APPENDIX F

MEMO

Date: May 11, 2011 **HCP Ref No.:** CZN1682

From: John Wilcockson and Martin Davies

To: David Harpley, CZN

Subject: Prairie Creek Mine – Predictions of Prairie Creek Water Quality (Memo 3)

1.0 INTRODUCTION

1.1 BACKGROUND

This memo is one of a series of memos which are designed to address questions and concerns which arose during technical discussions between regulators and CZN at Yellowknife on April 12, 2011. In this memo, water quality predictions modelled under various mine-discharge and creek-flow scenarios are compared against site-specific water quality objectives (SSWQO) for Prairie Creek.

These predictions of downstream water quality in Prairie Creek during operational effluent discharge were provided by Canadian Zinc Corporation, in their May 2011 submission, *Appendix C: Water Balance, Water Quality and Regulatory Proposals* (D. Harpley, CZN, *in litt.*, May 2011), and were based on predicted combined effluent chemistry and flows, upstream Prairie Creek water quality, and predicted mixing dynamics in the near-field area produced by Northwest Hydraulic Consultants (NHC).

2.0 PREDICTED EFFLUENT QUALITY

Briefly, discharged effluent will be comprised primarily of two treated effluent streams, and two secondary streams, as follows:

- process (mill) water, generated by the milling process;
- mine water (seepage water removed from the mine itself);
- site runoff water (ditch water); and
- treated camp sewage effluent.

The process water produced will be highly regulated, predictable (flows are known and do not change), and not dependant on external factors. The volume of mine water, however, will depend on the spatial development of the mine, permeability of the rock mass, and seasonal changes in infiltration, and therefore will be more variable. Therefore, the mine has developed four different volume management scenarios for consideration in predictions, representing low, best-estimate, high, and extreme mine-water discharge scenarios. As stated in a CZN memo (Appendix F of the second round Information Request [IR] reply, *Water Balance and Water Quality*), "the first three estimates are based on different hydraulic conductivities (K) from the Vein Fault…" and "the last estimate assumes an hydraulic connection between the Vein Fault and the

Prairie Creek Alluvial Aquifer (PCAA)." The extreme mine-water flow scenario is considered unlikely (5% possibility, RGC 2011).

No process effluent is planned to be discharged in February and March. In other months, process effluent is predicted to comprise 18-19% of total treated effluent discharge under the Low mine water scenario, 11-13% in the Best Estimate case, 7-9% in the High case, and 1-5% in the Extreme case. This has important implications to final effluent quality, water quality modelling, and establishment of Effluent Quality Criteria, given concentrations of most analytes of concern are much higher in treated process effluent than treated mine water, which exhibits quality that is more similar to that of upstream Prairie Creek water (Table 1).

Table 1 Concentrations used in Prairie Creek water quality model calculations.

	Units	Treated Mine Water1	Treated Process Water[1]	Camp Ditch	Upstream Prairie Creek (see text below)	Diavik U/G Drainage (for nitrogen estimates only)
As	µg/L	2.8	9	0.8	0.11	-
Cd	µg/L	0.04	24.3	0.35	0.03	-
Cu	µg/L	7.2	71	2.2	0.26	-
Hg	µg/L	0.01	2.04	0.028	<0.02	-
Pb	µg/L	1.7	304	23.2	0.01	-
Sb	µg/L	25.3	119	2.2	0.11	-
Se	µg/L	3.3	39.2	2.4	1.15	-
Zn	µg/L	17	1,350	53	3.33	-
NH_4 N	mg/L	0.043	0.29	0.054	0.005	0.69
NO_3 N	mg/L	<1	<1	0.42	0.15	5.354
NO_2 N	mg/L	<0.25	<0.25	<0.001	NA	0.013
Total P	mg/L	0.0033	0.23	0.005	0.002	-
Ortho-P	mg/L	0.0025	0.025	0.0025	0.0012	-
SO_4	mg/L	470	4,500	110	68	-
TDS	mg/L	700	6,100	380	269	-
Hardness	mg/L	576	470	378	255	-

[1] Highest value of two measurements of simulated, treated effluent chemistry in 2010 and 2011.

