APPENDIX I

MEMO

Date: May 9, 2011 **HCP Ref No.:** CZN1682

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To: David Harpley, CZN

Subject: Prairie Creek Mine – Potential Enrichment Effects (Memo 6)

This memo stems from technical discussions between regulators and CZN at Yellowknife on April 12, 2011.

Information presented in this memo builds upon materials previously presented regarding enrichment in Hatfield (2011).

1.0 HISTORICAL AND CURRENT CONDITIONS IN PRAIRIE CREEK

1.1 PERIPHYTON

Periphyton was sampled from locations upstream of the mine site and downstream of it (in near-field and far-field areas) in August 2006 by University of Saskatchewan researchers, as reported in Bowman *et al.* (2009) and Spencer *et al.* (2009). Although small (statistically in significant) changes in algal biomass (as chlorophyll *a*) were observed between upstream and downstream areas, algal biomass was very low at all stations, averaging 0.42 µg/cm^2 upstream of the mine site, 0.56 µg/cm^2 in the downstream near-field, and 0.38 µg/cm^2 in the downstream far-field (Spencer *et al.* 2009). Relative to conventional benchmarks of trophic status, these values indicate ultra-oligotrophic conditions.

1.2 BENTHIC INVERTEBRATE COMMUNITIES

Benthic invertebrate investigations in Prairie Creek in the vicinity of the mine site were undertaken in July 1980 and May 1981 by Beak (1981), and in August 2006 by University of Saskatchewan researchers (Bowman *et al.* 2009, Spencer *et al.* 2009).

In all cases, invertebrate densities observed at all stations in Prairie Creek upstream of the mine site were very low (i.e., near 100 individuals/m^2), to the extent that Beak (1981) remarked that "given the number of fauna collected in May 1981, it is not possible to utilize these figures as a basis for biological interpretation of environmental quality". Densities were similar downstream of the mine site in 1980 and 1981, previous to initial completion of the Cadillac mine infrastructure (Beak 1981). However, densities in 2006 were higher downstream of the mine in near-field and far-field areas, averaging approximately 300 and 200 individuals/m^2, respectively, although the differences between areas were not statistically significant (Spencer *et al.* 2008).

Numbers of invertebrate taxa present in Prairie Creek near the mine also were relatively low, with communities dominated by mayflies, stoneflies, caddisflies and midges. In 2006, taxonomic richness was significantly higher downstream of the existing discharge from the mine site, averaging 9 families upstream versus 18 in the downstream near-field and 11 in the downstream far-field (Bowman *et al.* 2006).

1.3 FISH COMMUNITIES

The fish community of Prairie Creek includes slimy sculpin, which are common residents throughout the creek, bull trout and mountain whitefish. The latter two have generally only been captured in Prairie Creek near the mine as adults (Beak 1981, Muchnacz 2001, Bowman *et al.* 2009, Spencer *et al.* 2008), and likely occur in the creek near the mine primarily during summer/fall spawning migrations, or as occasional foragers. There is only one study documenting small numbers of juvenile bull trout near the mine (Bowman *et al.* 2006). The general absence of juvenile bull trout and whitefish from this area suggests no spawning or rearing by these two species in this portion of Prairie Creek. Unlike bull trout and mountain whitefish, which can undertake substantial spawning migrations, slimy sculpin are territorial and occupy relatively small home-ranges, and therefore likely are year-round residents of Prairie Creek.

Spencer *et al.* (2009) measured higher condition (weight-at-age) of male and female slimy sculpin downstream of the current mine discharge relative to upstream conditions, an observation consistent with the observed increases in periphyton biomass and invertebrate densities mentioned above.

2.0 PREDICTED INCREASES IN NUTRIENT CONCENTRATIONS IN PRAIRIE CREEK RELATIVE TO ENRICHMENT THRESHOLDS

The type of nutrient limitation that occurs in a river will influence which nutrient will have the greatest effects on periphyton biomass; generally, systems may be limited by nitrogen or phosphorus, or co-limited by both nutrients. The form of the nutrient input also will influence the intensity and extent of eutrophication; inputs comprised of dissolved, bioavailable forms of nutrients will tend to cause more dramatic and localized effects (Dodds and Welch 2000). Many other factors influence periphyton growth, including flows, light, temperature, depth, turbidity, and the extent of grazing by benthic invertebrates. At the Prairie Creek Mine site, the highest predicted nutrient concentrations downstream of the mine discharge would occur under ice, at a time when periphyton growth is inhibited due to low light and water temperatures of approximately 0°C.

