# Aquatic Effects Monitoring Final Plan

## Canadian Zinc

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## 1.0 INTRODUCTION

An aquatic effects monitoring plan is an essential component of any development project with an effluent discharge, and for focused decision making, a clear sense of process for industry and regulators, and ultimately for sustainable development is required. Significant advancement has been made in developing integrated aquatic effects monitoring plans and programs including for sensitive northern Canadian rivers (Spencer et al., 2008 Bowman et al., 2009; Squires et al., 2009). In the latter instance, specific attention has been paid to indicators and use of decision triggers or benchmarks relative to natural variability.

AEMP programs need to consider the uniqueness of northern rivers. Northern aquatic ecosystems are considered to be sensitive to contaminants due to their high-latitude and extreme climate (Schindler and Smol 2006). The reduced ice-free period results in low primary production, slow growth cycles and reduced energy stores with invertebrates and fish commonly reproducing every two years compared with annual reproduction in southern watersheds (Evans 2000, Evans et al. 2005, Chambers et al. 2006, Lumb et al. 2006). Slower reproduction cycles leave northern species at an increased vulnerability to stressors in the environment (Barrie et al. 1992). Species diversity tends to be reduced due to the harsh climate, limited opportunity for species migration from southern ecosystems, and short period of time since the last glaciation (Evans et al. 2005). Most northern ecosystems are considered to be highly oligotrophic, with less productivity and species abundance than southern systems (Chambers et al. 2006, Schindler and Smol 2006).

Canada’s north is currently experiencing large growth in industrial developments and the potential for continued development is extremely high. In 2005, the value of mineral production increased nearly 100% from the mineral production in 2002 (NRCan 2005). As an indication of economic significance, diamond mining in the NWT and Nunavut accounts for 15% of the global market with exports totalling $1.9 billion in 2006 (MAC 2007). Given the significance of industrial development in the north, there is a need to assess the sensitivity of these unique high-latitude ecosystems and to develop AEMP programs to track changes over spatial and temporal scales (Mallory et al. 2006, Lockhart et al. 1992). Establishing a baseline of response to anthropogenic stressors is also critical as the advent of climate change and global warming will undoubtedly alter and potentially magnify responses of aquatic systems to stress (Schindler and Smol 2006). The increased pressures on northern ecosystems and their unique characteristics related to climate, reduced productivity, and lower species diversity emphasize the importance of effective monitoring programs which can be used for detecting changes in northern ecosystems and to provide early warning signals for higher trophic levels.

The South Nahanni Watershed includes part of Nahanni National Park Reserve, a UNESCO (*United Nations Educational, Scientific and Cultural Organization*) World Heritage Site and Canadian Heritage River, and is considered a sensitive northern environment with pristine aquatic environments (Halliwell and Catto 2003). Prairie Creek Mine is an industrial development located on a tributary of the South Nahanni River.

The objective of this document is to present a draft AEMP for the Prairie Creek Mine. The framework presented here is a straw-dog construct to focus the discussion and provide the basis for the next steps in the development of an AEMP.

## 2.0 LOCATION AND MONITORING REQUIREMENTS

### 2.1 Site

The South Nahanni River is located in the southwest corner of the Northwest Territories. The low subarctic climate in the Nahanni Plateau is characterized by cool summers (mean temperature is 9°C) and cold winters (mean temperature is -19.5°C; Environment Canada 1991). Most areas are less than 1372 m above sea level but mountain ranges reach to over 1800 m (Halliwell and Catto 2003). The terrain is underlain by Palaeozoic carbonates, and is incised by deep and narrow valleys. Vegetation is sparse at higher elevations but open stands of black spruce with an understory of dwarf birch, Labrador tea, lichen, and moss occur in valleys and at lower elevations (Environment Canada 1991). The South Nahanni River flows in a south-easterly direction 540 km from ice fields near the Yukon-NWT border through the Mackenzie Mountains into the Liard River which then converges with the Mackenzie River (Parks Canada 1984). The normal range of flows at the flow gauging station upstream of Virginia Falls is 55 to 1500 $m^3$ per second (Halliwell and Catto 2003).

Prairie Creek is a tributary of the South Nahanni and flows through deposits of dolostones, limestone, and shale (Halliwell and Catto 2003) containing mineralized veins of zinc, lead, copper, and silver. Prairie Creek originates in and flows through upland and steep canyon terrain which leads to reduced suspended sediments compared to other tributaries in the Nahanni watershed (Halliwell and Catto 2003). Due to the underlying geological formations, Prairie Creek precipitates carbonate and other minerals as well as metals from natural mineral deposits (Indian and Northern Affairs 2001). Flow rates in Prairie Creek are lower than those in other tributaries (e.g., Flat River) and the South Nahanni River, ranging from 0.5 $m^3/s$ in the winter months to 30 $m^3/s$ in the summer months (IWD 1991).