Upstream Prairie Creek water concentrations used in predictions are median values from the available data. The model previously presented in March 2011 (in Appendix F, Water Balance and Water Quality), used means instead of medians; however, during the April 12, 2011 technical session, it was noted that many upstream Prairie Creek water quality data points were reported as not-detectable concentrations. To help address this concern, use of the median as a measure of central tendency was used instead of the mean, which assumes a normal data distribution (and uses the value of ½ the detection limit for non-detects). Generally, medians may provide better estimates of "typical" water quality than means because of the tendency for water quality data to be positively skewed (i.e., many low values with few high values).

Sewage water will be stored with mine water in the large Water Storage Pond for several months. Both ditch water and sewage effluent will have some residence time in the final site pond (Catchment Pond) before being discharged. This will reduce concerns of impacts related to biochemical oxygen demand (BOD) and ammonia.

With regard to quality, treated mine water exhibits concentrations of some analytes that are similar to, or even below, concentrations found in Prairie Creek upstream of the mine. Similarly, ditch water has been analyzed and has been shown to have lower concentrations of the AOC relative to both treated mine and treated process water, and for some analytes, not substantially different than upstream Prairie Creek waters.

Concentrations of AOC in the different discharge streams and upstream Prairie Creek, as used in water quality modelling appear below. These data represent the higher of two sets of observations in simulated mine-site effluents created in September 2010 and January 2011; it should be noted that variability in constituent concentrations between these two samples was sometimes very high for AOC's (Table 2). However, treated process water generally exhibited high concentrations of metals, ions, and hardness relative to the other streams and upstream Prairie Creek water.

Table 2 Metal concentrations in simulated effluent, September 2010 and January 2011 trials.

	Total Metals (µg/L)									
	Ag	**As**	**Cd**	**Cu**	**Fe**	**Hg**	**Pb**	**Sb**	**Se**	**Zn**
Treated Mine Water										
Jan-2011	**0.01**	0.20	**0.04**	0.70	21	0.01	1.7	25.3	2.8	2.5
Sep-2010	**0.01**	**2.8**	0.01	**7.2**	2.5	0.01	0.10	22.9	3.3	17
Treated Process Water										
Jan-2011	**0.7**	**9.0**	**24.3**	**71.0**	5,400	1.90	304	119	10.0	1,350
Sep-2010	0.04	1.8	2.62	2.10	43.0	2.04	93.2	11.2	39.2	39

Bold numbers indicate the higher concentration of the two observations, which was used in water quality modelling.

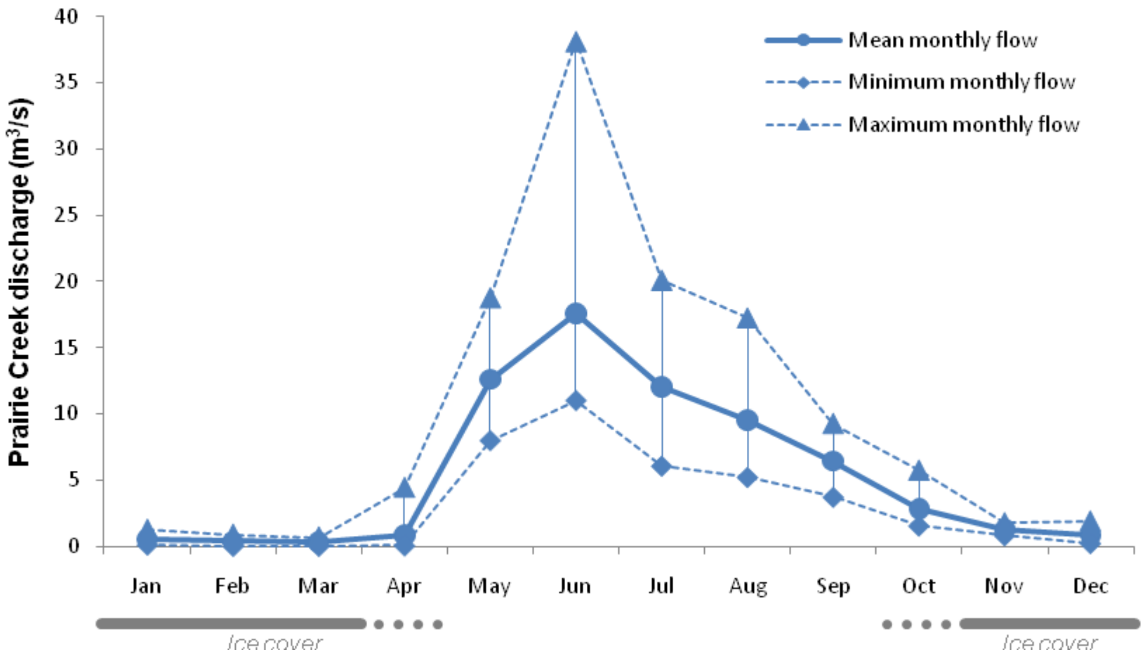
3.0 PREDICTED CONCENTRATIONS IN PRAIRIE CREEK