Growth saturation of periphyton occurs at very low concentrations. In oligotrophic, cold-water rivers, algal cell division switches from being nutrient-limited to nutrient-saturated at between 1 and 5 µg/L OP, and 2,000-3,000 µg/L (2-3 mg/L) DIN (Chambers *et al.* 2000, 2001, and references therein).

Background (upstream) concentrations of nutrients in Prairie Creek generally are low, with average orthophosphate (OP, which is fully bioavailable) of 1.2 µg/L (range <0. 5 to 1.8 µg/L) and dissolved inorganic nitrogen (DIN) of approximately 150 µg/L measured. Modelled concentrations downstream of the Prairie Creek Mine indicate an increase in DIN in all scenarios, particularly during low creek flows. However, only during the low creek flows and high effluent discharge scenarios do OP concentrations increase notably relative to background concentrations, although they remain under 1.5 µg/L in all scenarios (see Hatfield 2011).

Given the bioavailable-nutrient benchmarks mentioned above, OP concentrations at the downstream edge of the IDZ may be sufficient to cause mild enrichment. Predicted DIN concentrations are below the respective growth-saturation benchmark, but increase more than phosphorus downstream, which remain below the growth-saturation threshold. As such, bioavailable phosphorus in Prairie Creek is likely the nutrient of greatest importance from an enrichment perspective.

It should be noted that the DIN and OP concentrations used in the model do not incorporate any attenuation of these substances during water storage and treatment, or near-field uptake and bio-transformation in the creek. DIN concentrations were derived from untreated mine drainage concentrations for Diavik mine (see Hatfield 2011). DIN from sewage was not included because the anticipated input relative to mine water is small (<1%). It is anticipated that DIN and OP concentrations will be reduced while wastewater resides in the on-site water-storage ponds. Some phosphorus from sewage will also be precipitated via the use of alum.

CCME (2011) recommends a trigger value of 4 µg/L total P in water to protect ultra-oligotrophic streams. Similarly, Chambers *et al.* (2006) also proposed a guideline of 4 µg/L for the Wapiti River to protect its upstream, oligotrophic character. An objective of 4 µg/L TP has also been proposed for Prairie Creek downstream of the mine in an accompanying memo describing site-specific water quality objectives. Adherence to this water quality objective should ensure the absence of pronounced eutrophication in Prairie Creek, although some enrichment is likely to occur because algae in phosphorus-limited river systems are sensitive to very small additions of bioavailable phosphorus.

3.0 POTENTIAL ECOLOGICAL EFFECTS OF ENRICHMENT

The small, predicted increase in phosphorus in Prairie Creek is not expected to lead to high periphyton biomass, although additional increases above biomass currently present are expected. The precise amount of algal biomass generated is difficult to predict, given algal biomass is also affected substantially by water flows and turbulence (both to deliver nutrients and to scour growing mats), water temperatures, light availability, and invertebrate grazing pressure. Long-term, experimental-trough experiments undertaken by Bothwell (1989) found that standing periphyton biomass increased with increasing bioavailable phosphorus in water, up to a concentration of approximately 25 µg/L, at which point, diffusion kinetics through the algal mat limited further biomass accrual. In contrast, bioavailable phosphorus in Prairie Creek is only predicted to increase to approximately 1.5 µg/L, and the turbulent nature of the creek may help to limit accrual of standing biomass through scouring. Dodds and Welch (2002) proposed a periphyton guideline of 10 µg/cm^2 to protect the visual character of a stream; this value is approximately twenty times higher than the periphyton concentrations in the near-field area found by Spencer *et al.* (2009).

Benthic invertebrate community data measured by Bowman *et al.* (2009) suggest that the mild enrichment currently occurring downstream of the mine has increased invertebrate richness and diversity, presumably by increasing the productivity of the stream sufficiently to allow these additional invertebrate species to survive in the creek. Benthic taxa that have increased in numbers include Baetid mayflies, Sepata stoneflies, chironomid larvae, as well as other stoneflies, caddisflies and midge species (Bowman *et al.* 2009). The increases are seen primarily amongst those species known as grazers. Although this is a change from the natural character of the creek, it may be viewed positively as an increase in the ecological diversity of the creek, and as increasing available food for resident fish (as is likely shown by increased sculpin condition in the creek downstream of the mine). There do not appear to be any species with decreasing densities.