The Prairie Creek Mine is located upstream from the confluence with the South Nahanni River (Environment Canada 1991, Halliwell and Catto 2003). The property was initially explored in the 1950's and a mill complex and a tailings pond were constructed in the 1980's. Due to financial difficulties, mining and milling did not proceed at the Prairie Creek property and tailings were not generated. Canadian Zinc Corporation (CZN) took over the property in 1995 and has undertaken an advanced exploration program for base metals (i.e., lead, zinc, copper, and silver). A portal was constructed at the site before CZN's tenure for exploration and potential mining purposes. The portal discharges mine water. CZN commenced water treatment in 2006 with treated water sent to a polishing pond and subsequently to a catchment pond. The water from the catchment pond discharges to Harrison Creek and then Prairie Creek and has potential to be high in several metals including cadmium, copper, lead, selenium and zinc.

CZN's plans for mine operations (Canadian Zinc 2010) include the discharge of treated water directly to Prairie Creek via a diffuser. In addition, sewage from site is estimated based on 120 persons producing 270 L/day/person to total 32,400 L/day. Sewage treatment is based on a biochemical oxygen demand (BOD5) of 220 to 300 mg/l, and will involve aerobic biological digestion with the addition of air. After the solids settle, the effluent will be pumped to a water storage pond which will provide process water for the mill process. The design parameters for treated sewage effluent quality are BOD5 <20 mg/l, and TSS <20mg/l. The use of only non-phosphate based detergents in the camp will be mandatory to limit nutrients in sewage effluent.

Mine water will be treated with lime to at least pH 9, followed by pH reduction to 8.5 using sulphuric acid. Mill water will be acidified to pH 5 using sulphuric acid followed by sodium sulphide addition. Iron will then be added with lime to raise the pH to 9, followed by flocculent addition. After primary treatment of the two water streams, the streams will merge for the suspended sediment removal step (clarification) before discharge to the Catchment Pond. Thus, non-metal parameters expected in this discharge include increased hardness, chloride, sulphate, sodium, iron and conductivity.

Potential and actual discharges during Mine operations are as follows:

- Mine water;
- Waste Rock Pile ("WRP") seepage;
- Runoff from stockpiles;
- Process water from the Mill;

- Sewage effluent;
- Groundwater recharge to Harrison Creek; and.
- Site runoff.

The site water balance shows that the 2 most significant discharges during operations will be treated process water and treated Mine water. WRP seepage and runoff from stockpiles will be relatively small flows, likely containing elevated metals. These flows will be sent to the Water Storage Pond (“WSP”). The sewage effluent flow sent to the WSP will also be small, and should not contain nutrients (because of the use of non-phosphate detergents).

## 2.2 Recent and Relevant Previous Environmental Studies at the Site

### 2.2.1 Control-Impact EEM Monitoring Study

A control-impact monitoring survey was conducted in the summer of 2006 at reference, near-field (high exposure), and far-field (low-exposure) sites on Prairie Creek using methods outlined in the Metal Mining Effluent Regulations EEM Guidance Document (Environment Canada 2002; Spencer et al., 2008). This study provided valuable information on reference variability, existing state of water chemistry, benthic community structure and sentinel fish populations, and an evaluation of AEMP-relevant indicators for this site. Upstream reference conditions in the river were compared to sites downstream and further downstream of the mine. The endpoints evaluated included concentrations of metals in river water, sediments and liver and flesh of slimy sculpin; benthic algal and macroinvertebrate abundance, richness, diversity, and community composition; and various slimy sculpin (*Cottus cognatus*) measures, the sentinel forage fish species. Sites downstream of the mine on Prairie Creek had increased benthic macroinvertebrate taxa richness and improved sculpin condition. Biological changes in the river were consistent with mild enrichment downstream of mining activity. It was recommended that monitoring in Prairie Creek focus on indicators in epilithon and benthic macroinvertebrate communities due to their responsiveness and as alternatives to lethal fish sampling in habitats with low fish abundance. It was also recommended that monitoring of metal burdens in periphyton and benthic invertebrates be considered for assessment of exposure to mine effluent and causal association.