3.1.1 Near-field Dilution Model

NHC modelled dispersion and dilution of effluent from the Prairie Creek Mine under various seasonal conditions and mine-seepage scenarios (i.e., Low, Best-Estimate, High, and Extreme), as described in detail in NHC (February 11, 2011, and April 29, 2011).

The dilution model considered seasonal variation, given flow in Prairie Creek decreases significantly during winter, thus reducing the creek's assimilative capacity. The seasonal hydrograph for Prairie Creek (Figure 1) is typical of a smaller, northern stream, with high flows over a short, spring-to-fall period, peaking in June, and low flows through winter, under ice.

Figure 1 Range of mean monthly flows observed in Prairie Creek at Harrison Creek, 1974 to 1990.

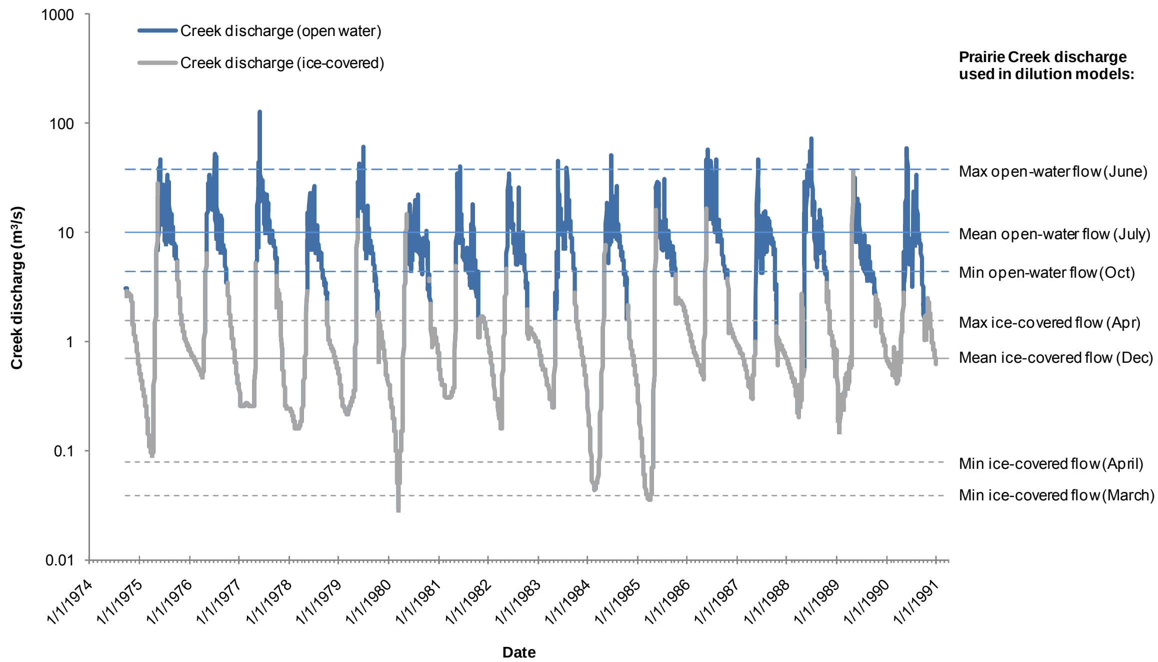


The treated process water has higher concentrations of most AOC, and therefore greater potential to cause toxicity. Given this, the process-water flow will be reduced significantly in winter. Various Prairie Creek discharge scenarios were modelled by NHC, including maximum, minimum and mean creek flows, in both open water and ice-covered conditions, as follows:

- Maximum open water – June (38.2 m^3/s);
- Mean open water – July (10.2 m^3/s);
- Minimum open water – October (1.57 m^3/s);
- Maximum ice cover – April (4.43 m^3/s);