Examples of other watersheds with more extreme enrichment effects may be drawn upon to ascertain potential ecological impacts of increased primary productivity. Increases in periphyton biomass, invertebrate densities, and fish condition have been closely studied for many years in both the Wapiti River in northeastern Alberta and the Thompson River in the British Columbia interior. In both cases, nutrient additions from a pulpmill and from a sewage treatment plant greatly increased concentrations of bioavailable nitrogen and phosphorus, and relatively high periphyton biomass is observed (Hatfield 2007a,b). Although periphyton biomass has been very high (i.e., up to 40 μg/cm^2 in the Wapiti River), benthic communities in both rivers exhibit taxonomically rich communities, with increases in abundance but no observed reductions in richness between reference and exposed areas of the Wapiti River. Fish species generally, and sculpins specifically, showed greater condition downstream of these discharges, but no negative effects suggestive of toxicity.

A second example relevant to the Prairie Creek mine is that of the Kemess mine, in northwestern British Columbia. This copper-gold mine is located in a subalpine environment, in the headwaters of the Finlay River system (a tributary of the Peace River). Over the mine's life from 1997 to 2011, periphyton biomass increased substantially in some local creeks, not because of nutrient discharges but because of substantial increases in biomass of the diatom *Didymosphenia geminata* (didyma), which is known to be an invasive species in some areas, and can bloom to high biomass in oligotrophic conditions (see Bothwell and Spaulding 2009). In South Kemess Creek, a second-order creek at the site, periphyton biomass increased from 0.3 μg/cm^2 in 1992 previous to mine development (similar to Prairie Creek upstream of the mine currently), to approximately 2.5 μg/cm^2 in 2010, a nearly ten-fold increase. South Kemess Creek is a locally important creek for spawning and rearing of bull trout, but also supports low numbers of slimy sculpins, and juvenile mountain whitefish and rainbow trout. From 1997 to 2010, annual surveys of spawning and juvenile bull trout were undertaken. Periphyton and benthos have also been sampled in the creek annually since 1999 (as well as during 1992 baseline surveys). The diet of several juvenile bull trout also was assessed in 1998 (Hagen and Taylor 2001) and again in 2010 (Hatfield 2011b) to determine how changes in periphyton abundance may have affected bull trout diets. Results of this provincial Environmental Effects Monitoring (EEM) program were reported by Hatfield (2011b), and were as follows:

- Although benthos and periphyton communities have shown considerable variability over time since monitoring began, it was apparent that substantial increases in periphyton biomass had occurred in South Kemess Creek, and that concurrently, densities of several invertebrate taxa known to graze on periphyton had shown large increases in density relative to baseline conditions as well, especially chironomid (midge) larvae, and the nymphs of several taxa of mayfly (especially Baetids) and stoneflies (especially *Zapada* sp.).

- Despite these increases in algal biomass and in the abundance of key grazer species, taxa present in periphyton and invertebrate communities had remained similar to those observed in baseline studies, with total numbers of algal and invertebrate taxa remaining similar among all stations over time, as well as the composition of those taxa. These observations were consistent with published accounts of similar didymo blooms in other regions.

- The abundance and biomass of bull trout fry, juveniles and spawning adults remained similar (although highly variable) over this time, suggesting continued spawning and rearing success of char in this system.

- Char are known to be generalist feeders, taking a wide variety of prey both from stream substrates and from benthic drift, in the Kemess system specifically and elsewhere generally (Hagen and Taylor 2001, and references therein). Diet samples collected from juvenile char in this study were consistent with this statement, with a wide variety of prey items observed, dominated by periphyton grazers with highest abundance (i.e., midges, mayflies and stoneflies). Differences between this sampling event and other, previous diet samples collected at this site earlier in the mine life perhaps reflected greater abundance and availability of grazing species as prey items.

- The mean length of char fry collected from South Kemess Creek from 1999 to 2010 showed a moderate correlation with algal biomass (r^2=0.53), consistent with greater growth of char fry in years of higher algal biomass and, by association, greater food availability. However, a similar relationship was not observed between algal biomass and the condition of bull trout parr, suggesting that any benefit to fry of increased availability of periphyton-associated prey items may not occur for older juveniles.

Taken in total, these data suggest that, even if mild enrichment occurs in Prairie Creek downstream of the mine discharge, resident invertebrate and fish species should not be negatively affected.

As part of the proposed Aquatic Effects Monitoring Program (AEMP), enrichment will be directly assessed in Prairie Creek in the first two years of mine life, and regularly afterward. This will allow any enrichment effects to be quantified and assessed against relevant benchmarks (i.e., federal EEM guidelines pertaining to changes in fish health and benthic community structure). Feedback from this monitoring program may be used to guide future management of water quality and effluent discharge from the site.

There is an emerging consensus that didymo and other invasive algae can spread on the felts of wader boots. To eliminate the potential for periphyton blooms in Prairie Creek related to invasive algal species like didymo, CZN will institute a felt ban for any mine staff or contractors undertaking instream activities, and will require instead that rubber or studded wader boots are worn.

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