### 2.2.2 Regional Reference Condition Monitoring Study

The reference condition study was implemented at the same time as the control-impact study but over a broader regional area (Bowman et al. 2009). Water and sediment chemistry, community composition of benthic algae and invertebrates and fish, and condition of a sentinel fish species, slimy sculpin (*Cottus* *cognatus*) were evaluated in two rivers adjacent to metal mines and in 20 reference rivers in the headwaters of the South Nahanni River Basin. The normal range (i.e., mean ± 2 standard deviations) of biological conditions in regional reference sites (grouped by community type) were used to set ecologically meaningful effect sizes. Impairments at sites influenced by current and historical mining activity were indicated by mild enrichment (e.g., increased benthic abundance and sculpin condition) and bioaccumulation of metals (e.g., increased concentrations of copper and iron in muscle tissue of sculpin). Concentrations of metals such as aluminum, copper, and iron in river water at reference sites were above federal and regional guidelines suggesting that these guidelines are not appropriate for the metal-rich headwaters of the South Nahanni River.

### 2.2.3 Development of Site-Specific Water Quality Criteria Study

In January 2010, an evaluation study of site-specific water quality objectives was conducted (Dube and Harwood 2010) to support development of effluent quality criteria that are protective of the environment and also considerate of natural elevations in metals in the water column. One of the most effective means of protecting water quality is to regulate the “quantity, concentration and types of waste” that may be discharged from a project into the receiving environment (Mackenzie Valley Land and Water Board 2010). Management Boards do this by setting discharge limits, also called effluent quality criteria (EQC), in the terms and conditions of a water licence. EQC’s define the maximum allowable concentrations or amounts (i.e., loadings) of each contaminant in the waste and the proponent must ensure that the waste discharged stays within these limits in order to remain in compliance with the water licence. Typically, an EQC value will be developed for any contaminant that is predicted to be in the waste at a concentration that may adversely affect downstream water quality. As stated in Mackenzie Valley Land and Water Board (2010) the objectives for EQC are to ensure that:

1. Water quality in the downstream environment is protected,
2. Contaminant loadings to the environment are minimized, and
3. The proponent can reasonably and consistently achieve the EQC.

It is often found in many highly mineralized watersheds in Canada where mining activities occur, that background concentrations of metals are elevated above national guidelines (Canadian Council of Ministers of the Environment) due to natural factors (de Rosemond et al., 2008). When guidelines are applied to aquatic systems, often exceedances occur prior to initiating any development or discharges of treated wastewater, which confounds interpretations of changes that may occur post development or discharge. Depending upon the jurisdiction, the benchmarks that are set to assess changes in water quality differ. Some jurisdictions apply the national CCME (Canadian Council for Ministers of the Environment) guidelines for the protection of freshwater aquatic life, some apply provincial or territorial water quality objectives, and some calculate site-specific objectives. The advantages and disadvantages of the respective approaches are summarized in brief in de Rosemond et al., (2008).

Our previous research has shown that application of certain federal (Canadian Council of Ministers of the Environment, Guidelines for the protection of Freshwater Aquatic Life) are not appropriate for the naturally metal-rich and neutral pH headwaters of these ecosystems. The reference benchmarks derived in our Reference Condition Approach study and in the upstream-downstream comparison by Spencer et al. (2008) also showed that concentrations of metals such as aluminum, copper, and iron in reference sites for the Flat River and Prairie Creek exceeded both Canadian Council of Ministers of the Environment guidelines (CCME 2003) and regional water quality objectives (Halliwell and Catto 2003). For example, the CCME guideline for total aluminum in surface waters is < 5-10 µg/L but concentrations exceeded 10 µg/L in 17 reference sites and exceeded 5 µg/L in all 20 reference sites (90th percentile was 80.7 µg/L). In addition, aluminum concentrations in reference sites consistently exceeded the water quality objectives previously derived for the Flat River (< 6.95 – 6.98 µg/L) and Prairie Creek (< 0.46 – 1.28 µg/L) further downstream, near their confluences with the South Nahanni River (Halliwell and Catto 2003). The work herein illustrates that for the metals examined, Cd and Se would benefit from a background reference condition approach to establish site-specific objectives as their natural background concentrations exceed CCME guidelines and/or regional objectives (Halliwell and Catto 2003).