- Mean ice cover – December (0.71 m^3/s); and
- Minimum ice cover – March (0.039 m^3/s).

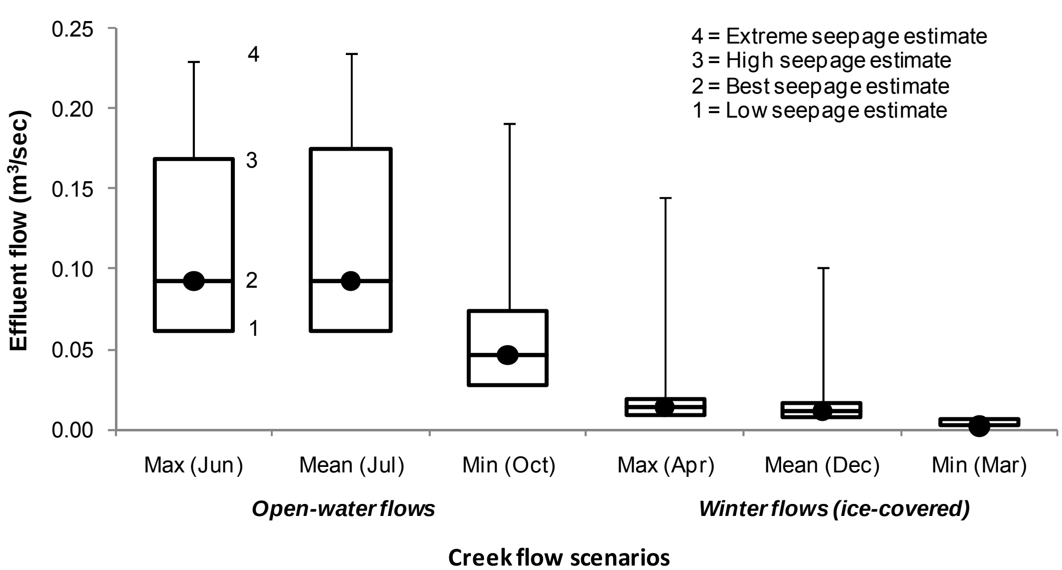
It should be noted that these low, late winter flows have not been not observed in most years; low March/April ice-covered flows only occurred for short periods of time (<1 week) in three of the 16 years of hydrometric monitoring undertaken on Prairie Creek (Figure 2).

Figure 2 Representative Prairie Creek discharges used in modelling, relative to historically observed daily flows, 1974 to 1990.



NHC conducted their simulations using flows of mine effluent discharged to the creek via one of two exfiltration trenches, under different creek flows (Figure 3). Model outputs included scalar dilution factors (i.e., descriptions of the ratio of effluent to upstream creek water, or vice-versa) at points of complete vertical mixing, and complete transverse mixing.

Figure 3 Effluent-volume scenarios modelled, incorporating potential mine-seepage flows.



3.1.2 Prediction of Downstream Concentrations of Analytes of Concern

Canadian Zinc Corp., in their May 2011 submission, *Appendix C: Water Balance, Water Quality and Regulatory Proposals* (D. Harpley, CZN, *in litt.*, May 2011), developed predictions of downstream water quality in Prairie Creek during operational effluent discharge.

