment Toxicity						Benthic Invertebrate Community Similarity to Reference						Direct Effects on Habitat Caused by Slag Deposition			Proceed to Evaluation of Risk Management Options?
	Survival			Growth			Site Comparisons			Multivariate Analysis						
	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	Magnitude	Causation	Uncertainty	
Korpak	○	○	??	○	○	??		-		○	○	?	○	○	??	No
Maglios	●	⊙	??	●	⊙	??		-		●	⊙	?	●	⊙	??	Yes
Casino	○	○	??	○	○	??		-		○	○	?	○	○	??	No
Airport Bar	○	○	??	○	○	??	○	○	?	○	○	?	○	○	??	No
Trimac	○	○	??	⊙	○	??		-		○	○	?	○	○	??	No
Fort Sheppard Eddy	○	○	??	○	○	??	⊙	○	?	○	⊙	?	⊙	○	??	Yes, but confirm with more data
Waneta Eddy	●	⊙	??	●	⊙	??	●	⊙	?	●	⊙	?	●	⊙	??	Yes

Notes: - = not applicable.

Magnitude:

- ● strong response.
- ⊙ moderate response.
- ○ weak response.

Causation:

- ● strong overall strength of causal evidence.
- ⊙ moderate overall strength of causal evidence.
- ○ weak overall strength of causal evidence.

Uncertainty:

- ? low uncertainty (high statistical power, full gradient design, all important natural variables accounted for).
- ?? moderate uncertainty (moderate statistical power, control/impact rather than full gradient design; most natural variables accounted for).
- ??? high uncertainty (low statistical power, important natural variables not accounted for).

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Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
102, 2535 - 3rd Avenue S.E.
Calgary, Alberta, T2A 7W5
Canada
T: +1 (403) 299 5600

Golder Associates