The objectives of the Dube and Harwood (2010) study were to: 1) assess the natural levels of key metals at a collection of reference sites in the Prairie Creek watershed; 2) calculate site-specific objectives for each variable (cadmium, copper, lead, mercury, selenium and zinc) using the reference condition approach; 3) compare the derived site-specific objectives to CCME guidelines and Canadian Zinc's proposed discharge strategy and estimated effluent concentrations; and 4) evaluate the results of acute and chronic toxicity tests conducted on treated mine and process water in relation to the recommended site-specific water quality objectives.

CCME (2003) outlines four different procedures for deriving site-specific water quality objectives: the background concentration procedure, the recalculation procedure, the water-effect ratio procedure, and the resident species procedure. Based on the availability of data for the site, we used the background concentration procedure to derive site-specific objectives by collating reference water quality data from four sources: 1) Parks Canada; 2) Environment Canada, Prairie and Northern Region; 3) University of Saskatchewan; and 4) Canadian Zinc.

When applying the reference condition approach to the six metals of interest, some of the site-specific objectives were lower than the national guidelines and some were higher. Of course if a case is being made to the regulators to develop site-specific objectives on the basis of naturally high background mineralization, then that approach could be interpreted as a ubiquitous one. That is, application of a reference condition approach to establish site-specific objectives for some variables and use of CCME guidelines for other variables is likely less defensible than adopting a unified approach across all variables. Nevertheless, there are examples when a combination of site-specific objectives and national guidelines has been adopted. For instance, in determining site-specific objectives for Environment Canada for the Upper Liard River, Tri-Star Environmental Consulting proposed site-specific objectives be employed if: a) national guidelines were exceeded; b) values were within 90% of guideline values; c) values were deteriorating through time; and/or d) if the contaminant in question was human in origin (Tri-Star 2005). Tri-Star (2005) ultimately proposed site-specific objectives for parameters that exceeded guidelines or were within 90% of guideline values. Similarly, in calculating a Site-Specific Water Quality Index (SS-WQI) for Newfoundland and Labrador, Khan et al. (2005) revert to CCME for cases where the background concentration based on local water quality is lower than the CCME water quality guideline. The argument for adopting CCME water quality guidelines for some metals and the mean + 2SDs of the reference condition for others may also be applied if there were a geological or mineralogical basis behind such an argument. In our experience, however, regulators in the Prairie and Northern Region of Environment Canada have recently adopted the reference condition approach across all variables, and we expect that this will be the preferred approach in this case given the sensitive nature of the downstream water body.

## 3.0 CORE ELEMENTS OF MONITORING PROGRAMS

The terms of reference for Canadian Zinc's Developer's Assessment Report (2010) ask for a conceptual framework for an integrated Aquatic Effects Monitoring Plan. A Monitoring program requires three key components; 1) Surveillance Network Program (SNP); 2) AEMP; and 3) an adaptive management loop (Indian and Northern Affairs Canada 2009). Its goal is to determine if the waste prevention/minimization and water quality protection measures (including EQC) are successfully meeting their stated objectives. While a SNP is not typically included in a AEMP it is linked to and should be the trigger for implementation of an AEMP under certain conditions and as such is integrated here.

Surveillance Network Programs (SNPs), consist of specific sites within a development at which water quality and quantity are measured. These programs are a requirement of every water licence. SNPs are designed to aid the proponent and the regulators in ensuring that the EQC are being and will continue to be consistently met. SNPs can require monitoring for some non-regulated parameters which allows all parties to ensure that the concentrations of some non-regulated contaminants do not unexpectedly increase. Typically, one of the SNP stations is the point at which the proponent must comply with the EQC and any other required parameter. Other SNP stations are often located at points of waste transfer or treatment prior to the 'compliance' point to ensure that the waste-handling system is working as expected.

AEMPs monitor the short- and long-term effects of a project on the wider receiving environment; such programs are currently only required of larger projects. AEMPs in particular can tell us if the water quality standards set for a receiving environment are being met. The AEMP includes definition of the boundaries of a study area, selection of monitoring stations in a rigorous and statistically valid study design, selection of indicators that are at least consistent with indicators in the SNP, determination of a reference baseline against which future change will be judged, development of triggers and targets tied to actions in a tiered monitoring strategy, to obtain sufficient information to determine the cause of any environmental effects if they do occur.

While selecting the best possible approach to water and effluent quality management is very important, adaptive management acknowledges that it can be difficult to predict all the effects of projects and developments on water resources (Mackenzie Valley Land and Water Board (2010). As a result, adaptive management involves monitoring the effects of actions and, where necessary, adjusting the actions based on the monitoring results. For example, if monitoring results show the effects of a project on the environment are much greater than predicted, further mitigation measures may be prescribed or EQC may be changed. Adaptive management ensures due diligence, continuity, consistency, and on-going reassessment back to primary objectives.