These predictions were made by combining available effluent and creek chemistry data with NHC plume-modelling results to calculate AOC concentrations along the plume centre-line at complete vertical mixing (i.e., shortly downstream of discharge). The model used to estimate creek concentrations after complete vertical mixing (and representative of concentrations at the downstream edge of the IDZ) was as follows:

$$[AOC]_{ds} = ([AOC]_{eff} \text{ x } P_{eff})+([AOC]_{us} \text{ x } (1-P_{eff}))$$

Where:

$[AOC]_{ds}$ is the concentration of a given analyte in Prairie Creek downstream of discharge.

$[AOC]_{eff}$ is the concentration of a given analyte in treated effluent. Concentrations were based on chemical analysis of simulated, treated process and mine water (see effluent quality description above).

$[AOC]_{us}$ is the concentration of a given analyte in Prairie Creek upstream of the outfall. Concentrations used in the model were average creek concentrations as provided in Dubé and Harwood (2010) and associated documents.

P_{eff} is the proportion of downstream creek flow comprised of effluent water. This is the inverse of the complete vertical mixing dilution factors provided by NHC.

3.1.3 Predicted Concentrations of Effluent and its Constituents in Prairie Creek

Dilution ratios of effluent in downstream Prairie Creek water were modelled by NHC under various seasonal and mine-water-release scenarios. In all seasons and mine-water-release scenarios except Extreme, effluent concentrations are predicted to fall to approximately 3% or less of release under typical flow conditions (Table 3), after complete vertical mixing. Complete vertical mixing is predicted to occur between 1.6 and 31 m downstream of the outfall, depending on the scenario and season. In historical-low-flow, open-water conditions, concentrations of effluent in the creek after vertical mixing are approximately 5%, while in historical-low-flow conditions under ice in late winter, concentrations of effluent in the creek after vertical mixing were nearly 12%.

In the unexpected case of "extreme" mine-seepage flows, volumes of effluent in the creek may be comparably higher at complete vertical mixing, with concentrations up to 16% predicted under most flows historically observed, and nearly 67% (i.e., two-thirds of creek flow) at historical-low flows under ice in late winter (Table 3). It should be noted that this extreme case is considered unlikely, and if it were to occur, mine water would likely be significantly better than predicted because of the greater influence of the Prairie Creek alluvial aquifer on mine water, which would exhibit water quality more similar to Prairie Creek (D. Harpley, CZN, *pers. comm.* May 2011).

Table 3 Predicted concentrations of proportion of downstream flow comprised of effluent in each of the modelled scenarios (at complete vertical mixing but before complete transverse mixing).

	Open Water			**Ice Cover (winter)**		
	Monthly max flow (Jun)	**Monthly mean flow (Jul)**	**Monthly min flow (Oct)**	**Monthly max flow (Apr)**	**Monthly mean flow (Dec)**	**Monthly min flow (Mar)**
After complete vertical mixing						
Low Mine-Water Estimate	0.36%	0.99%	1.90%	0.28%	1.50%	4.98%
Best Mine-Water Estimate	**0.54%**	**1.48%**	**3.27%**	**0.37%**	**2.14%**	**7.30%**
High Mine-Water Estimate	0.99%	2.80%	5.15%	0.55%	3.05%	11.6%
Extreme Mine-Water Estimate	1.35%	3.77%	13.5%	5.85%	15.9%	66.7%

Bold numbers indicate the dilutions expected under normal operating conditions.

Predicted concentrations of analytes of concern in Prairie Creek downstream of the discharge, based on these modelled concentrations (from CZN 2011), appear in Table 4. All predicted concentrations are less than the proposed SSWQOs, except in the Extreme mine-seepage-flow scenario at minimum winter flows in Prairie Creek. These excursions (for total selenium, ammonia, nitrate, sulphate and TDS) are within 2x their respective SSWQOs.

The probability of extreme mine-seepage water flows from the mine is considered low, as is the expected frequency of winter flows as low as those used in modelling (see Figure 2). However, extreme flows are unlikely to occur in combination with source concentrations as high as those assumed. Should this not be true, CZN has indicated that measures would be taken to reduce loads of water quality analytes of concern to the creek to ensure downstream water quality objectives are met (see Section 3.2).

Table 4 Predicted concentrations of analytes of concern in Prairie Creek, downstream of the IDZ (from CZN 2011), screened against proposed objectives.

Water Quality Variable	Proposed Objective (Derivation)	Mine Seepage Scenario	Open-Water Creek Flows			Winter Creek Flows (Ice-Covered)		
			Max (Jun)	**Mean (Jul)**	**Min (Oct)**	**Max (Apr)**	**Mean (Dec)**	**Min (Mar)**
Prairie Creek flows used in model (m^3/s)			38.2	10.2*	1.57	4.43	4.43	0.71*
Total Arsenic (µg/L)	5.0 (CCME)	Low	0.12	0.14	0.17	0.12	0.17	0.24
		Best	**0.13**	**0.16**	**0.21**	**0.12**	**0.18**	**0.31**
		High	0.14	0.19	0.26	0.13	0.21	0.42
		Extreme	0.15	0.22	0.49	0.27	0.55	1.90
Total Cadmium (µg/L)	0.38 (CCME)	Low	0.046	0.076	0.087	0.046	0.098	0.030
		Best	**0.046**	**0.076**	**0.086**	**0.046**	**0.098**	**0.031**
		High	0.046	0.075	0.085	0.046	0.098	0.031
		Extreme	0.046	0.075	0.082	0.046	0.093	0.037
Total Copper (µg/L)	5.17 (CCME)	Low	0.32	0.43	0.54	0.32	0.54	0.61
		Best	**0.34**	**0.47**	**0.63**	**0.32**	**0.59**	**0.77**
		High	0.37	0.56	0.76	0.34	0.65	1.07
		Extreme	0.39	0.62	1.33	0.70	1.52	4.89
Total Lead (µg/L)	7.0 (CCME)	Low	0.24	0.64	0.75	0.23	0.88	0.09
		Best	**0.24**	**0.64**	**0.77**	**0.23**	**0.89**	**0.13**
		High	0.24	0.67	0.79	0.24	0.90	0.21
		Extreme	0.25	0.68	0.88	0.32	1.04	1.14
Total Mercury (µg/L)	0.026 (CCME)	Low	0.021	0.024	0.024	0.021	0.025	0.020
		Best	**0.021**	**0.024**	**0.024**	**0.021**	**0.025**	**0.019**
		High	0.021	0.023	0.024	0.021	0.025	0.019
		Extreme	0.021	0.023	0.023	0.021	0.023	0.013
Total Selenium (µg/L)	2.22 (RCA)	Low	1.18	1.23	1.27	1.18	1.28	1.26
		Best	**1.18**	**1.25**	**1.30**	**1.18**	**1.30**	**1.31**
		High	1.19	1.27	1.34	1.18	1.31	1.40
		Extreme	1.20	1.29	1.51	1.30	1.58	2.58
Total Zinc (µg/L)	35 (CCME)	Low	4.30	6.01	6.71	4.28	7.28	4.01
		Best	**4.32**	**6.07**	**6.86**	**4.29**	**7.35**	**4.33**
		High	4.38	6.25	7.06	4.31	7.44	4.92
		Extreme	4.42	6.36	7.97	5.01	8.86	12.44
Ammonia (mg/L)	0.409 (CCME)	Low	0.007	0.009	0.017	0.006	0.014	0.039
		Best	**0.008**	**0.013**	**0.026**	**0.007**	**0.019**	**0.055**
		High	0.011	0.022	0.039	0.008	0.025	0.085
		Extreme	0.014	0.028	0.097	0.044	0.113	0.462
Nitrate (mg/L)	2.9 (CCME)	Low	0.16	0.18	0.24	0.16	0.22	0.41
		Best	**0.17**	**0.21**	**0.31**	**0.16**	**0.25**	**0.53**
		High	0.19	0.27	0.41	0.17	0.30	0.76
		Extreme	0.21	0.32	0.84	0.45	0.97	3.62
Total Phosphorous (mg/L)	0.004 (CCME)	Low	0.0022	0.0024	0.0026	0.0022	0.0027	0.0021
		Best	**0.0022**	**0.0024**	**0.0026**	**0.0022**	**0.0027**	**0.0021**
		High	0.0022	0.0025	0.0026	0.0022	0.0027	0.0022
		Extreme	0.0022	0.0025	0.0027	0.0022	0.0028	0.0029
Sulphate (mg/L)	200 (toxicity-based)	Low	71.8	78.5	84.9	71.5	85.3	88.0
		Best	**72.5**	**80.5**	**90.3**	**71.8**	**87.9**	**97.3**
		High	74.4	85.6	97.7	72.5	91.4	115
		Extreme	75.8	89.5	131	94	142	336
TDS (mg/L)	413 (RCA)	Low	274	282	290	273	291	290
		Best	**275**	**285**	**295**	**274**	**293**	**300**
		High	277	290	303	275	297	319
		Extreme	278	294	338	297	351	556