## 4.0 INDICATORS

### 4.1 Indicators for the SNP Monitoring Program

Indicators for the SNPs are those related to licensing requirements and are typically water quality and quantity parameters as well as chronic and/or acute effluent toxicity. The parameters measured and the methodology of analysis should be consistent for the same parameters measured in the AEMP. Many times discharge monitoring is not consistent with the AEMP which results in an inability to link any measureable environmental responses back to the point source discharge if they are detected. SNPs typically include average and maximum discharge concentrations and consider site-specific conditions. In the case of Canadian Zinc, the indicators for the SNP should include at least the indicators assessed in Dube and Harwood (2010). In addition to the metals, other general water quality parameters such as pH, conductivity, hardness, alkalinity, anions and cations (including chloride and sulphate), as well as nutrient levels should be measured. Effluent flows are also required for loading estimates. In the case of nutrients, particular attention should be paid to detection limits as nutrient concentrations are expected to be quite low in these oligotrophic systems of the South Nahanni watershed. Further, in many mining EEM programs we have found that different detection limits are used for the SNP and AEMP programs. This can confound causal investigations and introduce another source of uncertainty in the comparative analysis. The frequency of monitoring will likely be daily or weekly for some parameters, monthly for others, and quarterly for others. The frequency and selection of SNP indicators should be done in consultation with industry and regulators.

Of particular note at the Canadian Zinc site is the potential variance associated with seasonality. Mill process and STP effluent flows will not vary seasonally. However, mine flows may vary to some degree seasonally, being lower in winter. WRP and stockpile flows will also vary seasonally, being zero in winter. Flows to the WTP will increase in the open water season when those water sources with seasonal flows have higher flows. In addition, CZN plan to suspend mill water treatment in the later winter months when receiving water flows are low, sending the water to storage. The seasonality will result in different triggers in the SNP at different times of the year.

The only significant discharges of contaminated water from the Mine during the operations period will be treated process water and treated Mine water. The resulting in-stream or receiving water concentrations for the metals of concern (cadmium, copper, lead, selenium, zinc) have been modelled for Prairie Creek. The input parameters for the modelling are based on the water management strategy, the Water Storage Pond ("WSP") water balance, the treated Mine water and treated process water quality, and historical Prairie Creek flows and background water quality.

None of the predicted in-stream metals concentrations exceed site specific objectives in any month with average creek flows. This is because of the assimilative capacity of the creek flows, and the process water treatment strategy where the rate of treatment is matched to receiving water flows. However, if creek flows are abnormally low in the winter months, some predicted metal concentrations could exceed the objectives (copper, lead, selenium). Canadian Zinc proposes to monitor creek flows, and to curtail water treatment and discharge temporarily if abnormally low flows occur. Storage capacity in the WSP would be utilized to temporarily suspend discharge. With this approach, creek metals concentrations should remain below the site specific objectives, which are intended to be protective of all aquatic life in the creek.

It is clear from the modelling that a simple list of parameter concentrations that site discharge should not exceed will not be practical because of the seasonally large range of fluctuation in creek flows (Dube and Harwood (2010). To provide the greatest capacity for site discharge, and still minimize receiving water parameter concentrations, a different regulatory approach will be required.

## 4.2 Indicators for the AEMP

Indicators for the environmental AEMP need to be focused and tiered. The experimental design for the AEMP should be equivalent to that used in the Spencer et al (2008) study as it is consistent with the EEM program and has been effectively implemented at this site. One of the greatest mistakes made by industry and regulators is to change experimental designs, stations, indicators and triggers for the different monitoring programs conducted. It is common place for baseline monitoring before new project developments to be drastically different in design than follow-up monitoring conducted during and after development. Before and after studies can be incredibly powerful to illustrate if changes did or did not occur as predicted. Comparisons however cannot be done if different stations, indicators and benchmarks are used between monitoring studies. Monitoring under an AEMP requires an unwavering core consistency to ensure comparability over time and space.