Shading indicates predicted concentrations exceeding the proposed site specific Water Quality Objectives.

Bold numbers indicate dilutions expected under more likely operating conditions (i.e., most likely mine-water flow scenario).

*Mean flows for the period, not the month.

3.2 PROPOSED EFFLUENT QUALITY CRITERIA

Downstream water quality in Prairie Creek is predicted to meet proposed objectives in all modelled cases of effluent discharge, based on predicted concentrations of analytes of concern in final effluent, which represents a combination of process effluent, mine-seepage water, and site drainage (ditch) water. All of these effluent constituents have different characteristics, with process effluent containing high concentrations of metals and ions, while mine-seepage water and ditch water characteristics are much more similar to creek water.

However, modelling undertaken by CZN (2011) of effluent discharges under various creek flow conditions using single Effluent Quality Criteria (EQC) to define concentrations of analytes of concern in final effluent (rather than predicted concentrations in individual effluent constituents combined to form a final effluent) indicates excursions of proposed SSWQO's, with more excursions at higher mine-seepage rates (see CZN 2011). This is an artificial circumstance because treated mine seepage is expected to be of significantly better quality than the EQC.

As discussed in the regulatory meeting of April 12, 2011, establishment of a single EQC for final effluent constituents is problematic for the Prairie Creek mine discharge, because mine-seepage water strongly influences the total volume of effluent discharged but contributes little to the load of AOC's in effluent, while process effluent contributes much less of the effluent volume but the majority of the load of AOC's. Establishment of a single EQC for each AOC requires that it be set to capture final effluent conditions with the highest proportion of process effluent. However, use of only this worst-case concentration as an EQC results in substantial over-estimates of AOC load to Prairie Creek at higher effluent flows when more benign mine-seepage flows dominate the discharge.

Alternatives to definition of singular EQC's for each AOC in effluent could include:

- establishment of seasonal EQC's that capture some of the different seasonal changes in the proportion of process effluent and mine-seepage water in final effluent;

- load-based criteria, as is done in some other industries (e.g., pulp and paper, where kg/day of BOD and TSS are regulated end-points), which could potentially include near-real-time adjustments based on measured effluent quality and creek flow; or

- Use of receiving water quality as the regulatory end-point (i.e., requiring the mine to ensure that Prairie Creek water quality at the downstream edge of the Initial Dilution Zone meets all accepted objectives, in all seasons and operating conditions).

Use of environmental (receiving water) quality targets rather than effluent quality targets has precedents (for example, air quality permitting often follows this approach), and would place responsibility on the mine to ensure downstream water quality in Prairie Creek was maintained, while allowing flexibility in the management of effluent discharges to meet these downstream water quality compliance objectives. However, operationally this would be more complex than regulation of end-of-pipe loadings.

4.0 REFERENCES

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