All indicators represent significant tradeoffs in terms of the time lag to respond, their reversibility, their ecological relevance and the ability to trace the cause of the changes. There are compromises both in terms of monitoring level (i.e., biochemical, physiological, individual, population, community, etc), as well as sentinel species (e.g., plankton, invertebrate, fish, bird, mammal, etc), that must be considered when evaluating the consequences of indicator selection. Selection of AEMP indicators should focus on aspects of the ecosystem that would be expected to integrate stress. Indicators can include physical, chemical, and biological endpoints and should arise from consideration of the potential stressor-response pathways (see Antoniuk et al., 2009). Ideally, the compliance and performance monitoring programs should focus on rapid response indicators that monitor the potential impacts from operational activity if mitigation measures are unsuccessful, with AEMP employing indicators that integrate many facets of the environment thus providing information on environmental condition.

Many monitoring programs suffer from trying to do too many things with one program. The AEMP process is related directly to the ability to detect when the levels of environmental change are accumulating to the level that impacts are detectable. In the case of Canadian Zinc, Spencer et al (2008) recommend adoption of the same EEM approach and sampling stations with periphyton and benthic communities as the indicators to assess effects and water quality and quantity indicators to support identification of biological effects. Particular importance should be paid to location of suitable reference areas that are as least as consistent as those measured in previous studies at the site (Spencer et al., 2008).

## 5.0 TIERS AND TRIGGERS

As long as the endpoints being monitored are somewhat predictive of adverse effects, there is time to respond, and an ability to integrate triggers into the monitoring program. The simplest trigger would be a warning sign that signified an increased frequency of monitoring, or an increased level of detail of monitoring would be required. Triggers could be developed which would initiate a range of responses from increased frequency of monitoring, detail of monitoring, investigation of cause or mitigative responses, depending on the severity of the response. Ideally triggers would have at least two levels of concern - a lower warning level based on predictive changes that would signify that monitoring has to change, and a high level of maximum tolerable change that will require a significant management change (or a change in monitoring strategy).

Tiered triggers are required for both the SNP monitoring program and the AEMP. For the SNP program triggers could be at least the site-specific water quality objectives forwarded by Dube and Harwood (2010) for the Canadian Zinc site. If these objectives are exceeded more than once for any one of the parameters and the exceedance cannot be explained by sampling/analytical variables, then more frequent monitoring may ensue to ensure that the measured exceedances were not an anomaly. A decision would need to be made as to how many consistent exceedances in an EQC and/or toxicity test before the AEMP monitoring program was triggered for implementation.

Some may wonder why the SNP program would trigger the AEMP program. The response to this is that exceedances in EQC may or may not be relevant and related to adverse environmental effects in biological indicators and this would need to be determined by a well designed AEMP consistent in design with the AEMP program conducted before development (i.e., Spencer et al., 2008).

The federal EEM program uses warning signs of a 25% change to trigger confirmation sampling or investigation of cause (Environment Canada, 2005; Munkittrick et al., 2009), but there are a number of ways to calculate the size of changes that could be used as triggers (reviewed in Munkittrick et al., 2009). The development of the framework needs to include a process and criteria that will be used to define what level of change is to be considered an effect (whether an effect is a statistical difference or something else), and whether confirmation of a change is needed before proceeding (as in the EEM program; Environment Canada, 2005). Responses that surpass a pre-designed target act as a warning signal that monitoring needs to increase. The focus of the triggers should be to define a target that means the environment is protected and the situation is sustainable.

The program has to be developed so that monitoring is not reactive; this is addressed by selecting indicators that respond soon enough that you have time to react before irreversible damage. There also needs to be a large enough baseline data set so that there is confidence that effects observed are real.

## 6.0 DRAFT AEMP FOR SITE

Figure 1 illustrates steps and core elements of an AEMP program. The work conducted to date in Prairie Creek establishes proposed indicators and triggers for SNP monitoring. Discussion is required around seasonality as well as allowable variance for indicators (i.e., daily or weekly maximum allowable, daily or weekly average allowable concentration). The work conducted to date by Spencer et al (2009) and Bowman et al (2009) also establishes a starting point for AEMP experimental design, indicator selection and benchmark selection.

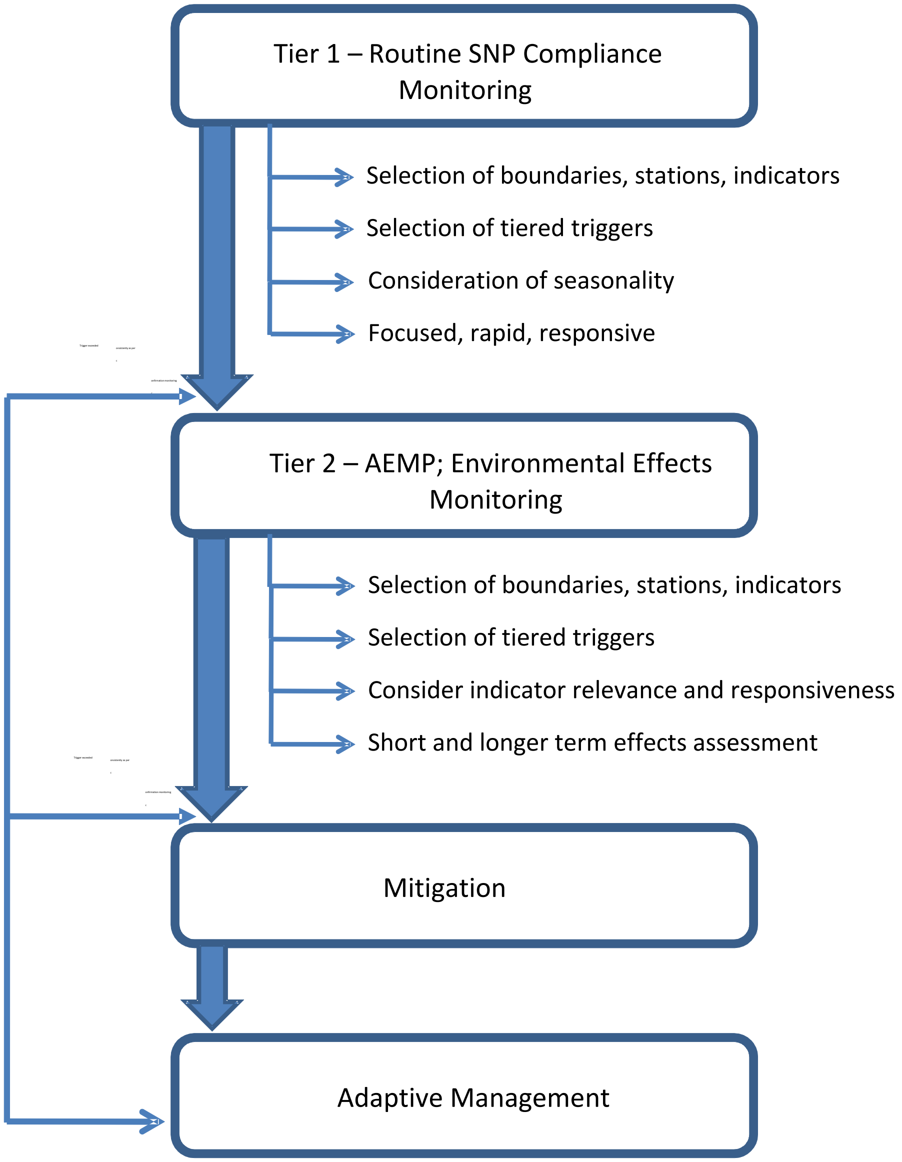

**Figure 1. Conceptual monitoring plan for Prairie Creek Mine**

## 7.0 REFERENCES

Antoniuk, T., S. Kennett, C. Aumann, M. Weber, S. Davis Schuetz, R. McManus, K. McKinnon, and K. Manuel. 2009. *Valued Component Thresholds (Management Objectives) Project*. Environmental Studies Research Funds Report No. 172. Calgary, AB. 164 p.

Barrie LA, Gregor D, Hargrave B, Lake R, Muir D, Shearer Ret al. 1992. Arctic Contaminants: sources, occurrence and pathways. *Sci Total Environ* 122:1-74.

Bowman M, Spencer P, Dubé M, West D. 2009. Regional reference variation provides ecologically meaningful protection criteria for northern World Heritage Site. Integrated Environmental Assessment and Monitoring, in press (accepted May 12, 2009).

Canadian Council of Ministers of the Environment (CCME). 2003. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Hull (QC), Canada: Canadian Council of Ministers of the Environment, Environment Canada.

Canadian Zinc Corporation. 2010. PRAIRIE CREEK MINE - DEVELOPER'S ASSESSMENT REPORT, Prairie Creek Mine EA 0809-002. Submitted to the Mackenzie Valley Review Board, Canadian Zinc Corporation, Vancouver, BC.

Chambers PA, Culp JM, Glozier NE, Cash KJ, Wrona FJ, and Norton L. 2006. Northern Rivers Ecosystem Initiative: Nutrients and Dissolved Oxygen – Issues and Impacts. *Env Monit Assess* 113:117-141.

de Rosemond S, Duro DC, Dubé M. 2008. Comparative analysis of regional water quality in Canada using the water quality index. Environmental Monitoring and Assessment DOI 10.1007/s10661-008-0480-6.

Dubé M and Harwood A. 2010. Development of Site-Specific Water Quality Guidelines for Prairie Creek, NWT. Report prepared for Canadian Zinc, Saskatchewan Research Council Publication No. 10432-1C10.

Environment Canada. 1991. Protecting the waters of the Nahanni National Park Reserve, Northwest Territories. Inland Waters Directorate and Canadian Parks Service, TR91-I/NAH, Yellowknife, Northwest Territories.

Environment Canada. 2002. Metal Mining Guidance Document for Aquatic Environmental Effects. http://www.ec.gc.ca/EEM/English/MetalMining/Guidance/ default.cfm. Accessed 1 November 2008.

Environment Canada. 2005. *Pulp and Paper EEM Guidance Document*. Environment Canada, National EEM Office, Gatineau, QC.

Evans MS. 2000. The large lake ecosystems of northern Canada. *Aquat Ecosystem Health Manag* 3:65-79.

Evans MS, Lockhart WL, Doetzel L, Low G, Muir D, Kidd K, Stephens G, Delaronde J. 2005. Elevated mercury concentrations in fish in lakes in the Mackenzie River Basin: The role of physical, chemical, and biological factors. Sci Total Environ 351-352:479-500.

Halliwell DR, Catto S. 2003. How and why is aquatic quality changing at Nahanni National Park Reserve, NWT, Canada? *Environ Monit Assess* 88:243-281.

Indian and Northern Affairs Canada. 2009. Guidelines for Designing and Implementing Aquatic Effects Monitoring Programs for Development Projects in the Northwest Territories.

Inland Waters Directorate (IWD). 1991. Protecting the waters of the Nahanni National Park Reserve, Northwest Territories. Yellowknife (NT), Canada: Environment Canada. Contract report TR91-I/NAH.

Khan AA, Tobin A, Paterson R, Khan H, Warren R. 2005. Application of CCME Procedures for Deriving Site-Specific Water Quality Guidelines for the CCME Water Quality Index. *Water Qual. Res. J. Canada* 40: 448-456.

Lockhart WL, Wagemann R, Tracey B, Sutherland D, and Thomas DJ. 1992. Presence and implications of chemical contaminants in the freshwaters of the Canadian Arctic. *Sci Total Environ* 122:1-74.

Lumb A, Halliwell D, and Sharma T. 2006. Application of CCME Water Quality Index to monitor water quality: A case of the Mackenzie River Basin, Canada. *Environ Monit Assess* 113: 411-429.

Mackenzie Valley Land and Water Board, Gwich'in Land and Water Board, Sahtu Land and Water Board, Wek'èezhìi Land and Water Board. 2010. Water & Effluent Quality Management Policy.

Mallory ML, Ogilivie C, and Gilchrist HG. 2006. A review of Northern Ecosystem Initiative in Arctic Canada: facilitating arctic ecosystem research through traditional and novel approaches. *Environ Monit Assess* 113(1-3):19-29.

Mining Association of Canada (MAC). 2007. Facts & Figures: A report on the State of the Canadian Mining Industry. pp 72.

Munkittrick, K.R., C.J. Arens, R.B. Lowell and G.P. Kaminski. 2009. A review of potential methods for determining critical effect size for designing environmental monitoring programs. *Environ. Toxicol. Chem*. 28:1361-1371.

Natural Resources Canada. 2005. Canadian Minerals Yearbook. www.nrcan.gc.ca. Accessed 19/07/06.

Parks Canada. 1984. Nahanni National Park Reserve resource description and analysis. Winnipeg, MB.

Schindler DW, Smol JP. 2006. Cumulative effects of climate warming and other human activities on freshwaters of arctic and subarctic North America. Ambio 35:160–168.

Spencer P, Bowman M, Dubé. 2008. A multi-trophic level approach to monitoring the effects of metal mining in otherwise pristine and ecologically sensitive rivers in northern Canada. Integrated Environmental Assessment and Management 4(3): 327–343.

Squires AJ, Westbrook CJ, Dubé MG. 2009. An Approach for Assessing Cumulative Effects in a Model River, the Athabasca River Basin. Integrated Environmental Assessment and Monitoring, in press (accepted May 2009).

Tri-Star Environmental Consulting (Tri-Star). 2005. Site-specific water quality guidelines for the Liard River at Upper Crossing for the Purpose of National Reporting. Prepared by Tri-Star Environmental Consulting for Environment Canada, May 2005.